Methodology for Evaluating Economic Impacts of Transportation

by

Guoxiong Huang

dissertation submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of
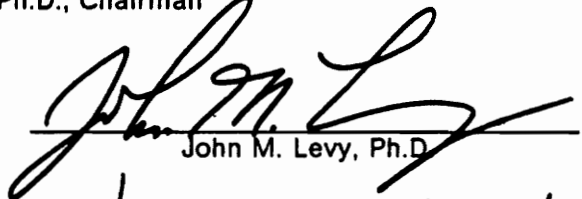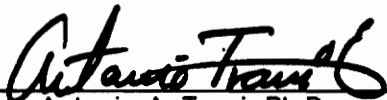
Ph.D.

in

Civil Engineering
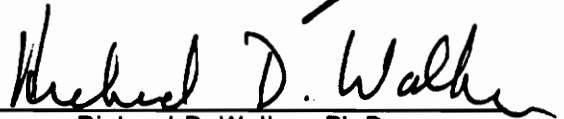
APPROVED:

_____
Donald R. Drew, Ph.D., Chairman

_____
Antoine G. Hobeika, Ph.D.

_____
John M. Levy, Ph.D.

_____
Antonio A. Trani, Ph.D.

_____
Richard D. Walker, Ph.D.

October, 1990

Blacksburg, Virginia

Methodology for Evaluating Economic Impacts of Transportation

by

Guoxiong Huang

Donald R. Drew, Ph.D., Chairman

Civil Engineering

(ABSTRACT)

This research addresses two important issues facing transportation economists and planners: the relationship between transportation investment and economic development and the methodology for evaluating transportation projects and programs. Transportation is viewed as an important factor which enters the production functions of firms and the consumption functions of individuals. The demand for and the supply of transportation cannot be determined within the transportation system. Changes in the transportation system may have far-reaching and, most importantly, feedback effects that not only generate secondary impacts, tertiary impacts, and so on; but also influence further decisions and, therefore, generate more changes further along in the system. The systems approach is crucial to the identification and quantification of impacts of transportation improvements and to the better understanding of transportation/economic development relationships. System dynamics is used in this research as a tool for modeling and simulating transportation/economic interactions.

This research conceptualizes the role of transportation in a broad socioeconomic context and develops a framework for applying the systems approach to the evaluation of transportation investments. Five scenarios examined with the methodology are: highway improvement, corridor development, HOV lane provision, impacts of transportation in a closed economy, and regional impacts of transportation. Conclusions are drawn which signify general policy implications.

Another contribution of this research is the introduction of an aggregate approach to the quantification of nonuser benefits.

Acknowledgements

I would like to thank my advisor, Dr. Donald R. Drew for his extreme patience, unending encouragement, and technical and financial support. His guidance was crucial to the development of this work and to the fulfillment of my teaching in the CE department of the Virginia Tech. I would also like to thank Dr. Antonio A. Trani for his encouragement and technical contribution to this dissertation and to the courses I taught in last two years.

To Dr. John M. Levy, I would like to express my heartfelt appreciation for imparting to me his knowledge of urban economics and for his encouragement during the preparation of this dissertation. My appreciation is also extended to Dr. Richard D. Walker and to Dr. Antoine G. Hobeika for their help with this work.

I would like to express my gratitude to Dr. Richard Swindell, a friend of mine, for his suggestions. I am most grateful to my wife, May. Without her love, support, encouragement, and understanding I could not have completed this study.

Table of Contents

List of Illustrations

1.0   Introduction

Transportation systems, particularly highways, ports, and airports, are essential to the effi-
cient functioning of national economies throughout the world, but experts say these systems
will be increasingly burdened by ever growing demand, limited supply, and increased con-
gestion. In spite of the fact that transportation systems are particularly vital to national and
regional economic productivity, there is no organized and well developed body of knowledge
regarding the effects of transportation infrastructure on development. Our ability in under-
standing the relationship between transportation and development is very limited. Progress
on key issues such as the relationship between transportation investment and regional pros-
perity and the relationship between national economic growth and levels of investment has
been very slow, if not stagnant for decades. Arguments about the stimulative and reflective
role of transportation have been mostly circumstantial or too qualitative to be subject to policy
analysis.

The transportation/development relationship is essentially a two-way interactive process, and
the results of the interaction depend on the type of economy involved and upon the level of
development at which transport improvements are initiated. At a given state of development,
an area requires a certain level of transportation in order to maximize its potential. There is
thus an optimum transportation capacity for any development level. The existence of unsat-

isfied demand for transportation may, over time, have serious adverse effects on the economy. Conversely, the results of over-capitalization may be unpleasant if too much is spent on transportation in anticipation of demand which never materializes [15].

Research is needed to clarify the relationship between transportation and economic development at both the national and state levels; to examine how far ahead, both temporally and spatially, incremental investments can be made that will be justified by the level of economic activity over a given period; and to improve techniques for analyzing project worthiness.

In its preliminary announcement of transportation research projects for FY 1990, the NCHRP points out: "the role of an effective transportation system in building and maintaining a vital economy has been recognized as a critical issue and is currently the subject of renewed interest. It is generally recognized that there is a need for better understanding of the various relationships between transportation decision (e.g., capital investments, regulatory actions, and taxing and pricing policies) and economic development. These relationships can be important in terms of both the net effect of the transportation system on the national economy and the impacts on local and regional economies." The NCHRP has emphasized the importance of decision makers at the State and local levels having reliable estimates of the economic health and productivity benefits of potential transportation investments so that they may make decisions responsibly in the following areas [40]:

- prioritizing highway improvement projects based on economic considerations

- estimating the relationship between improved transportation and industrial location decisions

- distinguishing between those transportation decisions that create new economic development and those that merely redistribute economic activity

- prioritizing the development of major highway corridors by focusing on potential economic development

- relating transportation investments to the market (job created directly and indirectly)

- estimating the portion of total cost related to transportation in various economic sectors

- assessing the economic consequences of severe metropolitan congestion, etc.

At a time when the economy of this country is threatened with recession, when the defense spending consumes more and more resources; blaming the deterioration of our transportation system on lack of funding and insufficient information cannot suffice to gloss over the weakness in our methodological and analytical capabilities for dealing with transportation-related problems. However, the most formidable obstacle in the way of transportation policy-making and planning is limited understanding of the effects that will follow from policy and planning decisions [14].

This research addresses two important issues facing transportation economists and planners: the relationship between transportation investment and economic development and the methodology for evaluating transportation projects and programs. Transportation is viewed as an important factor which enters the production functions of firms and the consumption functions of individuals. The demand for and the supply of transportation can not be determined within the transportation system. Changes in the transportation system may have far-reaching and, most importantly, feedback impacts that not only generate secondary impacts, tertiary impacts, and so on; but also influence further decisions and, therefore, generate more changes further along in the system. The complex relationship between transportation and other sectors of a society prohibits the use of analytical optimization technique for solutions to the issues. Pure qualitative analysis will not be effective either.

This research presents a framework for applying a systems approach to the solution of transportation problems. It begins with identifying research problem, proceeds to examining the structure of socio-economic-transportation system and modeling and simulating the systems, and ends with sensitivity and policy analysis.

1.1 Statement of the Problem

There is a growing concern that the nation's current transportation policies are not providing the necessary level, type, or quality of service that are required to maintain or improve national productivity and international competitiveness, or to enhance regional and State economic development. There are those who argue that there is no tangible link between the provision of transportation infrastructure investment and the pace of spatial economic development [8]. An examination of the current sate-of-the-art with respect to the relationship between transportation investment and economic development reveals no ready answer to the question of how a change in transportation affects a national, regional, or local economy. No wonder one transport economist concluded that the relevant areas of pure economic theory gives no unambiguous guidance to understanding those relationships. A new methodology is needed that allows policy makers to trace the feedback relations between population, economic, and transportation sectors of a region so that insights into the dynamic behavior of the system might be gained and appropriate transportation investment decisions might be made.

Another issue facing transportation economists and planners is the methods for determining whether an individual project is justified. Benefit-cost analysis is believed by many the best tool for analyzing project worthiness. However, the identification and quantification of actual cost and benefits of a transportation project or program are difficult if not impossible. An ex-

amination of the current theoretical development and practice indicates that the most urgent research problem in the area of project evaluation is whether and how the actual benefits that accrue can be incorporated into benefit-cost analysis.

1.2   *Research Objectives*

The primary objective of this research is to develop a methodology for determining (i) the economic worthiness of a transportation investment and (ii) the effects of transportation investments on economic development. A methodology is a body of methods, rules, and postulates. A methodology for creating solutions to transportation/economic problems will demonstrate how information in our knowledge base, such as facts and theories on population, economic, and transportation systems, will be used to analyze the problem.

Accomplishment of those objectives is discussed in detail in Chapter 4, **User and Nonuser Benefits** , and in Chapter 5, **Transportation Investment and Economic Development**. To briefly summarize, this research:

1. develops a framework for applying the systems approach to the evaluation of transportation investments

2. conceptualizes the role of transportation in a broad socioeconomic context

3. identifies key variables and interrelationships which exist among population, economic, and transportation sectors

4. models the causal structure of the system in the forms of verbal description, causal diagram representation, and mathematical expressions

5. simulates the dynamic behavior of the system with DYNAMO, a continuous simulation language for system dynamics models

6. conducts scenario analyses and draws conclusions which signify general policy implications

1.3   Dissertation Overview

Chapter 1 has presented an overview of this research. The significance of the problem was established, the problem was defined, the research objectives were stated, and the general approach to the problem was described. Chapter 2 presents a review of the current methodologies applicable to economic impact analysis of transportation investments. It continues with an in-depth discussion of the input-output analysis and concludes with a direction for future research in the area of transportation and economic development. Chapter 3 describes the systems approach to the problem for this research. Important concepts presented in the chapter are the system, system dynamics, and feedback structures.

Chapter 4 systematically analyzes the problem of user and nonuser benefits from transportation improvements, including the examination of the current state of the art, the identification and quantification of the network and locational impacts of transportation, and the determination of user and nonuser benefits. Chapter 5 explores and simulates the causal structure of the relationships between transportation investment and economic development. The final

Chapter, Chapter 6, provides a critique of this research, and identifies opportunities for further research.

2.0   Literature Review

The literature review presented in this chapter begins with a brief and yet complete review of the current methodologies applicable to economic impact analysis of transportation investment. It continues with an in-depth discussion of the input-output analysis deemed by many to be one of the most promising methodologies for modeling transportation/economic development relationships. Finally, the literature review concludes with a suggested direction for future research.

2.1   Current Methodologies

The methodologies for economic analysis of transportation investment can be classified into two categories: (1) methodologies focused on project evaluations and impact analysis and (2) methodologies concerned with general investment strategies. With regard to the first type of analysis, it is believed that traditional economic tools such as benefit-cost analysis and rates of return are most practical at the individual project level. The concept involved with project

evaluations is straight forward, that is, the benefits generated from the project should justify the cost of the investment. The problem with the approach is twofold. One is that the major benefit is the direct user benefit -- that is, the reduction in operating cost, savings in travel time, and savings in accident costs; yet it is clear that other things are valued, reliability and flexibility for example, which we can not incorporate. Second, long-run impacts such as the type and amount of net private investment attracted by the facility are difficult to incorporate into the analysis. Chapter 4 in this research describes a systems approach to the analysis of user and nonuser benefits.

By far the largest number of transportation impact studies have been evaluations of highway projects, while the special purposes of impact research vary from study to study. Three of the major purposes of impact studies are: (1) to identify some aspects of the level and distribution of benefits from the project, (2) to aid planners with general data and information, and (3) to help highway authorities with public relations. Many studies, whether they attempt to measure an impact or merely to gather data, seek to obtain information from a particular transportation project that might be useful elsewhere. In other words, they attempt to uncover and express cause and effect relationships that are, in some sense, generalizable. Studies of this type are often viewed as experiments, whose results are assumed to be generalizable to urban areas which in some sense replicate the experimental conditions [17].

With respect to impacts on nonusers, considerations that have been emphasized in the literature are location and land use, land values, and levels of economic activity. Changes in the uses of land served by a highway improvement are extensively documented in impact studies. The implicit theory behind most of these studies seems to be that the new economic activity in the vicinity of a highway improvement represents a net benefit for the region and that it is caused only by the highway improvement.

Models of impacts of transportation investment have been modified applications of national and regional economic models. In addition to the input-output approach, economic modeling

efforts which include some transportation variables are spatial equilibrium analysis, production function models, regional econometric models and regional projection models.

Spatial general equilibrium analysis divides an economy into several geographic regions. Market demand and supply equations are used to represent the behavior of each region. A typical assumption is that demand and supply equations are linear. A major drawback of this type of model is the difficulty of estimating a demand and supply equation for each type of commodity due to the need for detailed data and the multiplication of the number of demand and supply equations as the the number of regions multiplies [26, 17].

Production functions have been used to assess the broader impact of infrastructure investment on economic development. Examples are models set forth by Attaran. Attaran focuses on the highway component public infrastructure and attempts to show the impact of the slowdown in growth rate of the federal and state highway stock on private sector productivity. The first set of models analyzes the empirical relationship between private sector capital productivity and the total stock of state and federal highways (see equations 2.1 and 2.2). The second set of models analyzes the relationships between private sector total input or total factor productivity and total stock of highways (see equations 2.1 and 2.3).

$$Y = AK^kL^lG^g \qquad\qquad [2.1]$$

$$G = H + NH \qquad\qquad [2.2]$$

$$G = H + M + SW + O \qquad\qquad [2.3]$$

Where Y = private sector output, A = technological coefficients, K = private sector capital input, L = labor input, G = total stock of public infrastructure, k = elasticity of private capital input, l = elasticity of labor, g = elasticity of public infrastructure stock, H = total stock of

highways and streets, NH = non-highway infrastructure stock, M = stock of mass transit, SW = stock of sewers and water systems, and O = all others.

The author disaggregates capital stock into private and public capital stock. Public stock is divided between infrastructure and non-infrastructure capital stock. Infrastructure capital stock is further disaggregated into total capital stock of highways and streets, stock of mass transit, stock of sewers and water systems, and stock of all others [5].

Production functions are best suited for general analysis of a country, a state, or an industry. It is not the ideal mechanism for investigating economic impacts of an infrastructure investment in detail. When capital stock is disaggregated beyond large categories, severe problems develop with the data, especially in the input prices necessary to take full advantage of the underlying theories of this function [5].

Harris developed and applied the 'Multiregional, Multi-industrial Forecasting Model' to the evaluation of regional economic effects of alternative highway systems [19]. Location rent is an important concept in the theory, which is defined as 'the sum of profits per unit output and the rental value of land per unit of output'. 'The change in regional output is explained by input prices and the location decision of the firm. Input prices include transportation costs, wage rates, land prices and the cost of capital. The marginal transportation cost is computed by a linear programming model which determines a firm's location. The model is unable to predict any change in national output due to any change in the transportation cost. It identifies the industrial location due to the transportation system, but is not capable of describing the inter-regional trade and inter-industrial transaction in details' [20, 5].

Three most frequently used methodologies of economic impact analysis are: economic base, econometric, and input-output analysis. Economic base theories divides the total economy into two sectors: basic and non-basic. The basic sector (or export sector) is comprised of those activities that produce goods and services locally but which sell outside the local area.

This sector provides the means of payment for the area's imports and support for the local economy servicing the basic sector: the nonbasic sector. The nonbasic sector is made up of those activities that produce goods and services locally for consumption by local consumers. The theory holds that the basic/nonbasic relationship is stable and measurable and so are the economic-base multipliers (the ratio of total economic activity to basic sector economic activity). If the future development in the basic sector can be predicted, total economic activity can then be projected [18].

Econometrics is the use of statistical methods to verify and quantify economic theory. Econometric models are multiple-equation systems that attempt to describe the structure of a local economy; to forecast aggregate variables such as income, employment, and output; and to evaluate the effects of alternative policies. Time series data and regression analysis are employed to construct the model and to estimate the hypothesized relationships. Static concepts, open-loop structure, simplified relationships, insufficient data, correlated data, and statistical biases cause problems with regional econometric models [4, 21, 32].

Input-output analysis is most appropriate for short-run forecasting problems where considerable detail is required. The Multiregional, Variable Input-Output model developed by Chong K. Liew and Chung J. Liew is believed one of the most promising areas of research and of application in relation with public work and/or highway investment and economic development [24, 25].

Another promising area of research is the application of system dynamics to modeling transportation/economic development relationships. Pioneering work in the area has been done by Professor D. R. Drew in Virginia Tech. The methodology developed is flexible in terms of exploring causal relationships instead of casual relationships and allowing for more sophisticated mathematical representation of these relationships.

2.2   Input Output Analysis

First developed by Leontief in 1936, input-output analysis is now one of the most frequently used approaches to the assessment of secondary impacts of public sector development projects and programs. Among the economic evaluation methodologies, input output analysis represents the most rigorous and, if applied properly, the most accurate method (assuming enough time, expertise, and other resources). Developed in an attempt to take account of general equilibrium phenomena in the empirical analysis of productions, input output approach distinguishes itself from other methodologies in that it is more disaggregated and better takes into account interdependence between economic activities. Therefore, it better demonstrates the behavior of an economic system explicitly and in detail, at national, regional, and local levels, in response to various economic development policies employed within or outside a region. Conceptually, input output approach provides analysts with the ability to trace causal relationships between investments and induced changes in the inter-regional trade flows, inter-industry transaction patterns, and impacts on product outputs, household incomes, employment, and environment quality, etc. Although the academic investigation and empirical application of this approach to the justification of transportation projects has been limited, the input output approach could be a useful tool for the systematic analysis of the economic and development impacts of those projects, especially when detailed evaluation of secondary impacts is important.

Static Model.   Input output approach disaggregates an economic system into several sectors, including those of interest and one (or more) aggregated sector representing all other industries that may have minor influences on and weak relationships to the sectors of interest. Each sector produces just enough product, X, to sell to all sectors (including itself) for use as inputs into their production processes (intermediate use, AX) and to all final consumers (final demand Y). To facilitate comparison, all sales are expressed in monetary value. Given a

certain amount of final demand and certain types of production technology (expressed in the technical coefficients matrix A, where a_{ij} stands for the amount of input from sector i used by sector j per unit output in sector j), a set of simultaneous equations can then be formulated and solved for the amount of output, X, that keeps the system in equilibrium. Algebraically we have:

$$X = AX + Y \qquad\qquad [2.4]$$

So,

$$X = (I - A)^{-1}Y \qquad\qquad [2.5]$$

Where I is an identity matrix and column vector Y the final demand for the sectoral products.

The matrix $(I - A)^{-1}$ is usually referred to as the multiplier matrix, as it shows the direct and indirect requirements of output for the production of one unit of sectoral final demand. Expanding the multiplier matrix, we have

$$X = (I - A)^{-1}Y = (I + A + A^2 + ... + A^n)Y \qquad\qquad [2.6]$$

This iterative process shows the progressive adjustments of output to final demand and intermediate input requirements. The ith component $A^{i-1}Y$ of the equation above shows the direct output required as the intermediate use to produce output requirement, $A^{i-2}Y$ in the previous round [9, 30].

Obviously, this formulation interprets economic activities as demand-driven processes. Nothing of the supply side (cost and production) and nothing of the market (demand theory) of an economy have been explicitly taken into consideration.

Depending on how time is handled, input output models can be either static or dynamic. A static input output model, as described above, can be quite helpful to analysts in finding out the equilibrium sectoral production requirements and sectoral impacts due to changes in the final demand and changes in the structure of the economy. Because of its inability to incorporate the adjusting capability of industries and the time lag of the industries in response to the changes, a static model gives no answer to the description of the economic development process. They can be used only after the above multiplier process has worked itself out.

Dynamic Model   A dynamic input output model takes into consideration the investment behavior of industries through the use of a capital coefficient matrix B (where b_{ij} is the coefficient for capital stock produced in sector i and used in sector j), showing the additional capital stock (e.g. additional equipment from all sectors) required by each sector to change its production capacity by one unit. The output of each sector in a dynamic model must satisfy the requirement of the final consumption, intermediate use, and capital stock accumulation, as described by the following equation:

$$X(t) = AX(t) + B(X(t+1) - X(t)) + f(t) \qquad [2.7]$$

Where f(t) is the portion of output X(t) that goes to final consumption (i.e. sectoral supply). Furthermore, matrices A and B can also be treated as time dependent.

Under certain assumptions concerning sectoral growth patterns, it is possible to find the trajectory of X(t) and, if any, the steady-state solution to the output, X.

For example, let $X(t+1) = (1+\lambda)X(t)$ and $f(t) = 0$, then we have $|I - A - \lambda B| = 0$. The solution to the equation defines the maximum growth rate, λ_m, of the economy [40].

As another example, let $X(t+1) - X(t) = F (D(t) - f(t))$, where $D(t)$ represents consumer demand and F the adjustment factor of production to demand-supply discrepancy [38]. Then

$$f(t) = (I - BF)^{-1}(I - A)X(t) - (I - BF)^{-1}BFD(t) \qquad [2.8]$$

In dynamic equilibrium, if it exists, equation [2.8] gives us the following steady-state solution

$$X(t) = (I - A)^{-1}D(t) \qquad [2.9]$$

Moreover, if inventories are negligible, that is $B = 0$, equation [2.8] becomes

$$X(t) = (I - A)^{-1}f(t) \qquad [2.10]$$

This system of equations is similar in form to those described in equation [2.5] for static input output models.

A dynamic input output model has advantages over a static one not only in that it portrays the time path behavior of the system, but also in that it is more policy sensitive. It allows the model builders and analysts to test the consequences of different production strategies and different economic growth assumptions.

Regional Model   In order to quantify the spatial characteristics of a nation's economy, enormous efforts have been taken toward the development of sub-national input output models. Basically, there are two types of models that are used most widely, regional and multi-regional (MRIO). A regional input output model is a small-scale version of the national model.

But it is more open (in the sense of more transactions with the 'outside world') and the existing accounting data are less likely to be directly usable for constructing regional transaction tables. Moreover, regional economic structure is much more difficult to predict. Changes in technology and especially changes in trade patterns may greatly alter the composition of a region's economy. Empirically, it is suggested that the outputs of a regional input output model be interpreted carefully and cautiously.

Two methods of constructing a regional input output table are: (1) using direct survey data and (2) using adjusted national coefficients. The former is more expensive and time consuming, but is theoretically more accurate, although empirical applications yet to demonstrate much better forecasts. One of the most successful adjustment techniques is the simple location quotient approach which states that if the regional employment ratio of industry i to industry j is less than that of national level, the national coefficient a_{ij} should be adjusted by a multiple, L_{ij}, called the location quotient of industry i on industry j. The discrepancy, $(1-L_{ij})$ a_{ij}, is then added to the import row of that sector. Location quotient can be calculated from

$$L_{ij} = \frac{e_i/e_j}{E_i/E_j}$$ [2.11]

Where e_i is the regional employment in industry i and E_i the national employment in that industry.

Multiregional Model   Multiregional input output models represent the most disaggregated models in terms of delineating interindustry production relationships and interregional trade flows. Three sets of data are required to implement the model: (1) a set of regional input output tables by each region, (2) a set of interregional trade flow tables by each commodity, and (3) a set of final demands for each industry in each region (not necessarily produced in the region). It is assumed that there are n regions and m commodities. A regional technical

coefficient matrix A is constructed in such a way that it has n × n blocks, each diagonal block contains the corresponding region's direct input coefficients and all non-diagonal blocks the value zero. The technical coefficients in a MRIO model differ from those in regional models (for a single region) in that the origins of the inputs for intermediate use in a region are not restricted to that region only. For that reason also, the column sums and row sums of the regional input output tables in a MRIO model may not be equal.

One way of constructing the interregional trade coefficient matrix is by the use of the column coefficient method. The matrix, denoted as C, is constructed as an n × n block matrix, while each diagonal cell, c_i^{rs}, in block (r,s) indicates the percentage of the total consumption of commodity i in region s shipped from region r and all non-diagonal cells have the value zero. Following this method, the system of equations becomes

$$X = (CA)X + CY \qquad [2.12]$$

Therefore,

$$X = (C^{-1} - A)^{-1}Y \qquad [2.13]$$

Where X and Y are vectors of dimension mn × 1 and C and A matrices of mn × mn.

Interregional trade flow matrix T (mn × mn) for the horizon year can be estimated from

$$T = CcmD^t \qquad [2.14]$$

Where cm stands for matrix column multiplication, t the transpose of the matrix, and D (mn × 1) for a vector of estimated total consumption for each industry in each region, which is the

sum of final demand Y and the column of total intermediate demands [33]. Intermediate demand matrix D^x (mn × mn) can be determined by

$$D^x = AcmX^t \qquad [2.15]$$

A static version of this approach implies constant trade coefficients, which does not seem to allow for changes in the transportation system.

Multiplier Analysis   When decisions are to be made about the distribution of expenditures among different economic sectors or regions, input output multipliers such as output, earnings, and employment multipliers may be used. These multipliers reflect the potential total effect per unit sectoral spending. The output multiplier for a sector is the column sum of the elements for that sector in the multiplier matrix, while the earnings multiplier and other primary sector multipliers are obtained by multiplying the multiplier matrix (or interdependence coefficients matrix) by the technical coefficients of the row concerned. The same method of calculation can also be extended to the quantification of different external effects.

Some of the criticisms of the use of multipliers as a standard for sectoral comparisons are: (1) multipliers are essentially partial derivatives. A large multiplier may not necessarily be the result of large impacts, but may sometimes result from small direct effects (appear as denominator). (2) multipliers are usually derived from a static model with data from several years ago, there is no reason to expect them to keep the same magnitudes if the whole structure of the economy changes. (3) the multipliers are valid only when there are unemployed or under-employed resources in the area and the introduction of the projects or programs increases the final demand in the economy [34].

Limitations   Some of the shortcomings associated with the formulation of the input output technical coefficient matrix are (1) sector aggregation problems (homogeneous inputs, technologies, and productions), (2) static and linear production functions: fixed technology and

constant returns to scale (e.g., doubling outputs requires doubling each of the inputs), and (3) fixed trading relationships: fixed technical coefficients and no substitution among inputs. Although most of these limitations can be overcome by introducing more sophisticated models, available resources are not always favorable and the problem may not even be solvable.

Applications to Transportation System   Possible applications of input output methodology to economic impact analysis of transportation policies may be accomplished by (1) directly using the conventional input output formulations described above; (2) incorporating general economic theories relating to production and marketing so that more realistic responses such as substitution responses of industries caused by changes in the transportation system can be reflected by the model; and (3) combining the methodology with other economic quantitative techniques such as programming and computer simulation. Conventional input output models can be constructed mainly for descriptive purposes. First, they can be used as an accounting tool, providing a detailed description of the structure of economy at national or sub-national levels. Second, they can be used to assist analysts in quantifying the minimum transportation outputs necessary to satisfy the current or projected final demands and in identifying transportation bottlenecks which restrain the interregional trade flows. Third, they can also be useful in examining the capacity of the existing transportation system to absorb the possible changes in industrial production technology, products mix, and relative prices, or changes in technical coefficients, which may be predicted by the 'best practice' method. Fourth, sectoral multiplier analysis can be applied to obtain a quick appraisal of the efficiency of investment in the transportation sector as opposed to other uses of the resources. All these methods can be applied by incorporating the transportation sector into the model as one or more intermediate sectors.

However, because of their inability to express explicitly the feedback relations between producers and the transportation system, due to their oversimplification in treating input coefficients and interregional trade flow coefficients, conventional input output models can hardly

be used for projection purposes concerning the impacts of various transportation investments. Modification is essential if the input output approach is to be used for tracing these impacts.

The effects of transportation investments may be divided into three parts: (1) a multiplier process generated by the initial spending on the implementation of the project, (2) a series of changes in the economic structure and then in sectoral outputs, or 'indirect effects' attributable to performance changes in the transportation system, and (3) changes in final demands, or 'induced effects' due to income effects and population shifting. The former, or direct effects, are more or less defined by the economy. They can be calculated by using conventional input output models. The latter two are a subject of constant debate. Though transportation is a prerequisite of economic growth, its significance as a catalyst may depend largely upon the social and economic condition of the region concerned.

Changes in the transportation system may vary in expression from changing transport costs (money and time) to transport amenity (convenience, comfort, less accidents, etc.). They may set in motion the whole economy or have only a minor influence on it, depending on: (1) the production sensitivity of the economy to transportation costs, (2) the availability of markets and input factors and the possibility of using substitutes, (3) the existence of economies of scale and economies of agglomeration, and (4) local attitudes toward expansion in production. The relationship between those aspects of the economy and transport savings should be predicted and quantified and the possible changes in input coefficients and trade flow coefficients due to the investment should be estimated before input output analysis is employed to project the 'indirect effects' of the investment. It is challenging work. Further research should be encouraged though at present the computational burden seems to be formidable.

In general, transportation improvement reduces the spatial impedance between regions. Therefore it helps to open up the economy, in the sense of more choices of substitution among factor inputs and product outputs. Transport savings may be applied in two ways. First, it can be used to expand production capacity and market area, and to reduce commodity prices. In

a competitive economy, this will create a new system of input combinations, market shares and equilibrium prices. Furthermore, the final demands in all regions will also be changed (income effects). Second, it may be used to increase primary inputs, which will not only shift the inputs from the transportation sector to primary sectors, but also induce more final demand (income effects). To complete the analysis, the income effects of the transport savings from non-business travel should also be considered.

Input output analysis is essentially a set of linear equations. It does not provide an optimizing framework. To find out the optimal outputs to the pursuing objectives, one has to extend the input output relations of the economy (as economic constraints to the objective function) to accommodate possible variations in the final demand (substitution effects) and production capacity, and then solve the problem by using programming techniques.

Conclusions While input output analysis could be used for a variety of economic descriptions and investment policy-making purposes, its applicability to the justification of local transportation investments and to the evaluation of alternative transportation improvement projects is quite limited. Three severe drawbacks of the methodology need to be considered before it is to be used. They are: (1) tremendous data requirements, including data collection, data consistency checking, and coefficients updating, (2) insensitivity to marginal economic behaviors, and (3) the lack of a dynamic feedback mechanism.

2.3   Conclusions

It becomes clear that no single method would be capable of fully demonstrating the relationship between transportation investment and economic development. Combining the available

methodologies will not only combine the theoretical strength of each one but also exploit the necessary detailed information needed to make sound economic decisions. System dynamics, input-output analysis, and econometric models can be complementary. Together they are causal, behavioral, interactive, dynamic, spatially sensitive, and statistically verifiable.

While econometrics offers numerous techniques for finding empirical parameters and formal comparisons of model results with real-world observations, system dynamics provides a theory of causal structure and a methodology for system conceptualization and model specification. System dynamics complements econometrics in several ways. System dynamics emphasizes the dynamic aspect of a feedback system. It facilitates the transient analysis of non-linear feedback systems with delays. System dynamics is particularly applicable to long-term forecasts of systems behavior. Whereas econometrics deals mostly with static concepts and open systems, focuses on systems at or near equilibrium, and is best suited to short-term forecasts [35].

Input output analysis provides detailed information on inter-industrial and interregional commodity flows. System dynamics complements it by incorporating a dynamic non-linear technical coefficients matrix into the model and by taking into account the population movement, which makes the model more realistic and sensitive to transportation problems. Appendix A.1 shows a simple input output model in DYNAMO simulation language.

3.0   Systems Approach

The relationship between the transportation sector and other sectors of a society is intricate. While it is possible for experts to understand portions of the transportation/economic development process fairly well, synthesizing these in a consistent manner without a formal technique is impossible. The transportation/economic development process is composed of a large number of variables spanning many disciplines. The variables are causally related interacting among themselves to form higher-order feedback loops; the inputs are stochastic, the relationships are nonlinear, and there are delays and noise in the information channels. All these characteristics preclude predicting systems behavior by partitioning the problem along disciplinary lines and assembling the component solutions [15]. Systems approach is the key to success in analyzing transportation policy-related problems.

The systems approach is a technique for applying scientific methods and knowledge to the solution of complex problems. It emphasizes the analysis of a system as a whole, taking into account all the facets and all the variables instead of breaking down the system into its parts and assembling the solutions which are optimal for the parts, but not necessarily optimal for the system [28]. The basic characteristics of the systems approach are objective, multidisciplinary, interactive, and mostly quantitative. Modeling and simulation makes the use of systems approach to complex problems feasible.

In this chapter, a special method for analyzing the behavior of complex systems, system dynamics, is introduced. System dynamics is used in this research as a tool for modeling and simulating transportation/economic interactions.

3.1   System Dynamics

System dynamics is a method of dealing with questions about the dynamic tendencies of complex systems to show how systems structure and the policies used in decision-making govern the behavior of the system. Although system dynamicists are mostly interested in the general dynamic tendencies of a system: whether the system as a whole is stable or unstable, oscillating, growing, declining, or in equilibrium; the concepts of system dynamics and the computer simulation language, DYNAMO, can be used to predict the precise state of a feed-back system.

System dynamics is based on the foundations of decision making, feedback systems analysis, and computer simulation. Decision making refers to how action is to be taken. Feedback analysis deals with the way information is to be used for decision making, or the transmission and return of information. Simulation permits decision makers to evaluate the future implications of their decisions. The central concept in system dynamics is the idea of two-way causation or feedback.

The modeling procedure with system dynamics is sequential and iterative. It starts with the verbal description, which is translated into a causal diagram, from which the system equations are written. The model is exposed to criticism, revised, exposed again and so on in an iterative process that continues until additional knowledge gained about the system is trivial [15].

3.2 Representation of Feedback Structure

The system dynamics approach to complex problems focuses on feedback processes. It takes the philosophical position that feedback structures (or causal structures) are responsible for the persistent dynamic tendencies of any complex system [36]. Searching for feedback structure, system dynamics modelers pursue chains of cause-and-effect until they close on themselves. Thinking in terms of causal relationships is crucial when modeling with system dynamics. There are three complement ways of representing the causal structure of a system: verbally, visually, and mathematically. The easiest way of representing the causal structure is to develop a causal diagram.

Steps used in developing causal diagrams are:

1. identifying key variables which describe the system to the desired level of details;

2. connecting variables with arrows signifying the direct causal relationships existing between each pair of variables, where the arrow can be read as 'affects'; and

3. placing a positive or negative sign to each arrow to indicate the type of relationship between the two variables.

An example might be: PRICE ⎯⎯⎯⎯⎯⎯→ DEMAND

Two types of arrows were used in developing a causal diagram: solid and dashed arrows. Solid arrows indicate physical flows. They connect rate variables to level variables. Dashed arrows represent the flow of information between any other pairs of variables. Level variables, or state variables, represent the accumulation of resources in the system such as population, economic output, and transportation infrastructure. Rate of flows represent the activities or decision functions in the system, such as population movement, capital investment, and capital depreciation [13].

A feedback loop is a chain of causal links that close on themselves. It is said to be positive if it contains an even number of negative causal links. Conversely, a negative feedback loop contains an odd number of negative causal links. The number of level variables contained in a feedback loop is called the order of that loop. Thus, a second order positive feedback loop contains two level variables and an even number of negative links.

3.3   Simulation with DYNAMO

DYNAMO, from the words 'dynamic models', is a continuous simulation language specially developed for modeling real-world systems so that their dynamic behavior over time may be simulated by a computer. It is a tool used by many system dynamicists. But it is not exclusively a system dynamics tool. DYNAMO can be used to program not only high-order complex feedback system, but also linear open-system models that are not philosophically system dynamics at all [35].

A DYNAMO compiler facilitates a modeler to use up to seven types of equations and six types of control statements [37]. The following is a summary of the statements and their indicators used in DYNAMO:

*	title of the program
L	level equations
R	rate equations
A	auxiliary equations
N	initial values (for each level variable)
C	constant
T	tables (values for dependent variables)
SPEC	specification of DT (simulation interval), LENGTH (length of simulation), PLTPER (plot interval), and PRTPER (print interval)
PLOT	followed by variables to be plotted
PRINT	followed by variables to be printed
RUN	RUN statement (end of the program)
NOTE	comment
X	continuation of previous line

Each level equation represents a differential equation such as:

$$dL_t / dt \quad = \quad R_t$$

Because of the inability of a computer language to handle subscripts, DYNAMO uses a postscript notation in which .K stands for the present time t, .J stands for past time t-dt, .L stands for future time t+dt. Thus, a level equation in DYNAMO models would be:

L   L.K = L.J + DT*R.JK

Since rates are continuous, DYNAMO uses .JK and .KL to represent 'earlier than this time' and 'from now on'. An example would be:

R   R.KL = function(L.K, A.K, C)

Auxiliary equations are used for those variables other than levels and rates. Postscript .K is used in both sides of the equation.

Special functions used in DYNAMO are TABLE function, DELAY and SMOOTH functions, CLIP and SWITCH functions, and some test functions such as STEP, RAMP, PULSE, and NOISE functions.

TABLE function performs linear interpolation for nonlinear relationship. For example, equations

A   Y.K = TABLE(TNAME, X.K, XLOW, XHIGH, INC)

T   TNAME = YLOW/ /.../YHIGH

determine the value of Y between YLOW and YHIGH according to the value of X between XLOW and XHIGH.

CLIP and SWITCH functions enable a modeler to change values or expressions for a variable during a simulation. The form of the CLIP function is CLIP(A, B, X, Y), where A, B, X, and Y can be any constants or variables in the model. CLIP(A, B, X, Y) takes the value A as long as X is greater than or equal to Y, otherwise it takes the value B. The SWITCH function differs from the CLIP function in that Y = 0 and is thus omitted from the expression.

The STEP function is used to change a quantity abruptly at some point in time. It takes the form of STEP(A, B), where A represents the step height and B the value of TIME at which the value of STEP changes.

The RAMP function is a continuously growing or declining linear function of TIME. Its form in DYNAMO is RAMP(A, B), where A is the slope of the linear function and B the starting time for the ramp.

The PULSE function provides momentary jolts to a DYNAMO model. It is used to represent sudden changes in a variable, returning it immediately to its former value after each change. PULSE function in DYNAMO is expressed as PULSE(A, B, C), where A represents the height of the pulse, B represents the time of the first pulse, and C the time interval between successive pulses [36].

DYNAMO also provides a random number generator, a function called NOISE, where values vary in a completely patternless, random way. The form of the NOISE function is NOISE(). There is nothing, not even a space, in the parentheses there.

The following is a simple population model written in DYNAMO:

*	TRANSPORTATION / DEVELOPMENT MODEL
NOTE	POPULATION SECTOR
L	$P.K = P.J + (DT)(B.JK + IM.JK - D.JK - OM.JK)$
N	$P = PN$
C	$PN = 50000$
R	$B.KL = P.K^*BN$
C	$BN = 0.03$
R	$D.KL = P.K^*DN$
C	$DN = 0.015$
R	$IM.KL = 5000$
R	$OM.KL = P.K^*OMN$
C	$OMN = 0.07$

Where P = population, B = birth rate, IM = immigration rate, and OM = out-migration rate.

3.4   Systems Behavior

There are two kinds of feedback loops that may exist in a feedback system. A positive, or self-reinforcing, loop tends to amplify any disturbance and to produce exponential growth. A negative, or goal-seeking, loop tends to counteract any disturbance and to move the system toward an equilibrium point or goal. Certain combinations of these two kinds of loops recur frequently and allow system dynamicists to formulate a number of useful generalizations or theorems relating the structure of a system to the system's dynamic behavioral tendencies. For example, when the system exhibits exponential growth, the system dynamicist automatically looks for a dominant positive feedback loop. A tendency for a system to return to its original state after a disturbance indicates the presence of at least one strong negative feedback loop. Oscillatory behavior often indicates the presence of a negative feedback loop with a time delay in it. Sigmoid or S-shaped growth results from linked positive and negative loops that respond to each other nonlinearly and with no significant time delays [35].

3.5   Systems Analysis

3.5.1   Steady State Analysis

When a system is at its equilibrium, or steady state, all level variables stay constant over time. In other words, rates of flows offset each other so that they aggregately present no effect on any level variables. Thus, the steady state analysis of a system can be done by simply

equating the rates at equilibrium. The steady state analysis for the population model presented in section 3.3 is illustrated here:

$$P_e + IM_e = D_e + OM_e$$

$$P_e = 5000/(DN + OMN - \dot{B}N)$$

$$P_e = 90909$$

Steady state analysis enables policy makers to see the long-term effects a policy or an action may have on the system. It does not tell the time and the posibility for a system to reach the equilibrium, however.

3.5.2   Transient Analysis

Instead of relying on computer simulation for finding the path of growth, mathematical analysis may be applied to the solution of simple feedback systems by integrating each level equation in the system. An example of transient analysis would be:

L   L.K = L.J + DT*R.JK

$$(L_t - L_{t-1})/DT = R_t$$

$$dL_t/dt = R_t$$

$$L_t = L_0 + \int R_t \, dt$$

3.5.3 Sensitivity Analysis

Sensitivity analysis involves the examination of model behavior by slightly changing model parameters and model structure that are not policy-related. The purposes of doing sensitivity analysis are:

1. to test the validity of the model, and

2. to prioritize the needs of data collection and relationship establishment.

Obviously, more facts and research are needed to support the assumptions made in the model concerning sensitive parameters and model structure.

3.5.4 Policy Analysis

The purpose of policy analysis is to investigate why particular policies have the effects they do and to identify policies that can be implemented to correct the problematic behavior of real systems. The goal is to understand what policies work and why.

Policy alternatives in the real system correspond to two kinds of model manipulation: (1) parameter changes, including minor variations in table functions, and (2) structural changes such as changes in the form and number of equations. Both involve changing how decisions are made.

3.6   Summary

This chapter describes important concepts relating to this research, such as the system, systems approach, system dynamics, feedback structure, feedback loops, causal diagram, systems behavior, steady state, equilibrium, stability, sensitivity analysis, and policy analysis. Techniques used in modeling and simulation with DYNAMO are discussed, and some DYNAMO special functions are introduced.

4.0 User and Nonuser Benefits

4.1 *Introduction*

A fundamental issue underlying any transportation project appraisal is whether the project meets the region or country's economic and social objectives and whether it meets these objectives efficiently. In other words, the benefits generated from the project should justify the cost of the investment. Economically, a decision maker needs to know whether the net benefits are at least as great as that obtainable from other investment opportunities.

Benefits from highway investments include benefits exposed directly to the users of the highway, such as the reduction in operating cost, savings in travel time, and savings in accident costs, etc.; and the benefits gained by the communities at large, such as the increased economic activities, more equal income distribution, etc. The former type of benefits are referred to as user benefits. The latter are referred to as nonuser benefits. In the AASHTO's Redbook, user benefits are defined as "the advantage, privileges, and/or cost reductions that accrue to highway motor vehicle users (drivers and owners) and /or to transit users through the use of a particular transportation facility as compared with the use of another". They are generally

measured in terms of a decrease in user costs. Highway user costs are the sum of motor vehicle running cost, the value of vehicle user travel time, and traffic accident cost. These costs are easier to express in dollars than some other kinds of costs. Because of that, the determination of the economic desirability of a highway project is frequently interpreted as a comparison between user benefits and the cost of the project.

One approach to the user benefit computation is that adopted by the Redbook, which is based on the concept of consumers' surplus [3]:

- Consumers' surplus theory argues that the benefits of highway improvement include both savings in travel cost that accrue to current users and the 'surplus' willingness-to-pay that remains with the new or generated users. These new users are now able to make trips and participate in benefit-yielding activities elsewhere in the economy that they had foregone before the road improvement. The benefit of performing these activities is legitimately associated with the transportation improvement; there is no better estimate of these benefits than the users' willingness-to-pay for the transportation services that caused them to engage in these activities. If there were no real benefits to be earned, there would be no willingness-to-pay for the necessary transportation.

Therefore, in the simplest case, the estimate of the net user benefits of a highway improvement on a single link of a fixed length in one period will be the one suggested in Figure 4-1 by the area C_0KLC_1, where a road improvement will reduce the measurable costs of travel from what would have been C_0 to C_1 and traffic volume is expected to increase from the base level V_0 to V_1. This improvement will yield measurable cost savings to existing travelers of C_0KMC_1 and benefits to generated traffic of KLM, which can be referred to as surplus willingness-to-pay. The total shaded area C_0KLC_1 is the change in consumers' surplus, or simply consumers' surplus for short [3]. Algebraically,

$$Benefits = (C_0 - C_1)(V_0 + V_1)/2 \qquad\qquad [4.1]$$

This approach is essentially a steady-state solution to the quantification of highway benefits. It implies that there exists a demand function that depends solely on trip-maker's perceived cost; that no shifts in demand over time; and that all traffic using the facility is subject to the same base cost, P_0, no matter whether it is the existing traffic, generated traffic, or developed traffic. Unless the project covers only a tiny portion of the road network, it seems more appropriate to use a demand-performance equilibrium expansion curve over time, like SL in Figure 4-2, instead of a fixed point L in Figure 4-1.

Technically, this approach is more or less manageable and practicable for the purpose of engineering economic analysis. Even in applying the methodology, however, it would be more desirable if one could trace the benefits in a broader social-economic context comprising at least population sector, economic sector, and transportation sector. Two arguments are worth mentioning:

1. Travel is not for its own sake. Demand for transportation goods and services is essentially a derived demand. Without considering relevant economic and population growth, traffic forecasting is no better than a subjective extrapolation.

2. Value of traveler's time can not be determined exogenously. It must reflect the marginal productivity of the travelers. Therefore, understanding the region's demo-economic development is a prerequisite to the selection of the value of time.

The nonuser consequences of highway construction, though they are not necessarily benefits, are far reaching. In addition to intangible benefits such as more effective national integration, greater self- sufficiency, more equal distribution of income, and prestige of the country, highway construction is observed to have effects on the national economy and regional spatial
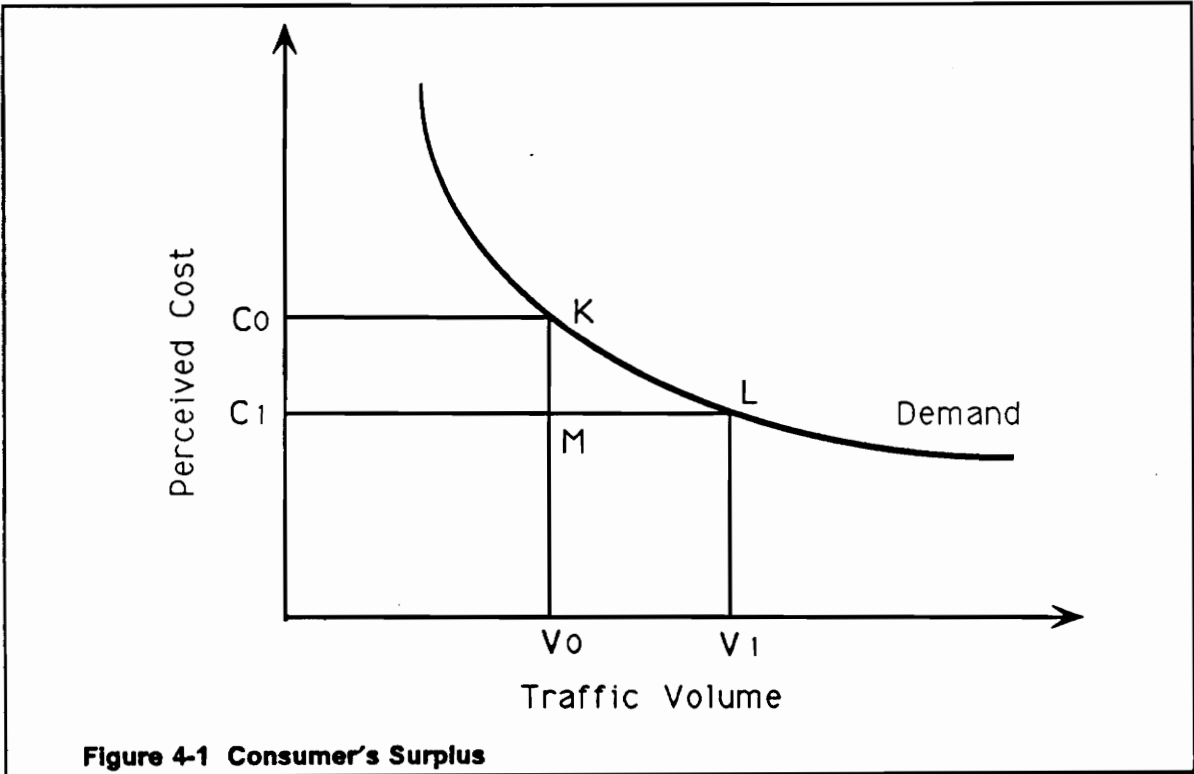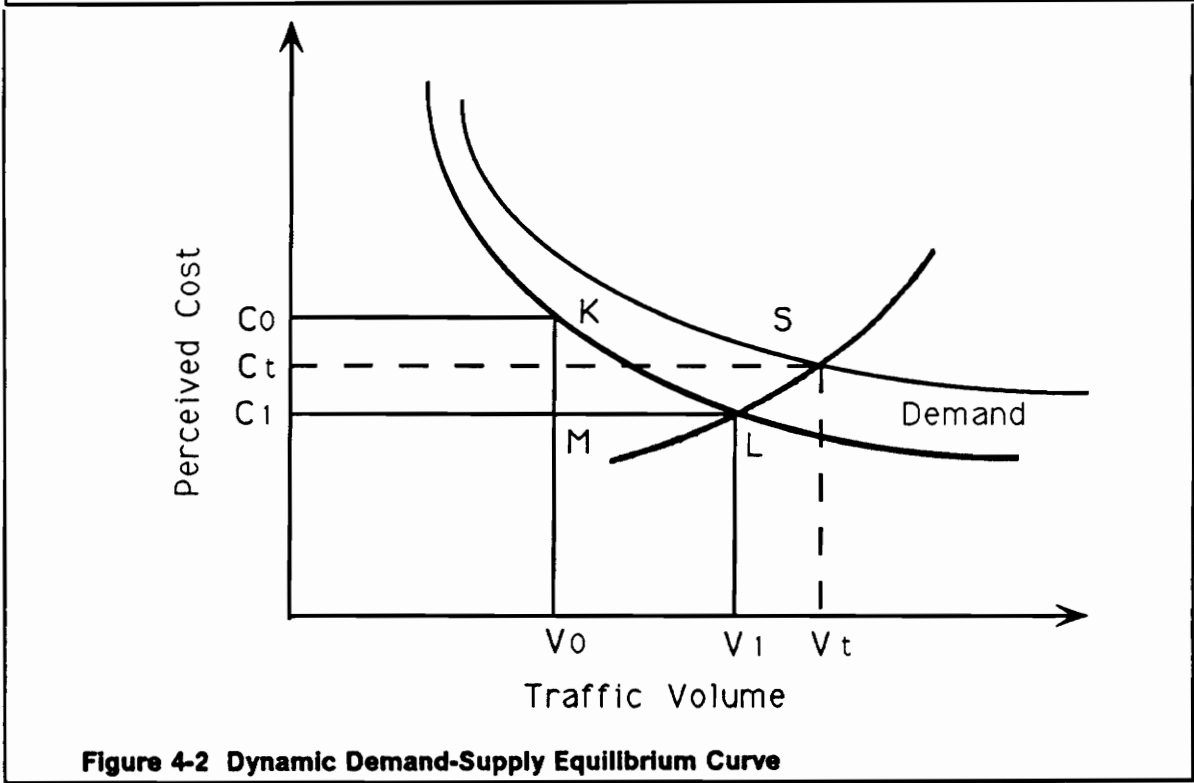
Figure 4-1 Consumer's Surplus

Figure 4-2 Dynamic Demand-Supply Equilibrium Curve

redistribution of economic competitiveness, population density, land use and land values, business composites, housing markets, and so on. Unfortunately, there is no model currently available to forecast these consequences quantitatively.

Another important issue, which is frequently neglected in the appraisal process, is the distribution of benefits (or losses) among the beneficiaries (or losers). The issue is important in the sense of considerations involving economic welfare, such as the reductions in the costs of transporting wheat to feed the poor being valued more highly than identical cost reductions for the wealthier passengers who can afford air transport, or a government according higher priority to a project in a less developed area of the country than to a project using the same resources in a more advanced area [1]. The distribution of benefits may also affect the overall size of benefits and the net gains of the economy. To carry out this type of analysis, the conventional concepts of the user and nonuser benefits may not be applicable. That nonuser consequences may not be identified from a single measurement of user benefit is expressed in the following report by Palmquist [31]:

- Where improvement in the accessibility of an area was substantial, property values appreciated significantly more rapidly. In Kinsgate (Washington state), Interstate 405 resulted in a 12 percent appreciation; in the North King County Study the appreciation that result from I-5 was 15 percent. In both areas, most residents used the highways for commuting to work and realized significant time savings. On the other hand, in Puyallup, few of residents used WA-512 for commuting, so there was little or no effect of highway benefits on property values.

Burkhardt [7] stated the needs of identifying and quantifying the consequences of highway development:

- An increased ability to predict the consequences of various kinds of highway develop-ments is needed. The reduced uncertainty of specific types of impacts will enable high-way planners to prepare designs that avoid adverse consequences or to design mitigating features into the project from the beginning where adverse consequences cannot be completely avoided. The reduced uncertainty will reduce the fears of negative conse-quences, which are often exaggerated. This increased ability to predict and alleviate concern over adverse impacts can lead to reductions in highway construction costs by eliminating serious delays. The improved predictability will thus lead to better highway practice and better highways less litigation (as well as serious litigation), and fuller com-pliance with the National Environment Protection Act, the Council on Environmental Quality, and other federal and state legislative provisions.

The following sections are aimed at proposing methodologies and developing computer sim-ulation programs that handle explicitly both the causal relationships between transportation sector and other relevant sectors and the identification of the user and nonuser benefits from a variety of highway development strategies.

4.2 Systems Approach to User Benefit Analysis

When a freeway is built to connect suburbs to adowntown area it changes the relative costs of traveling between various routes of the highway network. People begin shifting their travel routes to absorb the comparative advantages of freeway driving. Within weeks, the new or improved highway will create a set of ripple effects that eventually cover the whole highway network of the study area, generating a set of new equilibrium between travel demand and road performance in terms of traffic volume and travel cost on each link.

The effects of the freeway construction will spread beyond the highway system, however. Due to high speed and ease of driving, freeways create locational advantages of transportation for those areas adjoining and connected by the freeway. Since transportation is a basic good which enters the production function of almost every commodity and the utility function of almost every individual, it is very likely that residential and service activities will shift their locations, which in turn will affect demand for transportation, and so on. The redistribution effect may take place in a few years, and predicting it demands a methodology and an operational model that integrates the land use and the transportation system of the study area.

Unfortunately, the existing methodologies for user benefits analysis do not consider the open structure and dynamic nature of transportation systems. As a result, they are unable to take into account the benefits to the induced traffic or the shifts in demand over time.

Two implicit assumptions made in the AASHTO's method, which is based on the consumers' surplus theory, are worth mentioning:

1. There exists a defined demand function for each link of the road network

2. Traffic flows regain equilibrium immediately after the changes to the network are made

Arguments againt these two assumptions include those listed below:

1. In long run, there exist no unchanged demand functions

2. Without explicit considerations of the socio-economic context it is very difficult, if not impossible, to find a demand function for transportation .

3. The steady state of the land use and transportation, if any, may take years to realize.

In summary, user benefits from transportation improvements cannot be determined within the transportation system itself, and this is the underlying assumption of this research.

4.2.1   Modeling Land Use and Transportation

4.2.1.1   Urban Transportation Planning Process

Since the 1960's, the four-step sequential urban transportation planning process has become one of the most widely and most frequently used urban transportation forecasting methodologies. The reason for its having such a fundamental influence on urban transportation planning theory and practice lies not only in that it is the first methodology allowing urban transportation engineers, planners, and managers to attack the problem systematically and highly quantitatively, but also in that it is quite flexible in use. Although its models can be very sophisticated, the way of the thinking and the outcomes of the models are straightforward. The 'four-step' methodology divides a trip decision into four sequential steps: whether or not to make the trip, where to go, what means of transportation to take, and which route to follow. Correspondingly, four types of models are developed. They are trip generation, trip distribution, modal split, and traffic assignment models [6, 10].

For each specified land-use zone, trip generation models predict the total number of trips produced in or attracted to that zone. Regression analysis (linear, log-linear, etc.) is the most frequently used technique in relating trip measurements to zonal social, economic, and demographic variables; or land-use characteristics such as population, laborforce, income level for trip production models, and the number of employees and the value of retail sales for trip attraction models, etc. Cross classification tables of trip generation have been built for ref-

erence also. If the trip data are difficult to attain or when the city is undergoing rapid changes, cross sectional analysis may be used.

Techniques of estimating trip demand matrix from traffic counts have been developed recently to alleviate the financial burden incurred with the tremendous data collection and adjusting (consistency checking) work. They are, in essence, a reverse process of traffic assignments. The assignment models assumed for O-D estimation are frequently all-or-nothing assignment or (Dial) multipath assignment.

Trip distribution models deal with the distribution of trips generated in each zone to all other zones. Models developed are: the growth factor models (eg. Fratar's), the gravity models, the intervening opportunity model, and the competing opportunity models, etc. The gravity model is the most popular model that has been used. The double-constrained gravity model is recommended here. Mathematically we have:

$$V_{ij} = A_i B_j O_i D_j / t_{ij}^x \qquad [4.15]$$

Where,

$\quad V_{ij}$ = trip interchange from zone i t zone j.

$\quad O_i$ = total trip production in zone i.

$\quad D_j$ = total trip attraction to zone j.

$\quad t_{ij}$ = travel time from zone i to zone j.

$\quad x$ = travel time exponent, which may be calibrated from:

$$\log\left(\frac{V_{ij}\sum_i\sum_j V_{ij}}{O_i D_j}\right) = -x \log t_{ij} \qquad [4.16]$$

4.0 User and Nonuser Benefits 43

using the base year survey data.

A_i, B_j = parameters to be calibrated from

$$A_I = \left[\sum_j B_j D_j / t_{ij}^x\right]^{-1}$$ [4.17]

$$B_j = \left[\sum_i A_i O_i / t_{ij}^x\right]^{-1}$$ [4.18]

by iterating the equations until they converge.

After stratifying trips into groups by trip purposes such as home-based trips to work, shopping, social-recreation, schools, etc., nonhome-based trips, and truck trips, this model may be applied to calculate trip interchanges for each group.

Modal split models are concerned with the determination of interzonal trip interchanges by transportation mode. Two general groups of trip makers are considered: the captive riders who have access to public transportation only and the choice riders who may choose to use private cars. The percentage of choice riders who choose to use private cars can be determined by using the Logit model of the following:

$$P_{ij}^{\ c} = \frac{e^{\delta z}}{1 + e^{\delta z}}$$ [4.19]

Where, $\delta z = z_{ij}^b - z_{ij}^c$, the difference in generalized cost (ie. the money cost, time cost, and other measurable transport impedance) between using the public transportation and the pri-

vate cars [12]. Other modal split models such as the regression models, the transfer curve models, and the dissagregate models may also be used.
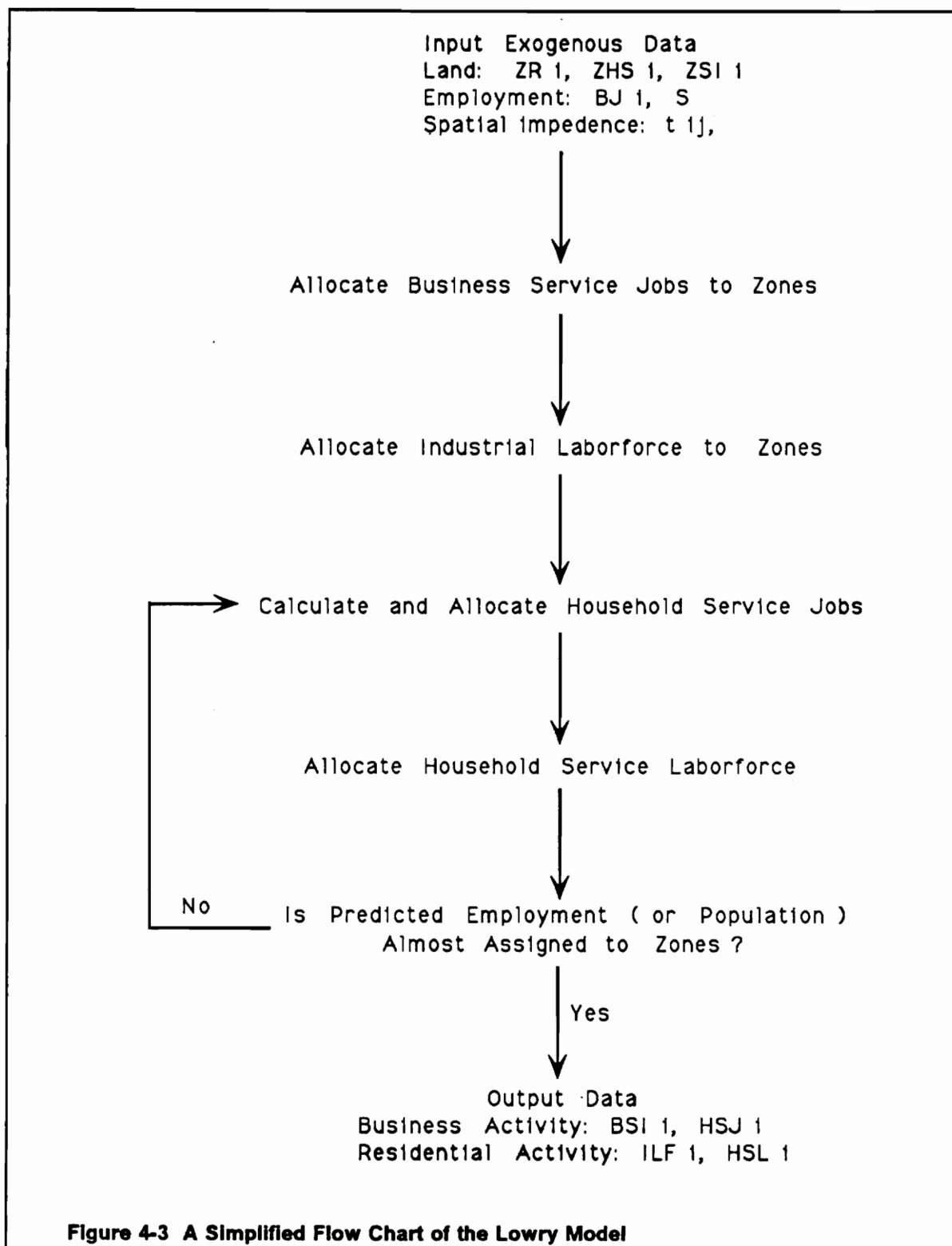
The dissagregate behavioral demand models have been developed since the early 1960's. The underlying thinking of the models is to assign a utility function to each transportation mode for each individual or group of individuals and then transform it to the probability of each rider's choosing each mode through the use of either Probit function or Logit function. Typical utility functions are linear functions of such variables as in vehicle time, out of vehicle time, and out of pocket cost, etc. One of the major issues with the dissagregate choice models is its probability aggregation problem. The simplest assumption to the solution of the problem would be that the probabilities computed at the mean values of the explanatory variables (in utility functions) represent the average choice probabilities for the group.

Traffic assignment is the last step of the planning process. There is a well developed body of models designed to assign interzonal trips to each specific route in the network, including all-or-nothing assignment, capacity constraint assignment (smoothed or unsmoothed), incremental assignment, multipath assignment (Logit-based stochastic assignment), stochastic assignment (Probit-based Monte Carlo simulation), and a variety of user equilibrium models and stochastic user equilibrium models. Two broad theories are that of Wardrop's (1952) and its extension with variations in trip-maker's perceptive travel time. Models presenting those theories are that of Beckman's (1956) and that of Sheffi's (1979). Increamental assignment has proven effective in my personal experience with transportation planning for small and medium cities. Incremental assignment algorithm divides total trips into several portions (4 to 5), performs all-or-nothing assignment and updates the travel time for each link, and then repeats the process until all trips are assigned to the network. Appendix A.2 lists a simulation program for projecting population distribution and traffic flows for a four-zone urban area to be served by an existing arterial and a proposed freeway.

4.2.1.2   The Lowry Model

The Lowry model classifies the activities of a region into three groups: basic activities, service activities, and residential activities. Basic activities are determined by external demand rather than by events within the regional economy. Correspondingly, employment in basic industries is site-oriented rather than constrained by access to the market in the region. Both the level and the zonal distribution of basic employment are given, exogenous to the model. The service activities are residence-oriented. They include such public facilities as schools, retail facilities, and local government services. These facilities must be accessible to the residents of the region. The level and the location of employment in this sector is to be predicted by the model. The size of residential activities depends on the number of jobs, which in turn determines the size of retail services. The location of households is assumed to depend on the location of jobs. Given the level and the geographic distribution of basic employment in the region, the model calculates the level and geographic distribution of service activities and the size and geographic distribution of laborforce.

Suppose that there exists a known distribution of basic employment over the zones of the region. The model first calculates the size of business service industries and distributes them according to the attractiveness (the multiplication of accessibility by holding capacity) of each zone to these jobs. Employees in the both sectors are then distributed in proportion to the residential attractiveness of each zone to the laborforce. Next, the number of retail jobs needed to serve these household is computed, and the level of retail employment is distributed over zones. As these retail jobs themselves require labor from additional households, the accessibility of each zone to jobs is calculated again and the additional households distributed accordingly. The newly-located households need retail service, which are again distributed over zones. This iterative process of adding retail jobs and households continues until the pattern stabilizes [45]. Figure 4-3 is a simplified flow chart of the Lowry model.

Input Exogenous Data
Land: ZR 1, ZHS 1, ZSI 1
Employment: BJ 1, S
Spatial impedence: t 1j,

↓

Allocate Business Service Jobs to Zones

↓

Allocate Industrial Laborforce to Zones

↓

Calculate and Allocate Household Service Jobs

↓

Allocate Household Service Laborforce

↓

No ⟶ Is Predicted Employment (or Population)
Almost Assigned to Zones ?

↓ Yes

Output Data
Business Activity: BSI 1, HSJ 1
Residential Activity: ILF 1, HSL 1

Figure 4-3 A Simplified Flow Chart of the Lowry Model

Equations 4.2 to 4.14 are mathematical representations of this iterative procedure, the solution to which describes the predicted spatial pattern of employment and residences.

1. Allocate business service jobs to zones.

$$BSJ_i = \frac{ASI_i ZSI_i}{\sum_i ASI_i ZSI_i} \sum_j BJ_j S \qquad [4.2]$$

$$ASI_i = \sum_j BJ_j S / t_{ij}^{\alpha} \qquad [4.3]$$

where: BSJ_i = business service jobs in zone i

ASI_i = accessibility of zone i service to basic industries.

ZSI_i = zone i holding capacity of service jobs

BJ_j = business jobs in zone j

t_{ij} = travel time between zone i and zone j

α = spatial impedance exponent

S = service industry multiplier.

2. Allocate industrial laborforce to zones.

$$ILF_i = \frac{ARIJ_i ZR_i^0}{\sum_i ARIJ_i ZR_i^0} \sum_j (BJ_j + BSJ_j) \qquad [4.4]$$

$$ARIJ_i = \sum_j (BJ_j + BSJ_j)/t_{ij}^\beta \qquad [4.5]$$

where: ILF_i = industrial laborforce residing in zone i

$ARIJ_i$ = accessibility of residential zone i to industrial jobs.

ZR_i^0 = zone i initial holding capacity of residents.

β = spatial impedance exponent for residing

3. Allocate household service jobs.

$$HSJ_i^0 = \frac{AHP_i^0 ZHS_i^0}{\sum_i AHP_i^0 ZHS_i^0} \sum_j ILF_j(p/f) \qquad [4.6]$$

$$AHP_i^0 = \sum_j ILF_j/t_{ij}^\gamma \qquad [4.7]$$

where: HSJ_i^0 = household service jobs initial

AHP_i^0 = accessibility of household service to population

ZHS_i^0 = zone i holding capacity of household service

γ = spatial impedance exponent for household service

p = household jobs per person

f = labor participation fraction

4. Allocate household service laborforce.

$$HSL_i^k = \frac{ARHJ_i^k ZR_i^{k+1}}{\sum_i ARHJ_i^k ZR_i^{k+1}} \sum_j HSJ_j^k \qquad\qquad [4.8]$$

$$ARHJ_i^k = \sum_j HSJ_j^k / t_{ij}^\beta \qquad\qquad [4.9]$$

where: HSL_i^k = household service laborforce residing in zone i

$ARHJ_i^k$ = accessibility of residential zone i to household service

ZR_i^{k+1} = zone i holding capacity of residents

k = sequential indicator of iteration: k=0,1,2,...

5. Allocate induced household service jobs.

$$HSJ_i^{k+1} = \frac{AHP_i^{k+1} ZHS_i^{k+1}}{\sum_i AHP_i^{k+1} ZHS_i^{k+1}} \sum_j HSL_j^k (p/f) \qquad\qquad [4.10]$$

$$AHP_i^{k+1} = \sum_j HSL_j^k / t_{ij}^\gamma \qquad\qquad [4.11]$$

6. Constraints.

$$ZR_i^{k+1} \le ZR_i^k \le ZR_i \qquad\qquad [4.12]$$

$$ZHS_i^{k+1} \le ZHS_i^k \le ZHS_i \qquad\qquad [4.13]$$

$$\sum_i (BJ_i + BSJ_i + \sum_k HSJ_i^k)/f = P \qquad [4.14]$$

where: P = predicted population of the study area

Figure 4-4 shows a DYNAMO simulation program for the Lowry model.

4.2.2   Simulating Traffic and Locational Impacts

System dynamics and its supporting language DYNAMO is used in this research to simulate the effects of highway construction and highway improvement. It is apparent that the demand for and supply of highway transportation are interdependent. To predict the impacts of highways precisely, one has to to place the highway in a dynamic socio-economic context of the region. System dynamics is the only methodology that handles feedback interactions effectively.

The following scenario analyses are designed to : (1) present insights into some typical highway transportation problems, (2) illustrate the system dynamics approach to the problem, and (3) show the modelling and simulation strategies with DYNAMO.

4.2.2.1   Scenario I: Highway Improvement

Suppose a freeway is built to replace the original arterial road linking the central city, denoted as zone 1, to its suburb, zone 2. The upgrading of the road reduces the travel cost between the two zones from t_{21} to T_{21}. Assuming that the central city has holding capacities of ZR_1 for

```
NOTE ******************** LOWRY MODEL *************************
NOTE
N       TBJ=SUM(BJ)
T       BJ=40000/60000/0/0
I       NZ=4
FOR     I=1,NZ/J=1,NZ
N       ASI(I)=SUMV(TS1(I,*),1,4)
N       TS1(I,J)=BJ(J)/T(I,J)
N       BSJ(I)=ASI(I)*ZSI(I)*TBSJ/SUM(TS2)
N       TS2(I)=ASI(I)*ZSI(I)
T       ZSI=1.75/0.80/0.40/0
T       T(*,1)=10/16/20/40
T       T(*,2)=15/24/20/30
T       T(*,3)=20/20/10/20
T       T(*,4)=40/30/20/20
N       TBSJ=TBJ*S
C       S=1
N       IJ(I)=BJ(I)+BSJ(I)
N       TIJ=TBJ+TBSJ
N       ILF(I)=ARIJ(I)*ZR(I)*TIJ/SUM(TS3)
N       TS3(I)=ARIJ(I)*ZR(I)
N       ARIJ(I)=SUMV(TS4(I,*),1,4)
N       TS4(I,J)=IJ(J)/T(I,J)
T       ZR=0/1.72/4/23
NOTE
L       LF.K(I)=LF.J(I)+(DT/AT)*CLF.JK(I)
N       LF(I)=ILF(I)
R       CLF.KL(I)=HSL.K(I)-LF.K(I)
A       HSL.K(I)=ARHJ.K(I)*ZR(I)*(SUM(HSJ.K)/SUM(TS5.K))
A       TS5.K(I)=ARHJ.K(I)*ZR(I)
A       ARHJ.K(I)=SUMV(TS6.K(I,*),1,4)
A       TS6.K(I,J)=HSJ.K(J)/T(I,J)
A       HSJ.K(I)=AHP.K(I)*ZHS(I)*((P/F)*SUM(LF.K)/SUM(TS7.K))
A       TS7.K(I)=AHP.K(I)*ZHS(I)
A       AHP.K(I)=SUMV(TS8.K(I,*),1,4)
A       TS8.K(I,J)=LF.K(J)/T(I,J)
T       ZHS=0/2.04/0.97/3.20
N       AT=DT
C       P=0.3
C       F=0.6
NOTE TBJ-TOTAL BUSINESS JOBS
NOTE NZ-NUMBER OF ZONES
NOTE TS-TRANSIENT SOLUTION
NOTE IJ-INDUSTRIAL JOBS (BASIC & BUSINESS SERVICE)
SPEC DT=1/LENGTH=10/PRTPER=1/PLTPER=1
PRINT BSJ,LF,HSJ
RUN BASE
```

Figure 4-4 Example of Simulation with DYNAMO

residential activities and ZS_1 for service activities, the suburb has ZR_2 and ZS_2 for the corresponding activities, and the basic industries are historically located at zone 1 with a business service multiplier s, the relationship between T_{21} and the residential and service activities can now be simulated by using system dynamics methodology.

Figure 4-5 displays a simplified causal relationship for the example. As travel time from the suburb to the central city decreases, the suburb becomes more accessible to both residential activities and service activities, which attracts more people to live in the suburb. The more people living in the suburb, the more likely the demand for commuting, which in turn increases the travel time between the suburb and the central city. A negative feedback structure as such will eventually adjust itself to a stable and yet new pattern of flows and activities.

Travel Time T_{21}. The performance of traffic stream on highway links is best described by Figure 4-6, where u_f, the free flow speed, is the speed observed when there is no traffic interference. Q_c is the capacity of the highway. From Figure 4-6, we can derive the following equations for the causal relationship between travel time through the link and traffic demand from the suburb to the central city.

T21.K	= 2*FFTT / (1 + SQRT(1-DCR.K)) + CDT
DCR.K	= Q21.K / CA
CA	= LC*NL
CDT	= 10
FFTT	- free flow travel time
DCR	- demand capacity ratio
CA	- link capacity
LC	- lane capacity
NL	- number of lanes
CDT	- collection-distribution time (min)

TRAVEL TIME $\xrightarrow{-}$ SUBURBAN ACCESSIBILITY

TRAFFIC VOLUME $\xleftarrow{+}$ SUBURBAN ACTIVITIES
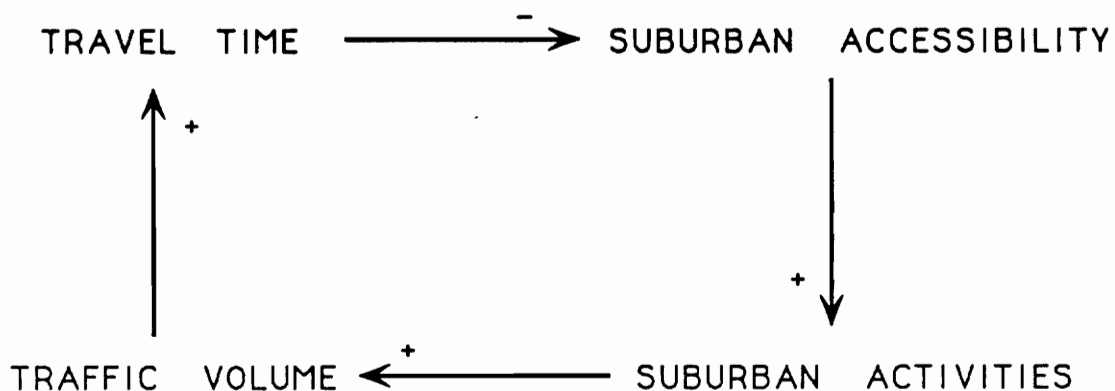
Figure 4-5   Linkage between Transportation and Activity System
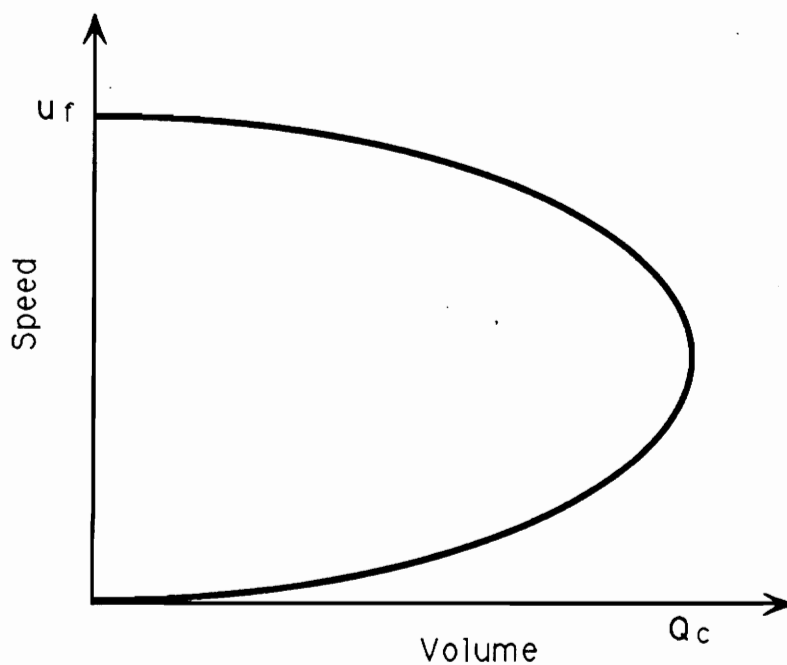

Figure 4-6 Flow-Speed Relationship

Traffic Demand Q_{21}. The number of trips from the suburb to the central city depends on the trip demand of the suburb and the attractiveness of the central city. The trip demand of the suburb is assumed proportional to the amount of laborforce residing in the suburb. The attractiveness of the central city is determined by job opportunities in the central city and spatial impedance for suburban populace to obtain those opportunities. Knowing the geographic distribution of jobs and laborforce, we can predict zonal trip-interchanges with a double-constrained trip-distribution model.

$$Q21.K \quad = V21.K \; / \; ACO$$

$$V21.K \quad = A2^*B1^*O2.K^*D1.K \; / \; T21.K$$

$$O2.K \quad = ILF2.K + THSL2.K$$

$$D1.K \quad = BJ1 + BSJ1.K + THSJ1.K$$

V21	- number of trips from suburb to central city
ILF2	- suburban industrial laborforce
THSL2	- total suburban household service laborforce
BJ1	- basic jobs in central city
BSJ1	- business service jobs in central city
THSJ1	- total household service jobs in central city.
ACO	- average car occupancy
A2, B1	- parameters

Suburban Laborforce LF_2. All other things being equal, accessibilities shapes the zonal distribution of laborforce. People tend to locate at the place of easist access. The aggregate result of this locational preference is predicted with a Lowry model, where basic employment BJ and the total employment of the area TJ are exogenously determined. For simplicity, $ZR_i^f = ZR_i$ and $ZS_i^f = ZS_i$ are assumed. Thus, each iteration of the Lowry model repeats the same pattern of distribution. In summary, we have:

$$THSL2.K \quad = THSJ^*ARHJ2^*ZR2 \; / \; (ARHJ1^*ZR1 + ARHJ2^*ZR2)$$

THSJ   = TJ - BJ - BSJ

THSJ   - total household service employment

ARHJ2   - suburban accessibility of residential area to household service jobs.

TJ   - total number of jobs

Suburban Accessibility A_{21}. The relationship between accessibilities and travel time is defined in the equations of the Lowry model.

Dynamic Representation. As mentioned earlier, the Lowry model is static and descriptive. It disaggregates the entire range of urban activities into several groups and then applies an iterative procedure to accumulate and distribute those activities over the study area. The model is intended to explain the formation of a city and to predict the probable future state of the urban system. It does not examine the process of the change.

An urban system is a dynamic system. Feedback reaction and time-lag mechanism play a very important role in the evolution of the system. In the case of highway improvement, a dominant feedback loop is illustrated in Fig 4-5. As can be seen from the diagram, a sudden decrease in travel time due to freeway construction will begin to be reversed by the shifting of traffic to the freeway until an equilibrium is reached. This widely-observed goal-seeking behavior of a society can be understood with no further elaboration. The question raised here is how the system evolves.

Though transportation advantage creates a 'pull' for firms and individuals to relocate; the mobility and capital accumulation, materialization, and recovery constraints restrict their relocation possibility and speed. Thus, the aggregate response of a society to the change is a steady adjustment to its future state.

System dynamics is equipped with a special function called SMOOTH function to accommodate delay and smoothing behavior of dynamic systems. Conceptually, a smoothed variable

(SVAR) retains only a fraction (1/smoothing time) of the fluctuation of the variable being smoothed. Or,

L   SVAR.K = SVAR.J + (DT/STIME)(VAR.J-SVAR.J)

N   SVAR = VAR

In this example, the dynamic process of the intra-metropolitan locational shifts is represented by the following equations:

O1.K   = SMOOTH(UO1.K,LRT)

D1.K   = SMOOTH(UD1.K,BRT)

LRT   - average laborforce relocation time

BRT   - average business relocation time

Example 4-1. A three lane (each direction) arterial road is upgraded into a four lane freeway, which reduces the free flow travel time from 30 minutes on the arterial road to 22 minutes on the freeway and increases lane capacity from 1800 to 2000 veh/hr. The collection-distribution time at both ends of the link is 10 minutes. Intra-zonal travel time will be stable at 30 minutes in the central city and 15 minutes in suburb. Economic analysis predict 36000 jobs in the area, 10000 of them are basic jobs located at the central city. The zoning ordinance of the city shows: ZSI = 20/10, ZR = 100/100, and ZHS = 20/20. The duration of peak period is two hours. Appendix A.3 lists a computer simulation program for this example.

Figure 4-7 and Figure 4-8 show the dynamic behavior of traffic flows and suburban activities before and after the highway improvement, where T is the travel time between the two zones, Q shows the traffic flow from suburb to central city, E represents the suburban employment opportunity, and P is the suburban population (F = 0.4). After freeway construction, the suburban employment and population increase steadily until the system stabilizes in about ten years. The adjustment of traffic flows to changes in the transportation system, however, pro-

ceeds much more rapidly. The flows stabilize in about two to three years. Quantitatively, the 30% saving in travel time in this example results in a 7% increase in suburban employment, 5% increase in suburban population, and 16% increase in peak hour flows from suburb to central city.

Sensitivity Analysis. The time profile of demand for urban transportation makes most highways congested during rush hours while 80% of time they are operated in excess of capacity. If somehow people can even up the demand over time or reduce the use of automobiles without sacrificing mobility, the benefits could be enormous. In this example, the user benefit of increasing either the duration of peak period or vehicle occupancy rate by 50% is valued at $40 million, nearly one half of the benefit from the road upgrading program. The nonuser consequences of the increase in DPP or AVO are a 2.3% increase in suburban population and 3.2% increase in suburban jobs.

Implication . Highway system, socio-economic activities, and the flow pattern on highways are interrelated and mutually dependent. Changes in highway system not only affect traffic flows immediately, but also affect activities in a longer time, which may in the long run place new demands on highway system.

4.2.2.2   Scenario II: Corridor Analysis

As suburbs grow, freeways may be built, not to replace any one of the existing arterial roads, but to add additional capacity and provide more rapid transport between the suburb and the central city. People are now not only to decide where to live and work, but also to decide which route to use for commuting. In a short time, the corridor equilibrium will be realized, at which juncture all routes used by trip-makers present the same impedance (or more specifically, the same travel time) to commuters. Technically, this process is treated as a traffic
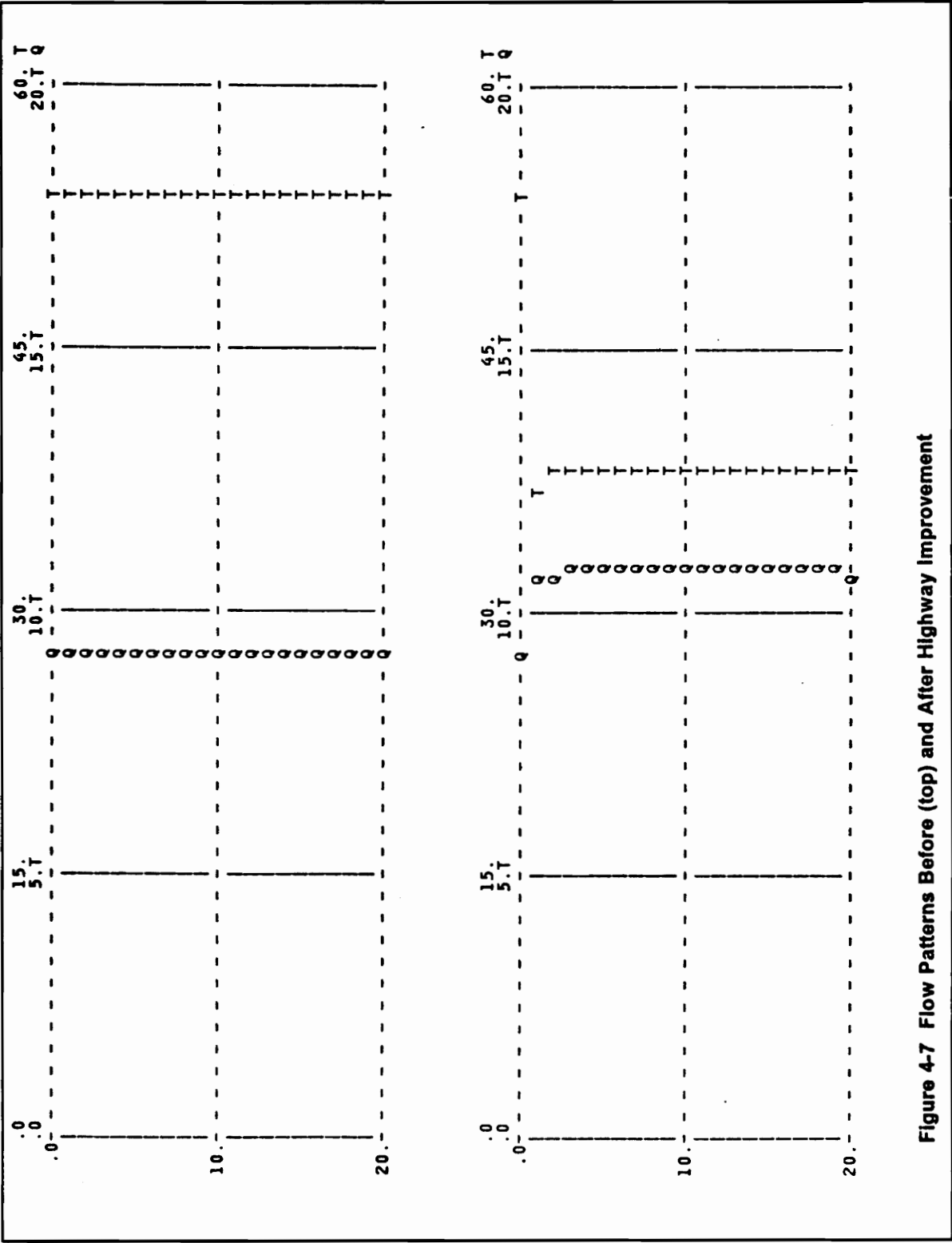
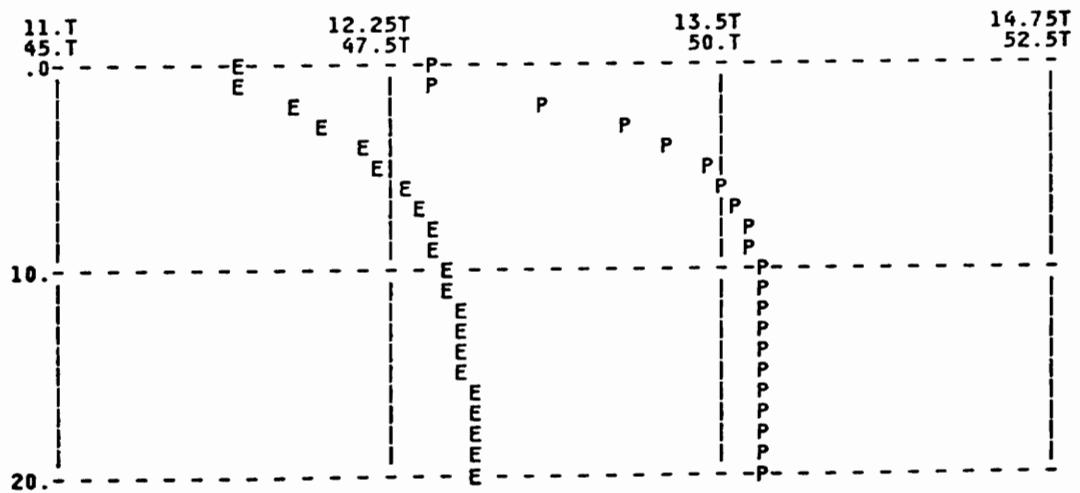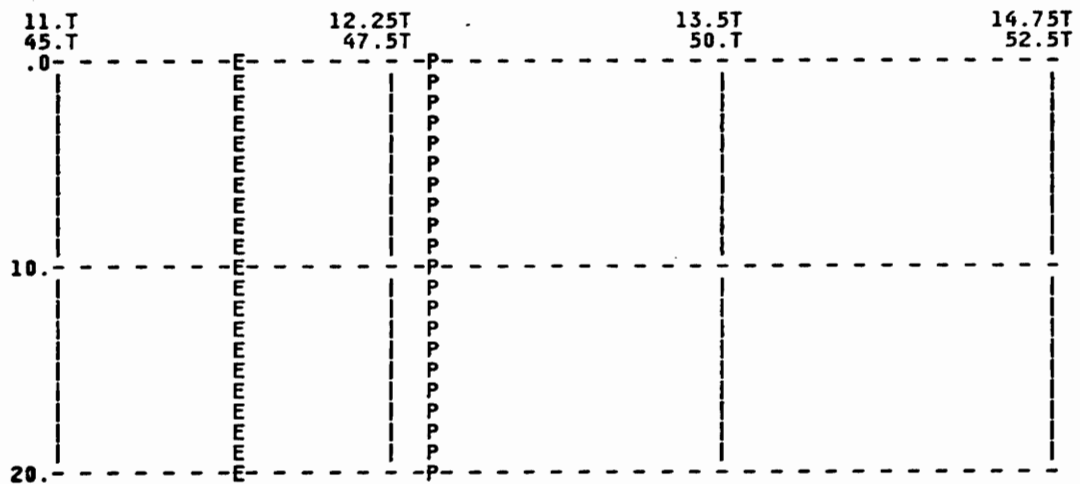Figure 4-7 Flow Patterns Before (top) and After Highway Improvement

```
   11.T                 12.25T        .       13.5T               14.75T
   45.T                 47.5T                 50.T                 52.5T
    .0-  - - - - - - - -E- - - - - - -P- - - - - - - - - - - - - - - - -
     |                  E             |P
     |                  E             |P
     |                  E             |P
     |                  E             |P
     |                  E             |P
     |                  E             |P
     |                  E             |P
     |                  E             |P
   10.-  - - - - - - - -E- - - - - - -P- - - - - - - - - - - - - - - - -
     |                  E             |P
     |                  E             |P
     |                  E             |P
     |                  E             |P
     |                  E             |P
     |                  E             |P
   20.-  - - - - - - - -E- - - - - - -P- - - - - - - - - - - - - - - - -
```

```
   11.T                 12.25T                13.5T               14.75T
   45.T                 47.5T                 50.T                 52.5T
    .0-  - - - - - - -E- - - - - - - -P- - - - - - - - - - - - - - - - -
     |               E                |P
     |            E    E               |P
     |              E                P   |
     |                E|            P    |
     |               E E|         P      |P
     |                |E|E                 |P
     |                |  E                   |P
     |                |   E                   |P
   10.-  - - - - - - - - -E- - - - - - - - - - - -P- - - - - - - - - - -
     |                |   E                      |P
     |                |    E                      |P
     |                |     E                     |P
     |                |     E                     |P
     |                |      E                    |P
     |                |       E                   |P
     |                |        E                  |P
     |                |         E                 |P
   20.-  - - - - - - - - - - - -E- - - - - - - - -P- - - - - - - - - - -
```

Figure 4-8 Suburban Activities Before (top) and After Highway Improvement

assignment problem in which all drivers seek to minimize their own travel time by shifting travel routes until discrepancies in travel time for all routes are negligible.

The causal diagram this situation can be treated as an extension of Figure 4-5. As an example, Figure 4-9 shows the causal streams from inter-zonal traffic demand (Q21) to inter-zonal travel time (T21). Before freeway construction, all the traffic flows are on the original roads, and this determines the travel time from suburb to central city and thus the accessibility of the suburb as well. When the freeway is opened, some drivers will shift to the freeway. The rate of diversion from the original roads to the freeway (TDR) depends both on the flows on the original roads and the travel time ratio of the original roads to the freeway (TTR). Expressed in DYNAMO equations, we have:

TA.K $= 2^*$FFTTA / (1+SQRT(1-DCRA.K)) + CDT

DCRA.K $=$ QA.K / CAA

QA.K $=$ Q21.K - QF.K

QF.K $=$ QF.J + (DT)(TDR.JK)

TDR.KL $=$ QA.K*(TTR.K - 1)

TTR.K $=$ TA.K / TF.K

TF.K $= 2^*$FFTTF / (1+SQRT(1-DCRF.K)) + CDT

DCRF.K $=$ QF.K / CAF

TA, TF   - travel time on arterial roads and freeway

QA, QF   - flows on arterial roads and freeway

DCRA, DCRF - demand-capacity-ratio of the arterial road and freeway

CAA, CAF - capacity of the arterial road and freeway

Incorporating Figure 4-9 into Figure 4-5, one will be able to predict the performance of the corridor traffic.
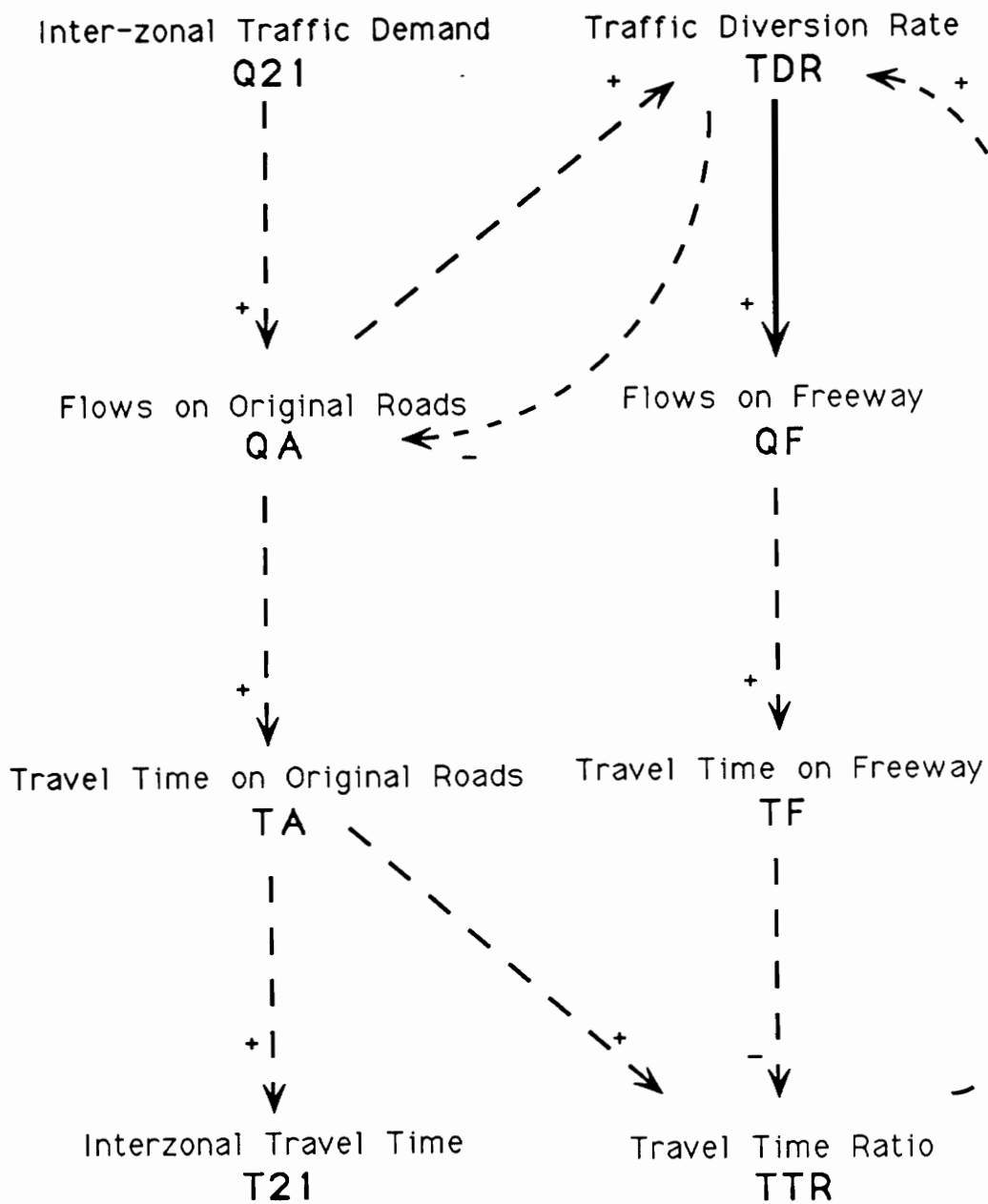
Figure 4-9 Causal Diagram for Traffic Diversion

Example 4-2. A four lane freeway is proposed as an alternative route to the existing three lane arterial road linking a city to its suburb. The assessment of the project is based on the following information. Economic activities: 70000 employment with 20000 basic jobs located in the city. Zoning ordinances (central city / suburb): ZSI=30/15, ZR=200/100, ZHS=40/20. Traffic characteristics: 30 minutes of free flow travel time on the arterial road and 22 minutes on the freeway with collection-distribution time CDT=10, duration of peak period DPP=2, and average car occupancy ACO=1. A computer simulation program developed for this example is listed in Appendix A.4.

Figure 4-10 and 4-11 summarize the traffic flows and travel time on both the arterial road and freeway over twenty years following the freeway opening; where Q, T, F, and C represent traffic flow and travel time on the arterial road and freeway, respectively. Figure 4-10 illustrating the situation without the freeway, all other factors being equal. Figure 4-11 shows the progressive effects of the freeway construction on the flow system. The freeway not only attracts a majority of the drivers originally using the arterial roads (see the values Q and F in Figure 4-11 at time=0 and time=1 year), but also generates more traffic between the central city and the suburb (see the steady increase in Q and F over the first 6 years of the freeway opening).

Figure 4-12 shows the changing process of suburban activities with and without the freeway, where E and P stand for the job opportunity and population of the suburb. Numerically, the freeway construction reduces the travel time between the suburb and central city by 39%, increases the corridor traffic flows by 37%, increases job opportunity of the suburb by 27% (or 3500 jobs), and increases suburban population by 22% (or 4500 laborforce).

Sensitivity Analysis. Experiments on the model show that:
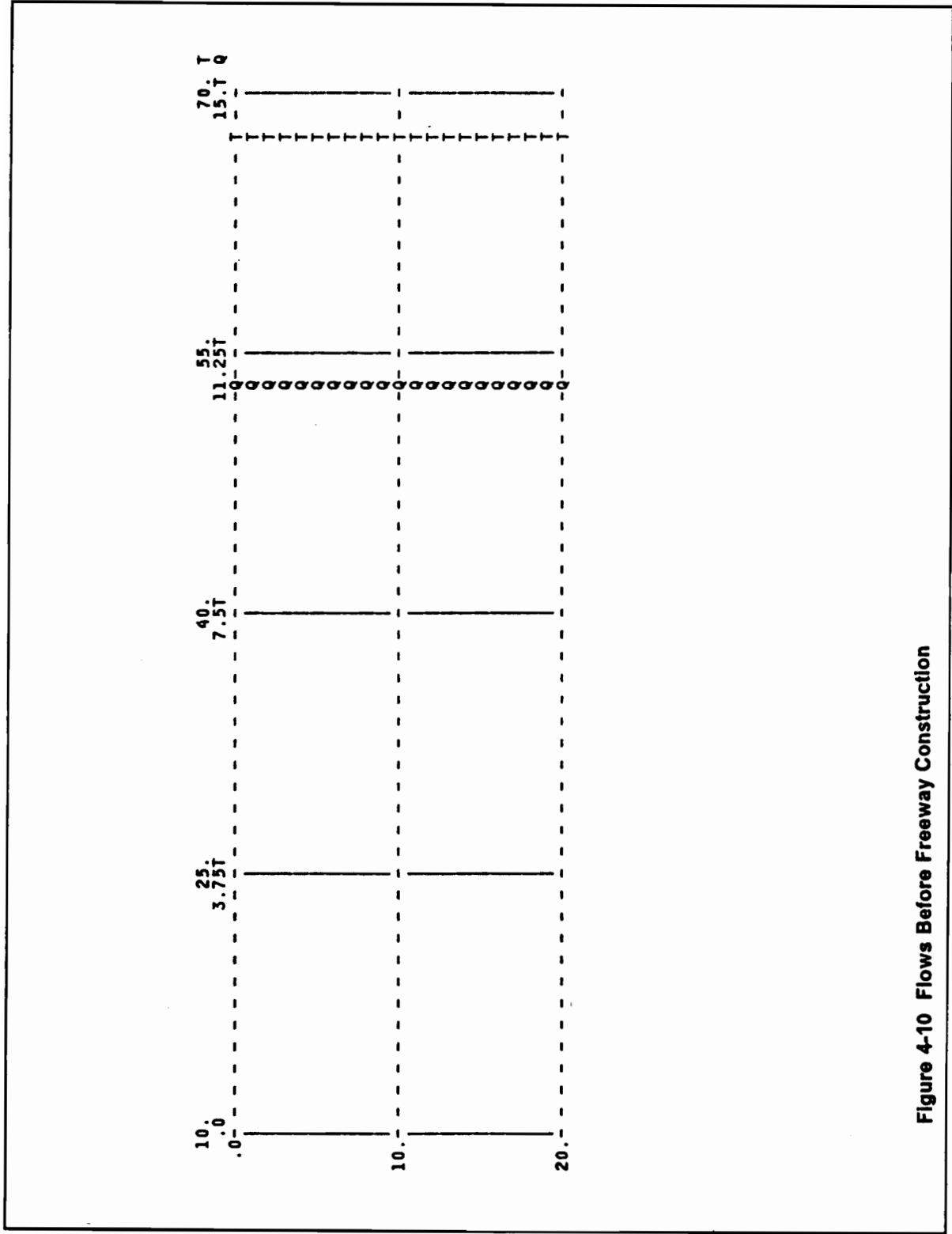
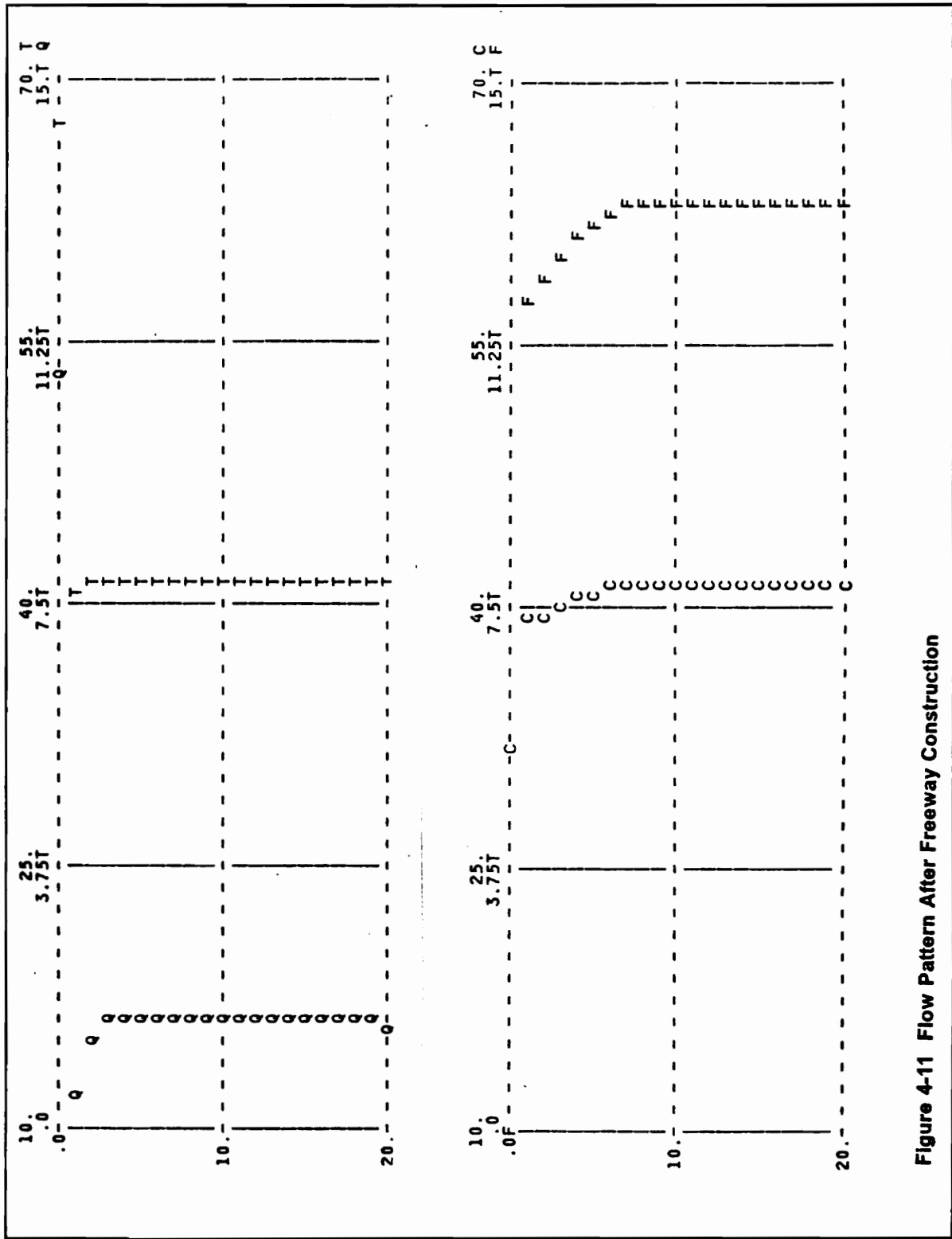Figure 4-10 Flows Before Freeway Construction

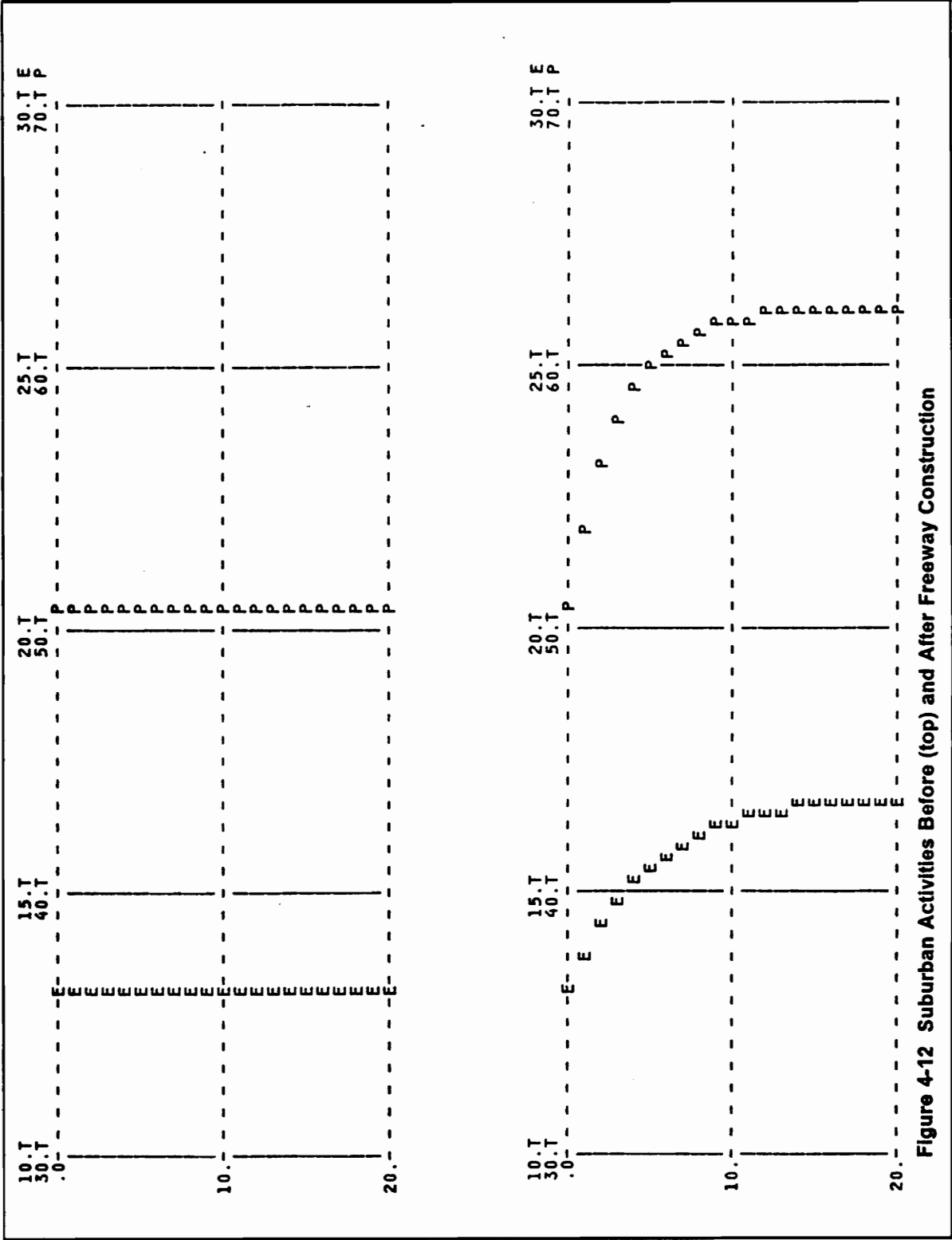Figure 4-11 Flow Pattern After Freeway Construction

Figure 4-12 Suburban Activities Before (top) and After Freeway Construction

1. In long run, BRT and LRT (business and laborforce relocation time) have negligible effects on the user and nonuser consequences of the project, which makes the model more generically applicable.

2. Whereas increasing suburban business holding capacity (or attractiveness) tends to decrease the user benefits of the project because fewer people are forced to commuting, increasing suburban residential holding capacity (or amenity) dramatically increases the user benefit of the project because more people are living in the suburb. The overall benefit of a highway project is very sensitive to the economic and demographic context of the region.

Example 4-3. Another example of corridor analysis goes to the relationship between central city and satellite cities. A satellite city differs from a suburb in that it is also a place of employment and center of commerce by its own right. Therefore a satellite city may be technically treated as a location with its own basic jobs. Appendix A.5 provides a simple simulation model of the problem.

4.2.2.3   Scenario III: HOV Lane Provision

Instead of relying on a heavy investment like roadway expansion or freeway construction, highway authorities may tackle congestion problems from the demand side, seeking to channel vehicular demands so that the total cost of transportation is minimized. Two basic tactics employed are staggered working hours and priority treatment of high-occupancy-vehicles. The significance of increasing duration of peak period and vehicle occupancy rate, in terms of user and nonuser consequences, has been discussed in the first scenario analysis. The purpose of this section is to present a methodology and computer simulation program that could be used in evaluating the effectiveness of HOV lane provision.

Trips by HOV. Among a variety of HOV preferential treatments, such as offering economic incentives, faster link connection, and priority terminal treatments to HOVs; an HOV lane is typically designed to reduce the travel time of HOVs by partitioning them from other traffic. The goal of the procedure is to increase ride sharing and vehicle occupancy rate and thus to alleviate congestion problems. A causal diagram showing how and why trips are made by HOV or LOV is illustrated in Figure 4-13, where the relative attractiveness of an HOV lane is represented by the change in FHOV, the fraction of trips by HOV, induced by the cost difference of travelling by HOV and LOV, and calculated with a Logit type model. Precisely, one can translate the casual diagram into the following mathematical equations. A smooth function is used here to reflect the progressive changing behaviors of trip makers.

$$VHOV.K = V21.K^*FHOV.K$$

$$VLOV.K = V21.K^*FHOV.K$$

$$FHOV.K = FHOV.J + (DT)(CFHOV.JK)$$

$$CFHOV.KL = SMOOTH(UFHOV.K,1) - FHOV.K$$

$$UFHOV.K = MFHOV/(1+EXP(CD.K/2))$$

$$CD.K = ZHOV.K - ZLOV.K$$

$$ZHOV.K = THOV.K^*VT + MHOV$$

$$ZLOV.K = TLOV.K^*VT + MLOV$$

VLOV	- trips by low occupancy vehicle
CFHOV	- changes in FHOV
UFHOV	- unsmoothed FHOV
MFHOV	- model parameter

Model Parameter MFHOV. The criterion for selecting model parameters and initial values is to keep them consistent within the model and with reality. Knowing the initial value of FHOV, FHOVN or the fraction of trips by HOV before the implementation of HOV lanes, one can determine the value of MFHOV from the equations cited above by simply setting the time of simulation at zero:
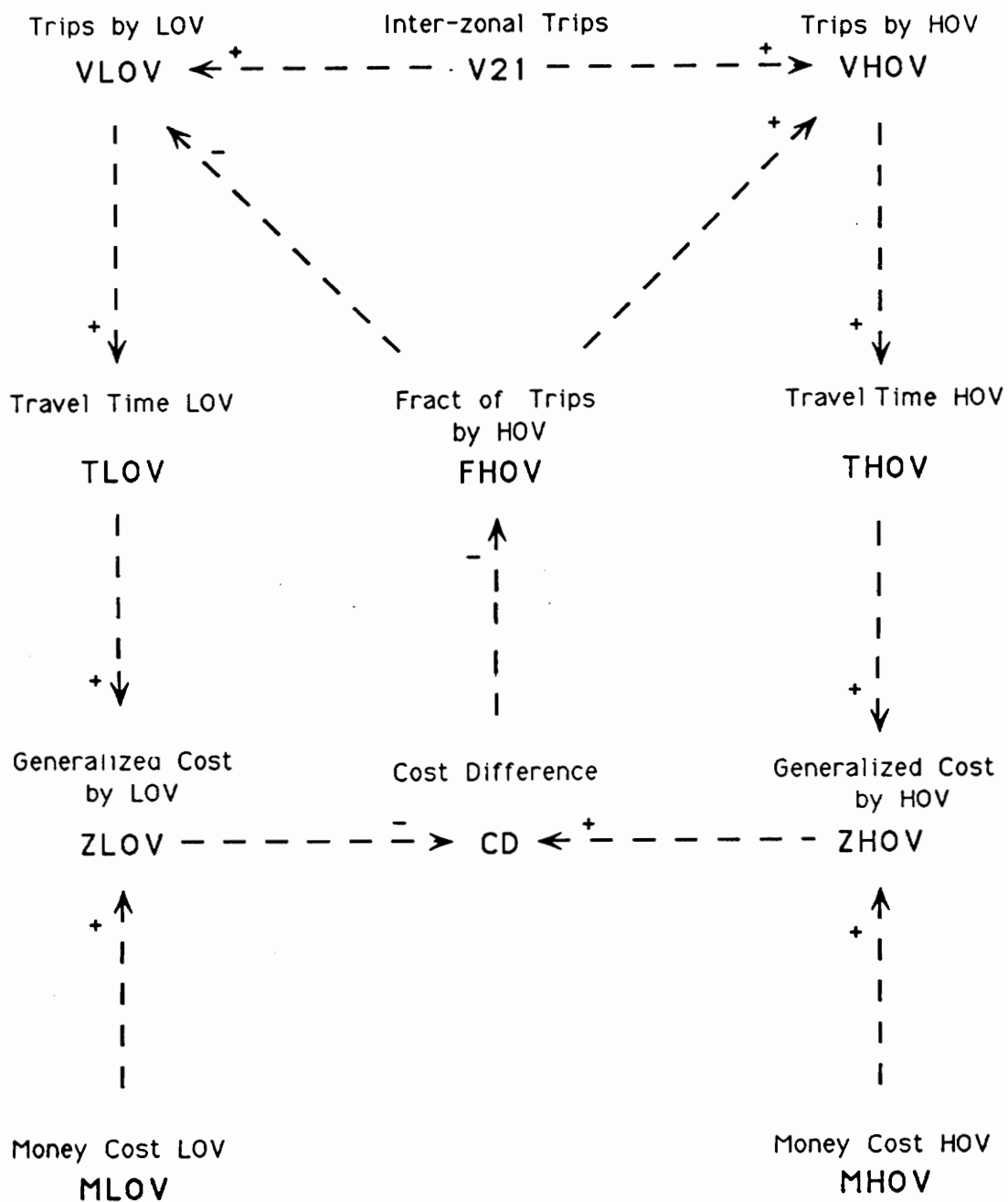
Figure 4-13 Causal Diagram for Trips by HOV

CFHOV = 0

UFHOV = FHOVN

MFHOV = FHOVN*(1+EXP(CD/2))

Assuming CD=0, or the higher collection-distribution time by HOV is initially just offset by lower money cost, we have:

MFHOV = 2*FHOVN

The relationship between occupancy rate of HOV (VORHOV), overall occupancy rate of all trips (VOR), and initial fraction of trips by HOV (FHOVN) is:

FHOVN (1/VORHOV - 1) = (1/VOR - 1)

Example 4-4. An HOV exclusive lane is proposed as an alternative project to scenario I, example 4-1. Test the user and nonuser consequences of the project if initially 20% of trips are made by HOV with an occupancy rate of 3. By sharing rides, each trip maker saves just enough money to compensate for higher collection-distribution time and possible inconvenience by HOV. In other words, the only user benefit of the project, if any, is due to the change in like travel time. Appendix A.6 shows a computer simulation program for the example.

Figure 4-14 summarizes the consequences of providing the HOV lane; where V = trip interchange, T = average travel time for all trips, F = fraction of trips by HOV, H = travel time by HOV, and L = travel time by LOV. Because of the HOV lane, the travel time of LOVs jumps from 42 to 68 minutes and stabilize at 61 minutes in two years while the travel time of HOVs drops to 32 minutes. Though the fraction of trips by HOV is increased by 37%, or the vehicle occupancy rate by 6%; the net effects of the project are a 3.5% increase in average travel time, 2% decrease in suburban population, and 2.4% decrease in suburban jobs.
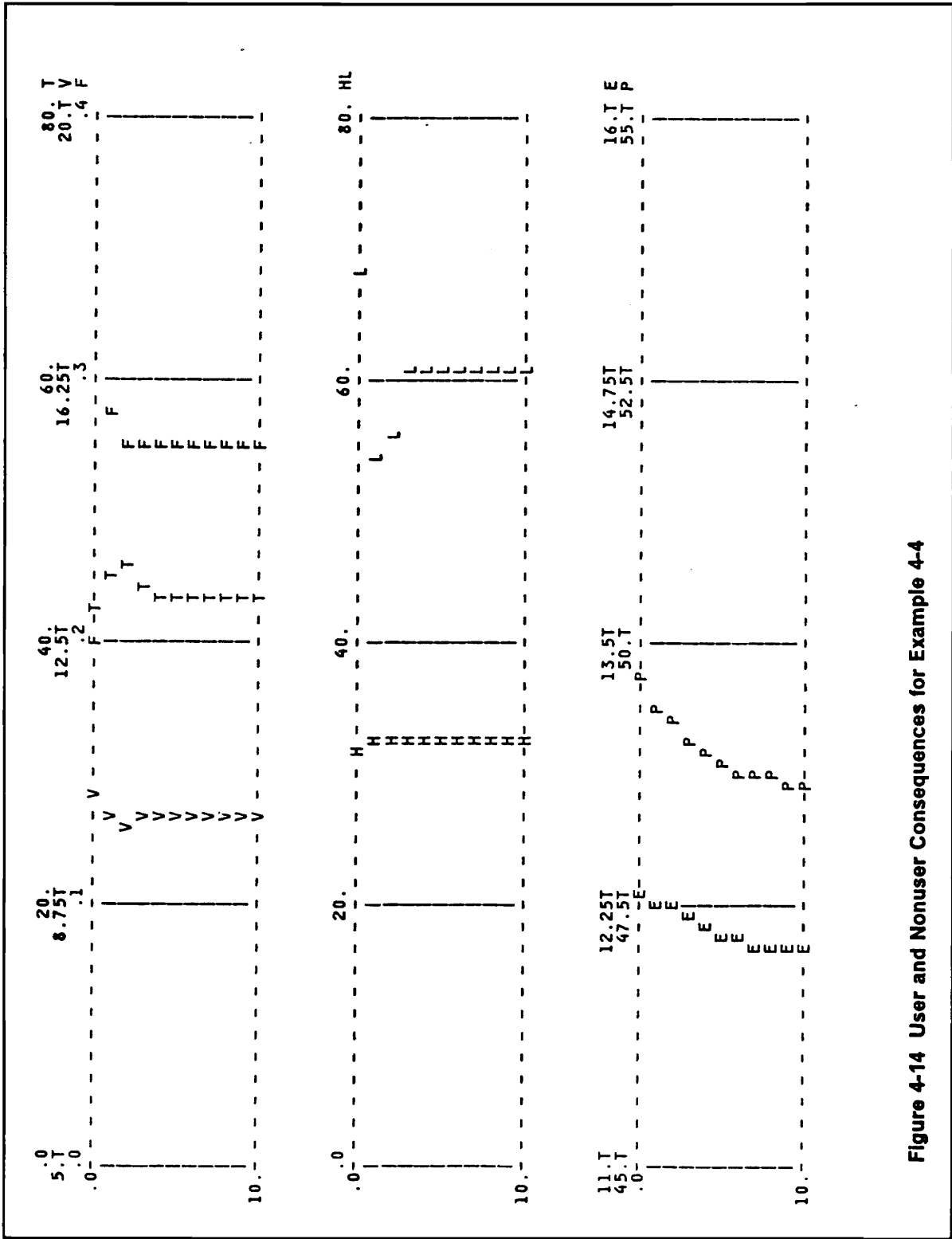
Figure 4-14 User and Nonuser Consequences for Example 4-4

Sensitivity Analysis. Further experiments on the model show that changes in occupancy rate of HOVs have minor influences on the system, in terms of LOV travel time and savings in average travel time. The possible benefits of an HOV lane is dominated by the demand elasticity for HOV. Empirically, one may turn to the initial fraction of trips by HOV's, FHOVN for rough information.

Conclusions.

1. Where LOVs are discriminated against to increase their travel cost, HOV policies require careful examination because they may decrease the overall mobility of trip-makers.

2. Where m lanes of n lane highways are to be used by HOV only, Pareto optimality for both HOVs and LOVs exists only if HOV lanes attract at least m/n portion of the demand for the highway.

3. demand elasticity for HOVs is the key element affecting the desirability of HOV lanes. Unfortunately, with the increase of income, demand for HOVs tends to be very inelastic.

4.2.3   Calculation of User Benefits

User benefits from reduced transportation costs include benefits to the existing users and benefits to the induced users. In Figure 4-15, where curves S_0 and S_1 respectively represent the transportation performance before and after the improvements; benefits to the existing users at any time t over one period would be the area $C_0 J K C_t$, or the existing trip demand V_0 times the reduction in travel cost $(C_0 - C_t)$; while the benefits to the induced users for the same period would be the area JKL, or $(C_0 - C_t)(V_t - V_0)/2$.

The accumulated user benefits up to time t can then be calculated from the following equation:

$$UserBenefits = \sum_t (C_0 - C_t)(V_0 + V_t)/2 \qquad [4.20]$$

where: C_0 = existing transportation cost

C_t = transportation cost at time t

V_0 = existing demand for transportation

V_t = demand for transportation at time t, which should

be determined with the methodology discussed in previous section.

4.3 Nonuser Benefits

It is very unclear and very difficult to know how far the ramifications of impacts from changing transportation performance will reach. It is clear, however, that there is a need to develop and perfect an impact assessment methodology that can provide an indication of all significant impacts and indicate remedial policies. Research on the problem may be carried out in two directions. One is to focus on partial solutions by tracing down the primary, secondary, tertiary, and the subsequent impacts; collecting data and establishing models to quantify each of those impacts. This approach provides us with detailed information about the potential impacts of changing transportation performance, but runs a high risk of incompleteness, complexity, and double counting. Another approach, the one used in this research, is to concentrate on the aggregate analysis of the system, abstracting concepts and developing indicators.
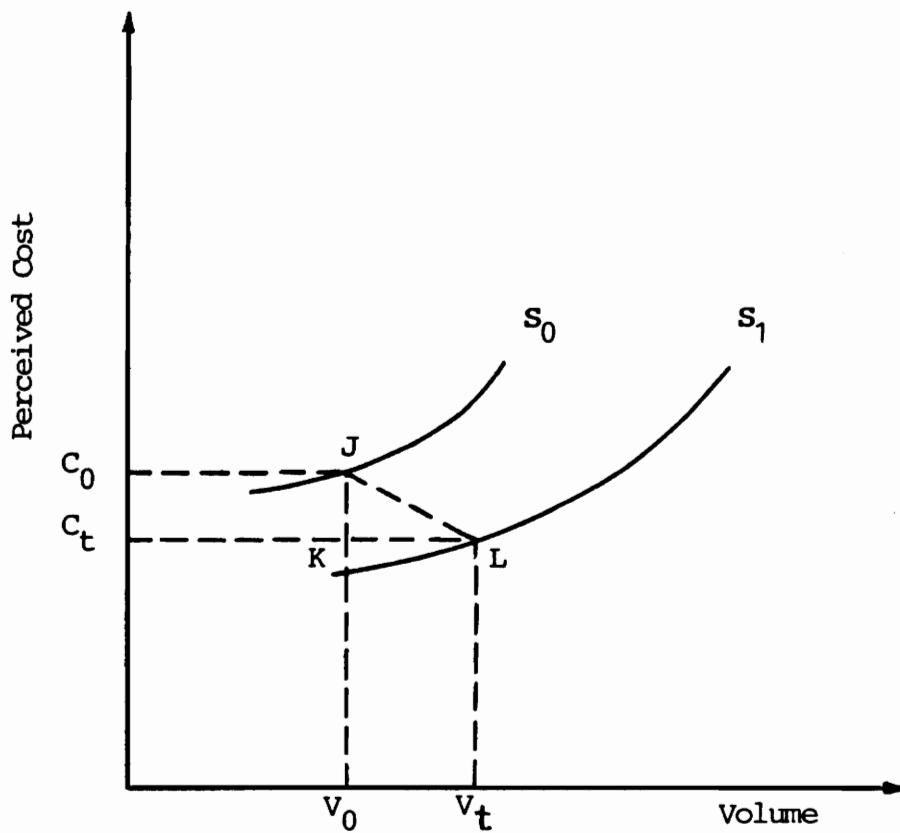
Figure 4-15   User Benefits

4.3.1   Economic Benefits

It is obvious that reductions in transportation costs create locational advantages for the region and may, as a result, induce capital influx, strengthen the economic base, increase commercial services, and promote the potential for an economic boom; which would benefit nonusers of the transportation system either in reduced costs or increased profits. Figure 4-16 suggests a way of aggregating the economically significant nonuser benefits generated by changes in transportation performance.

In Figure 4-16, F_0 and O_0 represent the fraction of economic output to transportation input and the amount of economic output before the transportation improvement, respectively; F_t and O_t indicate the fraction of economic output to transportation input and the corresponding economic output at time t; and the curve D represents the relationship between the scale of economic production and the fraction of economic output to transportation input, which is shaped by the inherent economic forces. The down-slope of the curve is the result of the law of diminishing returns on factor inputs.

The aggregate nonuser benefits over one period is the area F_0KLF_t and the accumulated nonuser benefits would be:

$$\sum_t (F_0 - F_t)(O_0 + O_t)/2 \qquad [4.21]$$
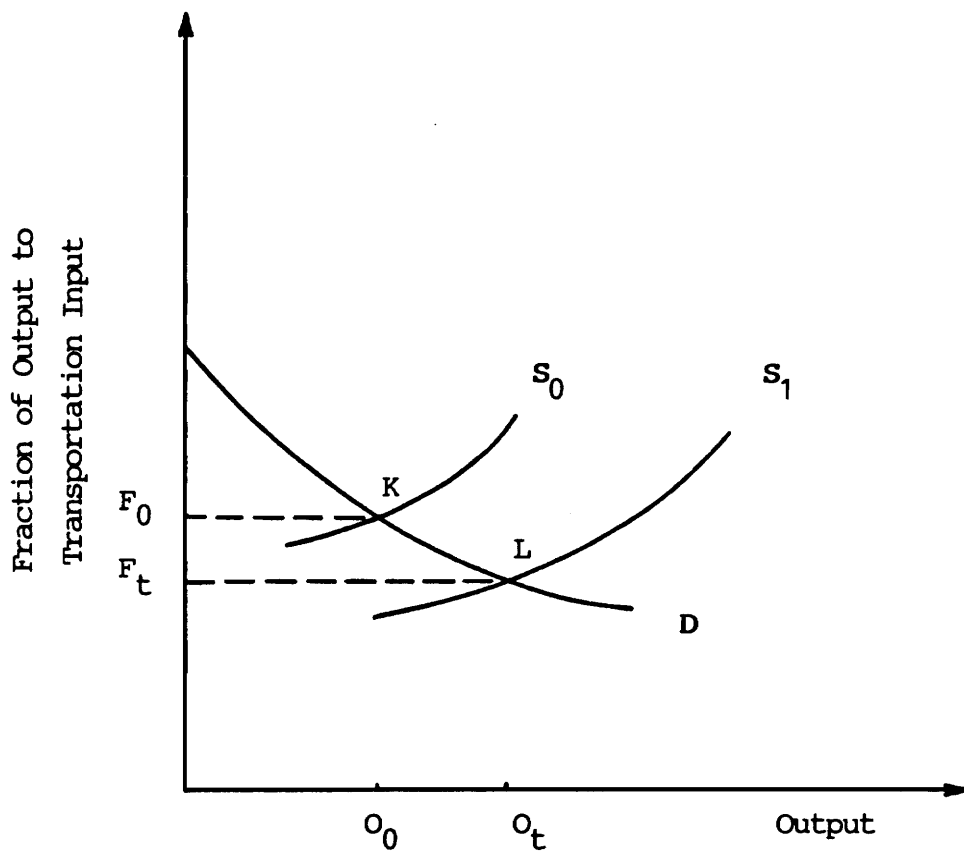
Figure 4-16   Nonuser Benefits

4.3.2   Other Nonuser Benefits

There are two approaches that may be followed in the analysis of nonuser benefits: categorized component analysis and simplified cause-effect analysis. Both are complementary. Regarding to the first, major categories of the nonuser banefit analysis include its impacts upon population distribution, community organizations and services, cultural and normative aspects, economy, recreation/amenities, land use patterns, and the environment. With respect to the second, one may follow the chains of effects such that changes in transportation performance induce shifts among modes and locational distribution, which affects economies of scale and the demand for consumptions. These in turn change transportation use and, in turn, cause further changes in transportation performance.

There appears to be no single way of measuring all the possible impacts of transportation improvements. Nevertheless, it is believed necessary to quantify the economic benefits of transportation decisions and to identify the possible consequences of the socio-economic system, such as the scale of population, employment, economic output, and transportation use, etc.

4.4   Summary

Chapter 4 systematically analyzes the problem of user and nonuser benefits due to transportation improvements. This include the examination of the current state-of-the-art, the identification and quantification of the network and locational impacts of transportation, and the determination of user and nonuser benefits. To illustrate the application of the systems approach to transportation problems, this chapter analyzes three highway investment scenarios:

freeway construction, highway improvement, and HOV lane provision. Finally, this chapter presents a framework for identifying and quantifying nonuser benefits.

5.0 Transportation Investment and Economic Development

5.1 Introduction

It has been recognized that a major impetus for growth comes from the ability of a region to produce goods and services demanded by the national economy and to market them at a competitive advantage with respect to other regions. This propensity to export obviously depends to some extent on the access that a region has to outside markets both for its inputs and its outputs, and is also related to the efficiency that a region shows in assembling its factors of production. It depends therefore on the internal economic structure of the region. In the long run, growth becomes more self-sustaining when a region can achieve sizeable regional markets for activities other than those oriented directly toward export [23].

Transportation, by enhancing mobility and accessibility of a nation or region's socioeconomic activities, has been regarded as a shaper of development. At national level, by connecting regions, transportation develops regional resources on the basis of interregional comparative

advantage. It helps to achieve efficient use of resources. For regional economists, the function of transportation extends beyond the mere interregional exchange of commodities and services. Good interregional connections facilitate the convergence of the factors of production, labor in particular, toward the centers of production. They contribute to the geographical concentration of activities originating in the advantages of large-scale production and help the cumulative process by which cities grow. Conversely, they may relieve cities by inviting congested industries to disperse. Finally, the development of an extensive internal transportation network permits regions to achieve sizeable internal markets by integrating subregions into larger geographical units [23].

Transportation has been a major driver of national economic development and productivity. Lack of investment leads inevitably to undesirable consequences in the economy. However, over-capitalization can be even more detrimental. It is generally agreed that transportation by itself is not sufficient to stimulate economic development. An optimal scale of transportation development would be the one that keeps just ahead of the progress of economic development.

Despite the fact that the transportation system is of vital importance to socioeconomic development, our understanding of the relationship between transportation and development is very limited. Progress on key issues such as the relationship between transportation investment and regional prosperity and the relationship between national economic growth and levels of transportation investment has been very slow, if not stagnant for decades. Arguments about the stimulative and responsive role of transportation have been mostly circumstantial or too qualitative to be subject to policy analysis.

Given the current state-of-the-art, providing an answer to question of an optimal transportation system seems to be too ambitious. However, if one could keep every additional investment justified economically and socially, the end result of all investments might not be far from optimal.

This chapter identifies the causal structure of the socio-economic-transportation system in a large area. Two scenarios analyzed are: (1) the role of transportation in the national economy and (2) the regional impacts of transportation investment. The causal structures are conceptualized in the forms of verbal description and causal diagram representation. Conclusions which signify general policy implications are drawn from the results of the computer simulation and policy analysis. The main purpose of the following sections is to develop a framework for analyzing transportation/economic development relationships.

5.2   Impacts of Transportation in a Closed Economy

In a closed economy, transportation improvements act on economic development in two ways:

1. Transportation improvements promote the productivity of labor by improving the welfare of commuters. They also promote the productivity of capital by encouraging the spatial concentration of factors of production, therefore allowing firms to reach optimal levels of production.

2. Transportation improvements reduce the cost of transportation for both firms and commuters. Savings in transportation cost will be gained as value-added, part of which may be reinvested to increase industrial output.

To identify the stimulative role of transportation in the economic development, this section traces the effects of cost savings in transportation. The conversion of these effects into the promotion of productivity is much more complicated. Empirical case-by-case studies have not yet led to conclusions precise enough to be quantified.

First, let us draw the boundary of analysis in such a way that population growth, technological development, and the productivity of labor and capital are exogenous to the system. Transportation investments are considered to alter the accumulation of capital and thereby affect economic development. The significance of this is expressed in a simple production function like equation 5.1

$$Q = AL^{\alpha}K^{\beta} \tag{5.1}$$

Where Q = output, a measure of economic development

A = efficiency parameters

L = labor input

K = capital input

α, β = distribution parameters

Figure 5-1 presents a causal diagram relating transportation investment to economic development. Transportation investment depletes resources that would otherwise be used in industrial production. On the other hand, transportation investment increases the mobility of freight and passengers, decreases overall transportation cost, decreases the fraction of industrial output to input, and thereby increases the gross national product, which may lead to an increase in capital investment and eventually to an increase in industrial capital. The net effects of transportation investment are determined by the relative strength of the positive and negative feedback loops involved.

Causal relationships. As shown in Figure 5-1, industrial capital will be increased with capital investment and decreased with capital depreciation. Capital investment comes from normal capital investment rate, as a share of the GNP, and the added capital investment from transportation funds. By allowing transportation funds to be used in industrial production, the model enables us to identify the comparative benefits of investing in transportation versus
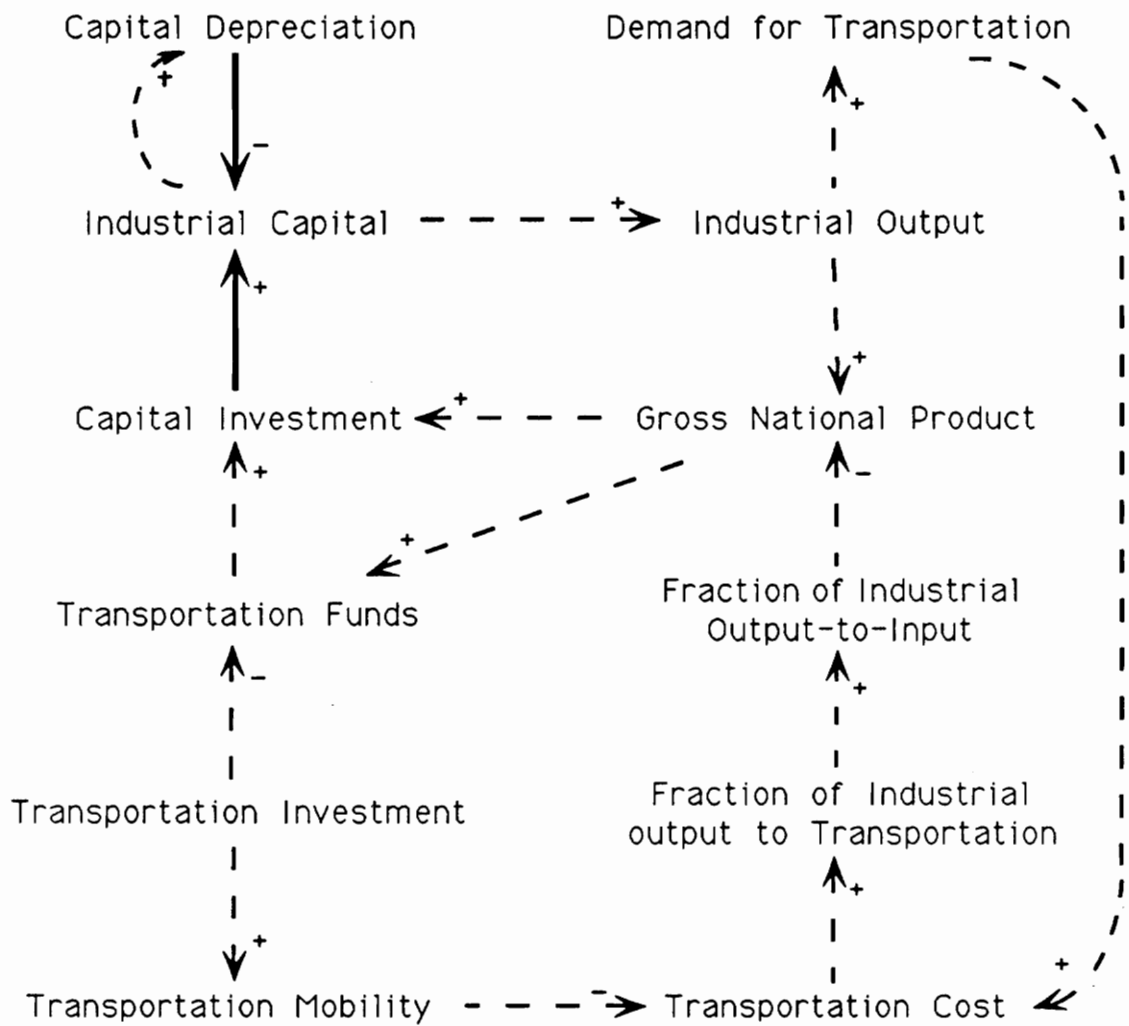
Figure 5-1 The Role of Transportation in a Closed Economy

industry to the national economy. For simplicity, the normal capital investment rate is assumed to be a fixed fraction of the GNP for each economy and the capital depreciation rate is determined by the aggregate average lifetime of capital.

Transportation funds will be increased by a fraction of the GNP and decreased with transportation investment. The former depends on the amount of industrial (in its broad meaning) outputs not used as sector-intermediate-inputs. The latter will increase transportation mobility and reduce transportation cost. Knowing the level of capital-output-ratio, one can calculate the amount of industrial output from the amount of industrial capital and then determine the demand for transportation. The higher the demand for transportation, the lower the transportation mobility will be.

Systems Equations.   The following equation system is used to simulate the dynamic behavior of the causal structure depicted in Figure 5-1.

$$IC.K \quad = IC.J + (DT)(CI.JK - CD.JK)$$

IC - industrial capital, .J stands for past and .K for present.

CI - capital investment

CD - capital depreciation

$$CD.KL \quad = IC.K / ALC$$

ALC - average lifetime of capital

$$CI.KL \quad = GNP.K{}^{*}FGNPI + TF.K$$

GNP - gross national product

FGNPI - fraction of GNP invested

TF - transportation funds

$$GNP.K \quad = IO.K{}^{*}(1 - FIOI.K)$$

IO - industrial outputs

FIOI - fraction of industrial output to input

$$IO.K \quad = IC.K / COR$$

COR - capital output ratio

FIOI.K = FIOO + FIOT.K

FIOT - fraction of industrial output to transportation

FIOO - fraction of industrial output to other inputs

FIOT.K = FIOTN*TCM.K

FIOTN - initial value of the FIOT

TCM - transportation cost multiplier

TCM.K = 1 / TMI.K

TMI - transportation mobility index

TMI.K = (1 + FFSR.K)*(1 + DCR.K) / (1 + DCRN)

FFSR - the ratio of free-flow-speed (expressed as percentage increase)

DCR - demand to capacity ratio

DCRN - initial value of the DCR

DCR.K = (DCRN*IO.K/ION) /(1 + CAR.K)

ION - initial value of the IO

CAR - Capacity ratio (expressed as the percentage increase)

ION = ICN / COR

COR - capital output ratio

TF.K = FGNPT*GNP.K - TI.K

FGNPT - fraction of GNP to transportation funds

TI - transportation investment

Equations for the transportation mobility index (defined as the ratio of of the initial travel time to the current travel time) and the demand capacity ratio are derived as follows:

TMI.K = TTN/TT.K

$$= FFTTN*(1+DCRN)/(FFTT.K*(1+DCR.K))$$

$$= (FFTTN/FFTT.K)(1+DCRN)/(1+DCR.K)$$

$$= (1+FFSR.K)(1+DCRN)/(1+DCR.K)$$

where TT = travel time; TTN = initial travel time

FFTT = free flow travel time; FFTTN = initial free flow travel time

DCR.K = D.K/CA.K

= (DN*IO.K/ION)/(CAN*(1+CAR))

= DCRN*(IO.K/ION)/(1+CAR)

Where D = demand for transportation; CA = capacity

DN = initial value of the D; and CAN = initial value of the CA

Parameter Consistency. The close-loop-modelling strategy with system dynamics enables us to test the value consistency among model parameters. Assuming the economy is initially at equilibrium, we can derive the consistency equation for the model by setting the sum of rate variables at zero. Or let

CIN = CDN

Substitute for CIN and CDN, we have

GNPN*FGNPI + TFN = ICN/ALC

ION*(1-FIOIN)*FGNPI + GNPN*FGNPT = ICN/ALC

(ICN/COR)(1-FIOO-FIOTN)(FGNPI+FGNPT) = ICN/ALC

And finally, (1-FIOO-FIOTN)(FGNPI+FGNPT) = COR/ALC

Example 5-1. The input-output table of an economy shows a total output of $50 billion and a total value-added of $25 billion. It also displays 10% of the output as input from the transportation sector. The propensity of investment is about 20% of the value-added, while the productivity of capital is about 1.68 for capital-output-ratio and 16 years for capital lifetime. Currently, the transportation system has a demand-capacity-ratio of 1.0 and budget of 1% of the GNP, which may or may not be used for transportation investment. Policies to be considered are:

1. Whether and how to invest in transportation systems and

2. What benefit may accrue to the economy by accepting loans from foreign countries requiring a starting payback time of 10 years with normal interest rate.

Appendix A.7 lists a computer simulation program for the example.

Policy Analysis.   Specifically, four policies regarding transportation investment are tested. They are:

1. Increasing the capacity of the transportation system by 30% in ten years

2. Increasing free-flow-speed on the system by 30% in ten years

3. Increasing both the free-flow-speed and capacity by 15% in ten years

4. Accepting loans and starting pay back ten years later in policy 3

Figure 5-2 to 5-5 show the dynamic development of the economy and transportation system, where M, O and R represent the transportation mobility, economic output and demand-capacity-ratio, respectively. Each alternative is assumed to incur the same cost: 5% of the initial GNP for doubling either the capacity of or free-flow-speed on the system.

As long as transportation investment does not go so far as to bring down productivity because of the shortage of resources, improving the transportation system with any of the aforementioned policies will no doubt stimulate economic growth. In 30 years, changes in the industrial output, demand-capacity-ratio and transportation mobility for the example are respectively a

3% increase,   21% decrease, and 11.6% increase for policy 1;

6.6% increase, 6.6% increase, and 25.9% increase for policy 2; and

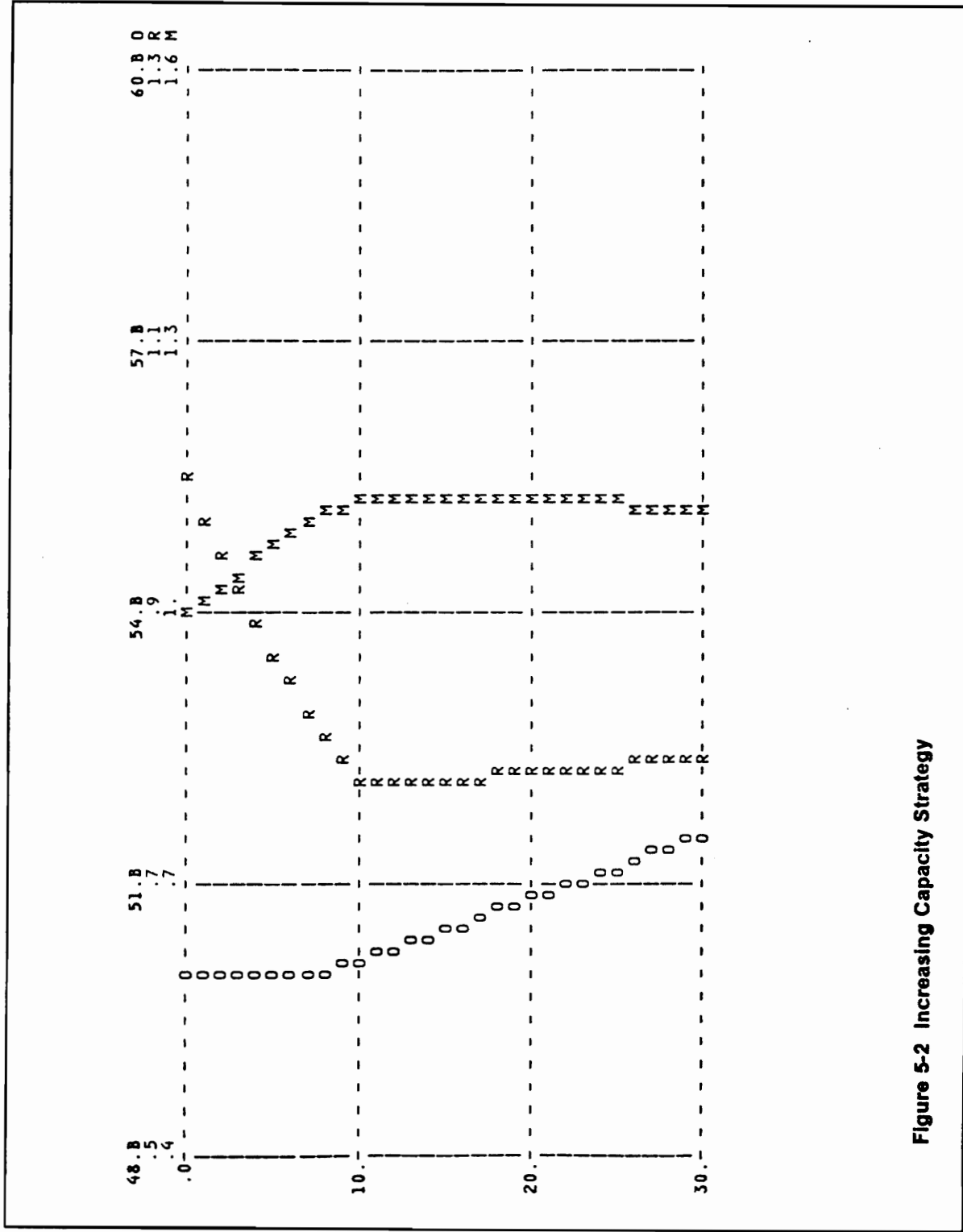5.2% increase, 8.5% increase, and 20% increase for policy 3 & 4

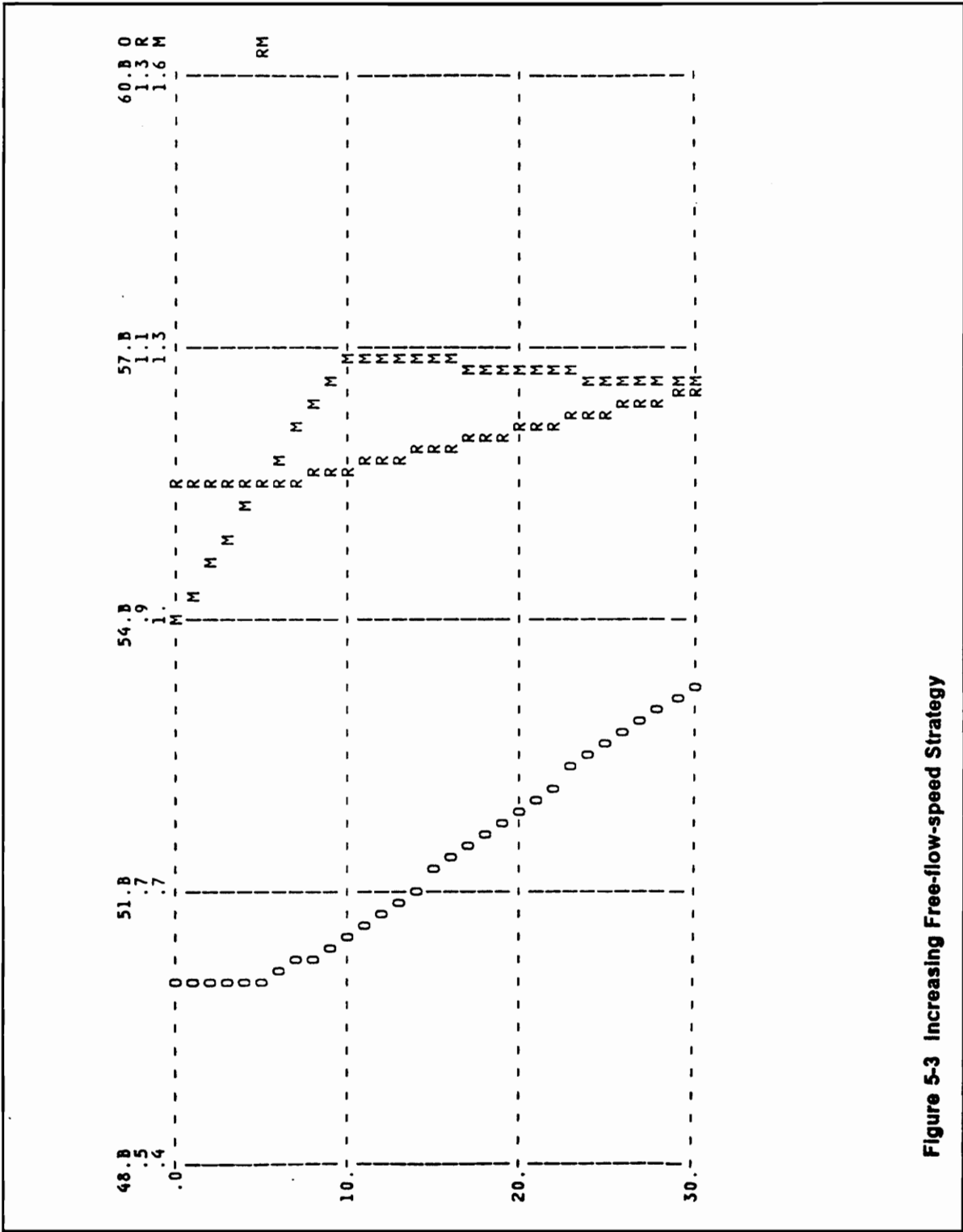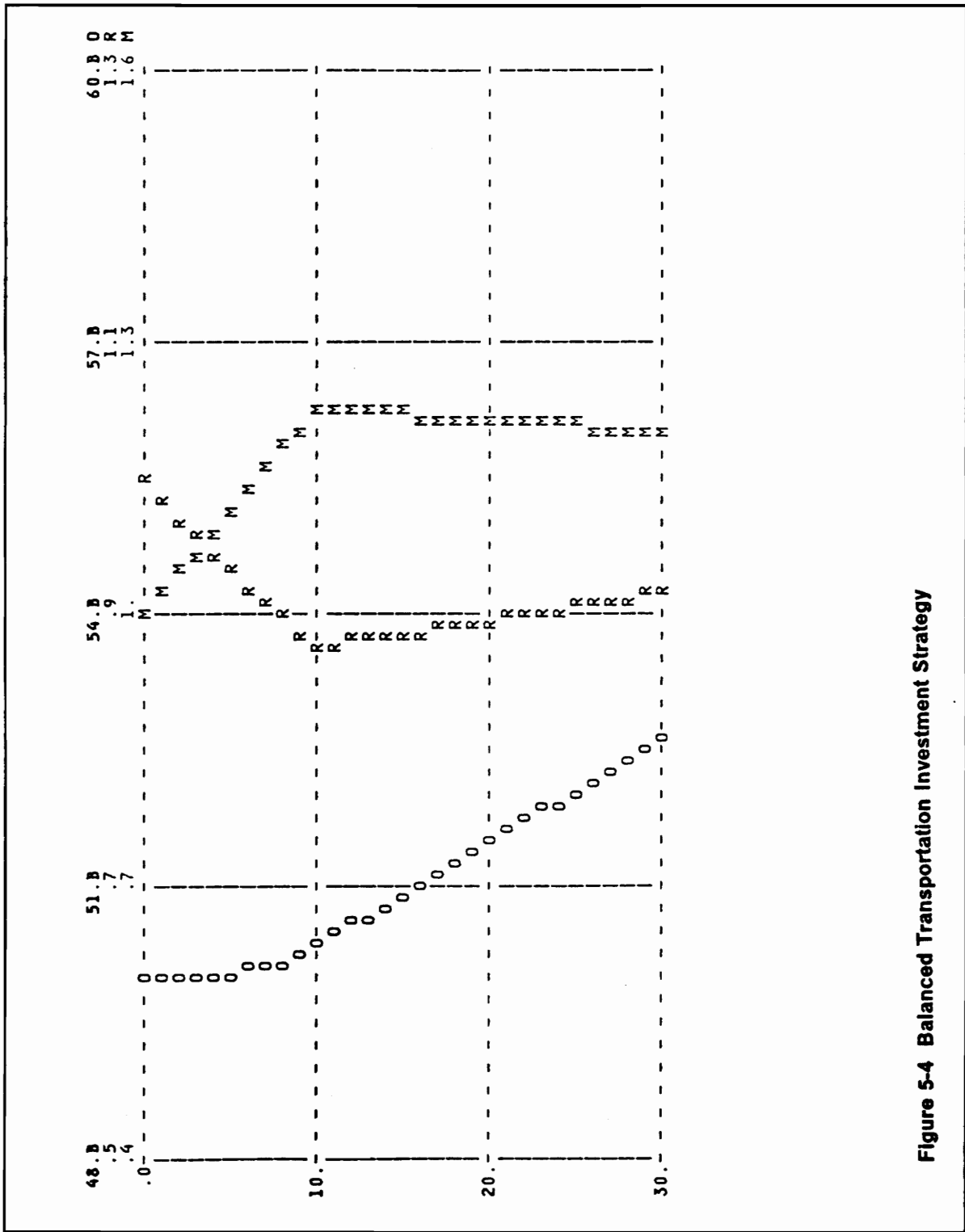Figure 5-2 Increasing Capacity Strategy
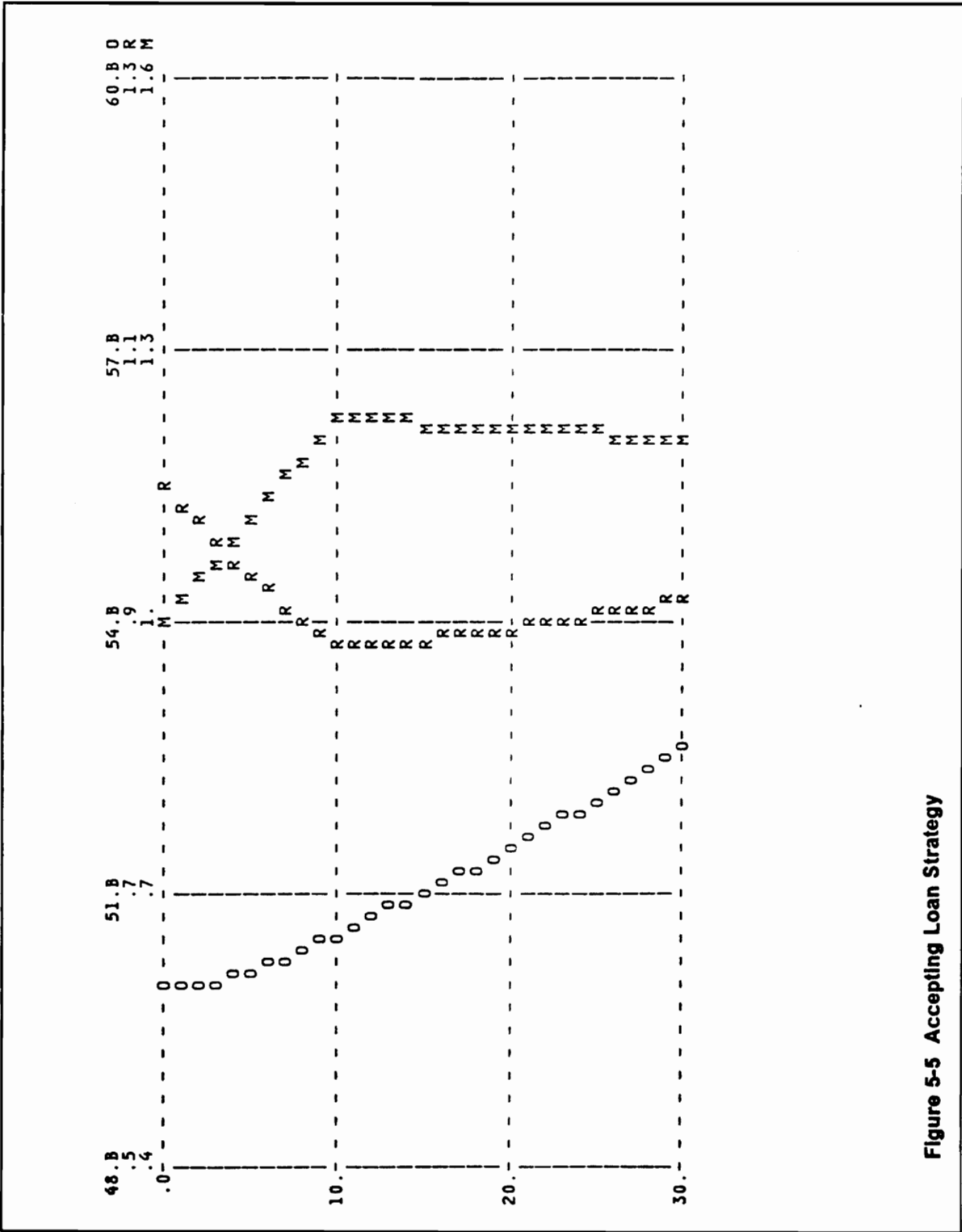
Figure 5-3 Increasing Free-flow-speed Strategy

Figure 5-4 Balanced Transportation Investment Strategy

Figure 5-5 Accepting Loan Strategy

Steady-state Analysis. The steady-state analysis of the model shows that in long run transportation improvement tends to stimulate economic growth. However, transportation investment will not solve congestion problems.

The following equations summarize the steady state of the system.

Policy 1: $DCR_e = DCRN$

$IO_e = ION^*(1+CAR)$

$TMI_e = 1$

Policy 2: $DCR_e = DCRN + FFSR^*(1+DCRN)$

$IO_e = ION^*(1 + FFSR^*(1+1/DCRN))$

$TMI_e = 1$

Policy 3&4: $DCR_e = DCRN + FFSR^*(1+DCRN)$

$IO_e = ION^*(1+CAR)^*(1 + FFSR^*(1+1/DCRN))$

$TMI_e = 1$

Where DCR = demand to capacity ratio, IO = industrial output, and TMI = transportation mobility index. Subscript e stands for the equilibrium values.

Sensitivity Analysis. According to the steady state analysis presented above, the cost of transportation improvements does not affect the equilibrium values of the system. They do have temporary effects on the economy, however. For example, by increasing the cost of implementing policy 3 from 5% to 20% of the initial GNP, we may observe a temporary reduction in economic output of less than 0.7% (see Figure 5-6). IF the cost were increased to 40% of the GNP, the reduction would be as high as 2.4% (see Figure 5-7).

Implications. The results of the analysis described above indicate that:
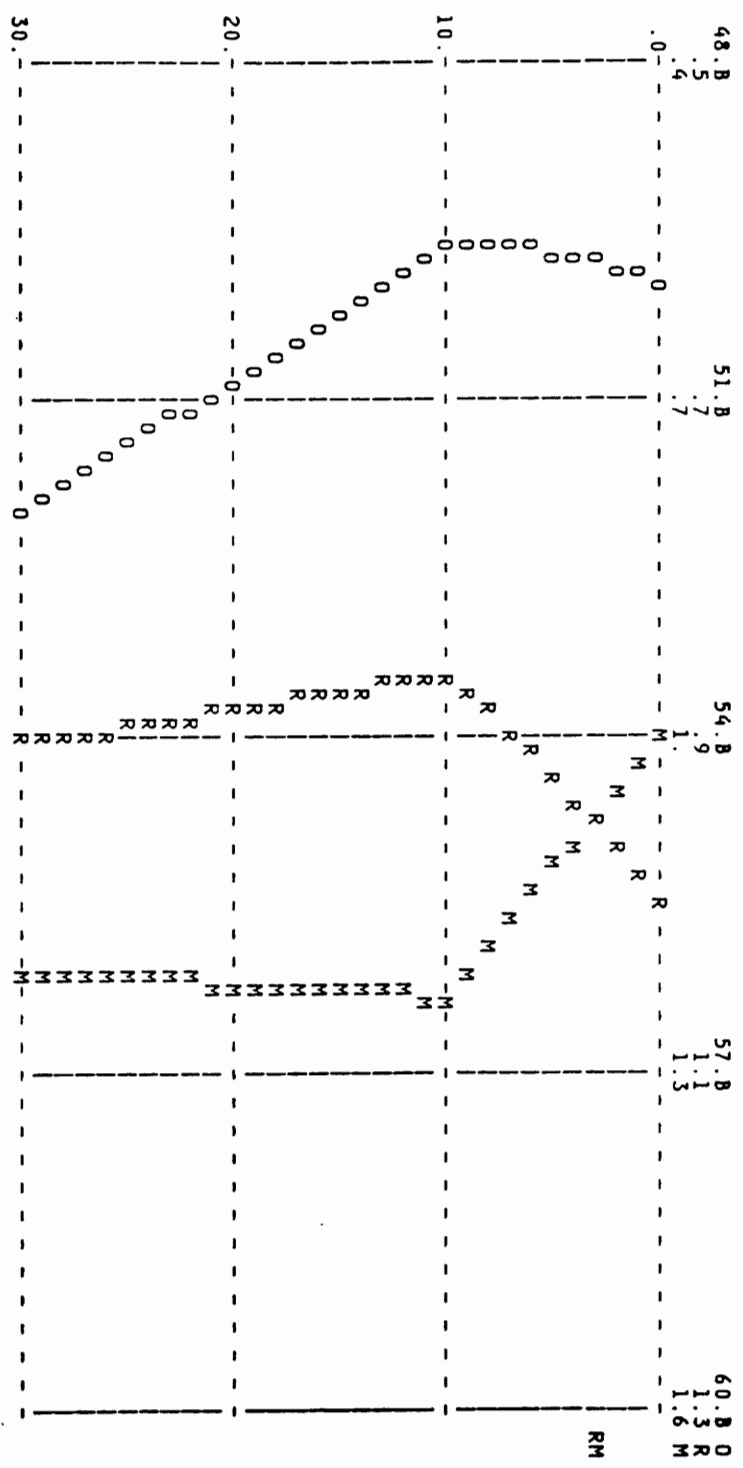
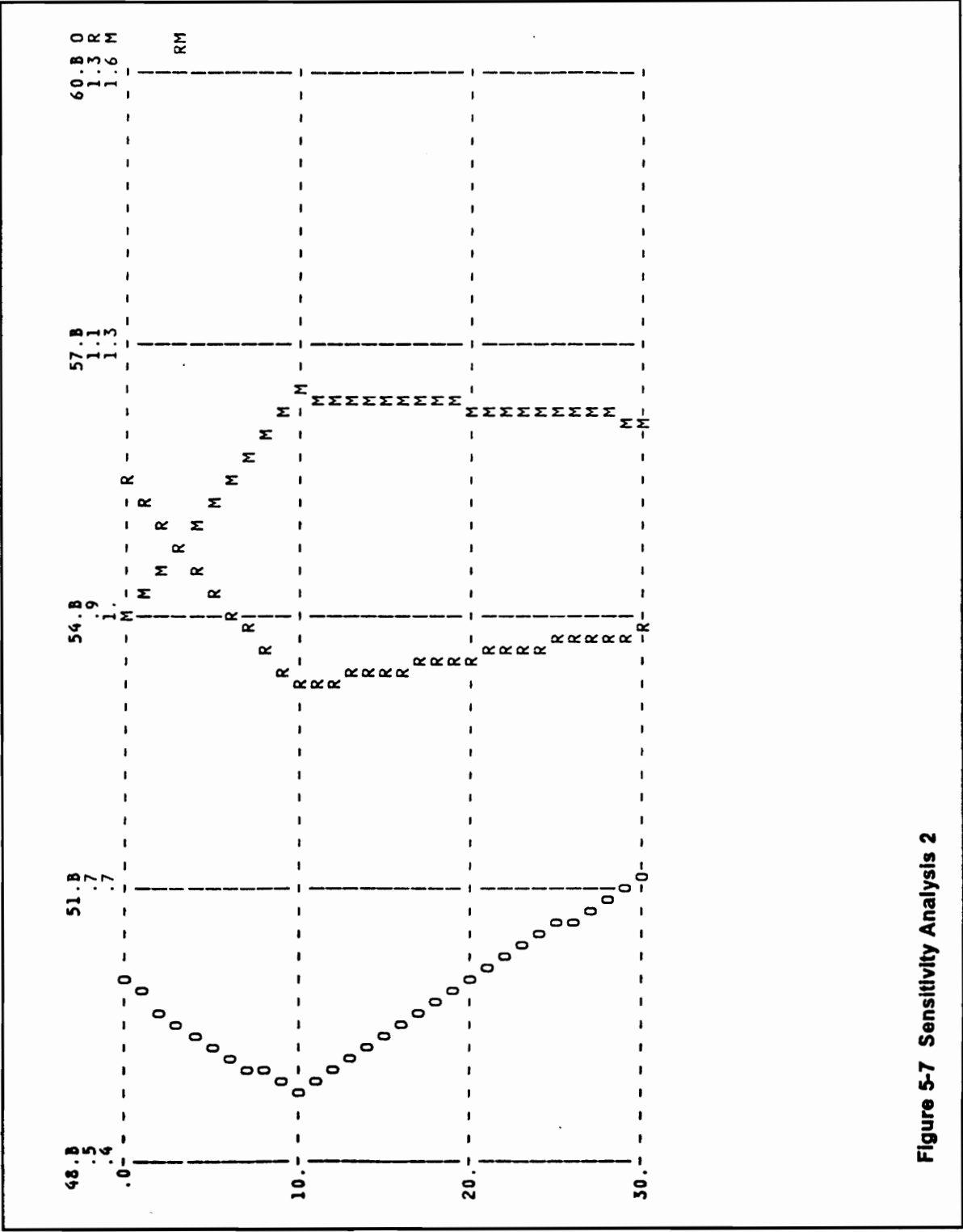Figure 5-6 Sensitivity Analysis 1

Figure 5-7 Sensitivity Analysis 2

1. The meaning of transportation bottleneck should not be limited to the mere comparison of transportation demand and capacity. After all, it is the transportation mobility that really matters. Aiming at reducing congestion (reducing demand-capacity ratio) can be misleading. Upgrading the existing system (or even creating new system, so as to increase free-flow speed) should be at least as important as extending the system.

2. In long run, transportation investment will by no means solve congestion problems. It will, however, improve mobility and increase economic development.

3. Given uncertainties in economic development, a balanced transportation investment strategy like policy 3 is more likely to alleviate congestion while enhancing economic development and transportation mobility steadily in even the short-run.

4. Whereas there may not exist an optimal scale of transportation system, there is an optimal transportation investment strategy for each economy at each development stage.

5. The power of loan to transportation investment should not be overstressed. It would be unfortunate if the money saved is not used to promote productivity.

5.3   Regional Impacts of Transportation

A regional economy is much more open than a national economy. It is less self-sufficient and demands more transactions with the economy of other regions. Two characteristics of a region are of vital importance to the modelling and simulation of the impacts of transportation investments:

1. the mobility of people

2. the mobility of capital among regions.

Figure 5-8 displays a causal diagram relating the transportation sector to the industrial sector and the population sector. Transportation investments are represented in the diagram by changing either or both policy variables, free-flow-speed and capacity of the transportation system. Together with demand for transportation, which is positively influenced by population and industrial activities; they affect transportation cost and thereby the fraction of industrial output to transportation. The latter has negative impacts on the attractiveness of the region to capital. The laborforce-job-ratio links the population sector to the industrial sector by influencing the attractiveness of the region to population and capital. It functions to balance population immigration and capital investment. Other feedback loops within the population sector and the industrial sector are the natural population growth (birth rate minus death rate), net immigration, and capital depreciation.

Systems Equations   For purposes of simulation, the following equations are used to define the causal relationships depicted in Figure 5-8.

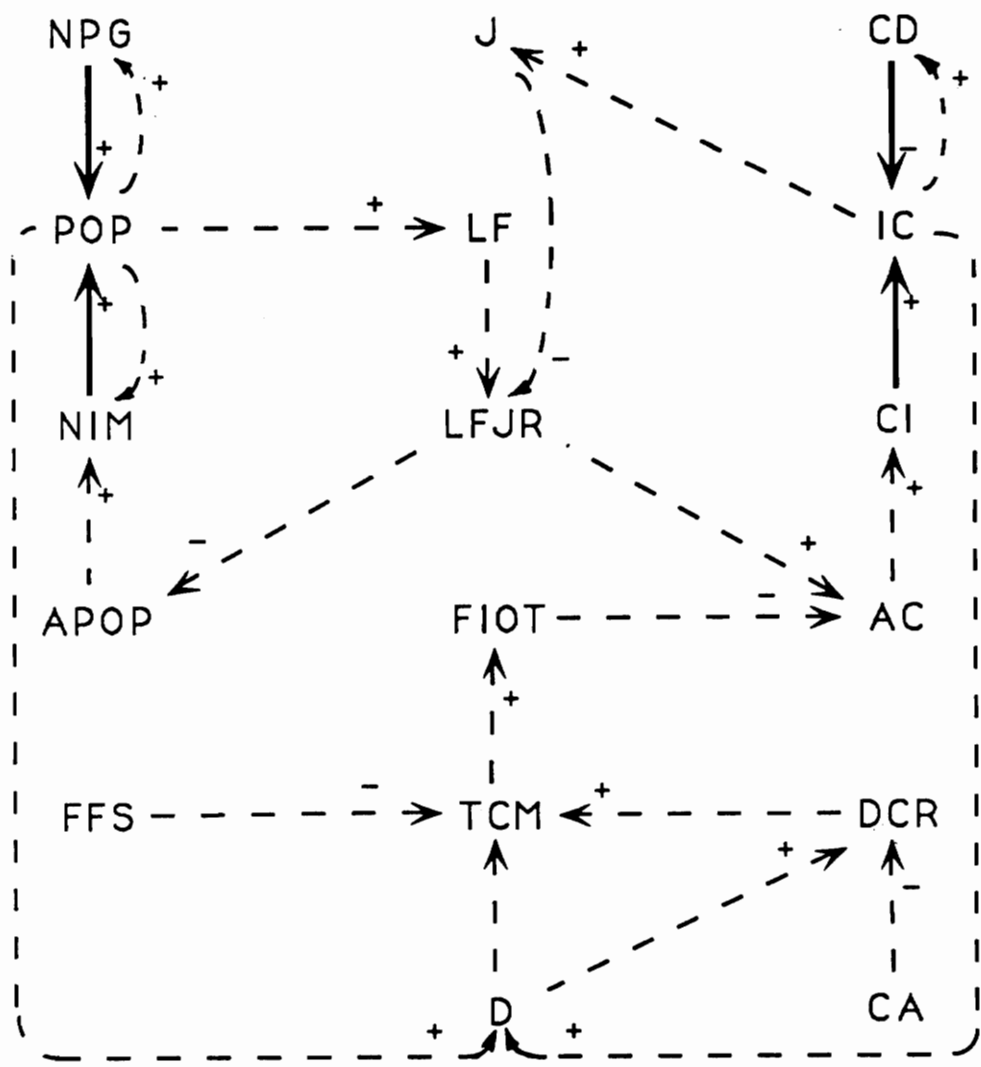|	
POP.K	= POP.J + (DT)(NPG.JK ╪NIM.JK)
NPG.KL	= POP.K * NGF
NIM.KL	= POP.K*NIMN*APOP.K
APOP.K	= TABLE (APOPT, LFJR.K, 0, 2, 0.2)
APOPT	= 5/4.8/4.2/3.4/2.4/1/-1.8/-2.0/-2.2/-2.4/-2.6
LFJR.K	= LF.K / J.K
LF.K	= POP.K * LPF
J.K	= IC.K / CLR
IC.K	= IC.J + (DT)(CI.JK - CD.JK)
CD.KL	= IC.K / ALC
CI.KL	= CIN * AC.K
AC.K	= AC1.K * AC2.K

Figure 5-8 Regional Impacts of Transportation

AC1.K   = TABLE (AC1T, LFJR.K, 0, 2, 0.2)

AC1T   = .2/.25/.35/.5/.7/1/1.35/1.6/1.8/1.95/2

AC2.K   = TABLE (AC2T, FIOT.K, 0, 0.2, 0.02)

AC2T   = 1.5/1.4/1.3/1.2/1.1/1/.9/.8/.7/.6/.5

FIOT.K   = FIOTN * TCM.K

TCM.K   = (1 + DCRN)/(FFS*(1 + DCR.K))

DCR.K   = DCRN * (IC.K/ICN + POP.K/POPN -1) / CAM

POP   - population

NPG   - natural population growth

NIM   - net in-migration.

NGF   - natural population growth factor

NIMN   - net population immigration normal

APOP   - attractiveness of the region to population

APOPT   - table function for APOP

AC1T,AC2T - table function for AC1, AC2

LFJR   - laborforce job ratio

J, LF   - number of jobs, laborforce

IC,CD,CI - industrial capital, capital depreciation, capital investment

LPF   - labor participation factor

CLR,ALC   - capital labor ratio, average lifetime of capital

AC   - attractiveness of the region to capital

FIOT   - fraction of industrial output to transportation

TCM   - transportation cost multiplier

CIN,FIOTN - initial value for CI, FIOT, DCR, DN

DCRN   - initial value for DCR

FFS,CAM   - free flow speed, capacity multiplier

DCR   - demand-capacity-ratio

Example 5-2   The regional impacts of transportation are to be tested on a region with the following statistics: a population of 7 million, 0.5% natural population growth, 2% net population immigration, 40% labor participation, 20000 ($/job) for the capital labor ratio, 16 (years) average lifetime of capital, 2 (years) capital-output ratio, 1.0 initial demand-capacity-ratio, 0.1 initial fraction of output to transportation, 51.41 (billion dollars) total capital, and a capital investment rate of 2779 (million dollars /yr). All sectors of the region are initially at equilibrium (see Figure 5-9).

Two transportation investment strategies are of special interest: (1) increasing the capacity of the system and (2) upgrading the system. Appendix A.8 provides a simulation program for the problem.

Figure 5-10 displays the result of a 30% increase in the region's transportation capacity and Figure 5-11 the result of a 30% increase in the free-flow-speed, where O, U, D and P represent the economic output, unemployment rate, demand-capacity-ratio, and population of the region, respectively. Numerically, a 30% increase in the transportation capacity reduces the demand-capacity ratio by 17%, increases the regional population by 4% and increases the industrial output by 4%; while a 30% increase in the free-flow-speed will increase the demand-capacity ratio by 16%, increase the population by 8% and increase the output by 8.2%.

Implications   Comparing Figure 5-10 & 5-11 with Figure 5-9, one may conclude that:

1. There is a positive relationship between transportation investments and regional prosperity.

2. In long run, transportation investments have minor effects on the unemployment rate of the region.
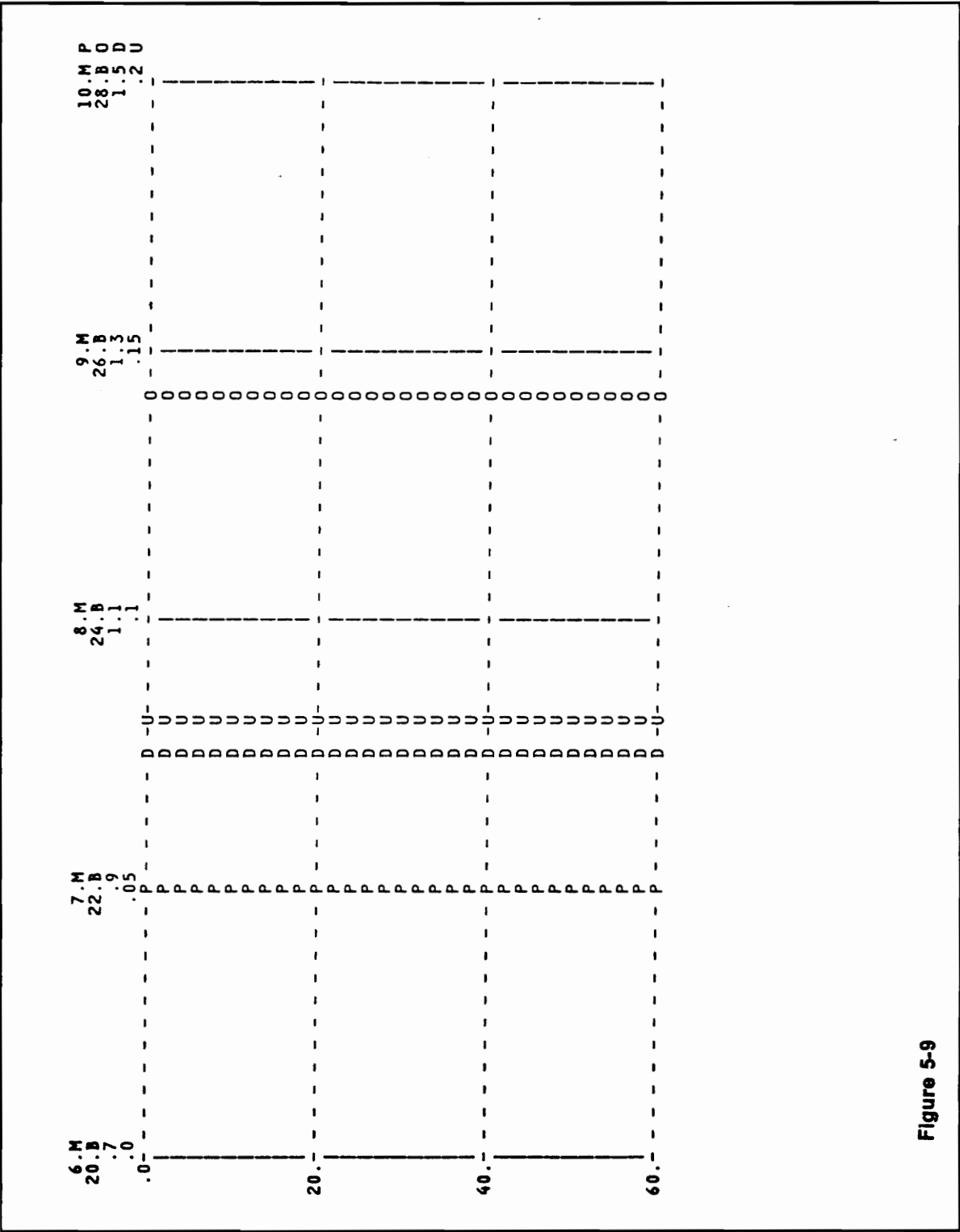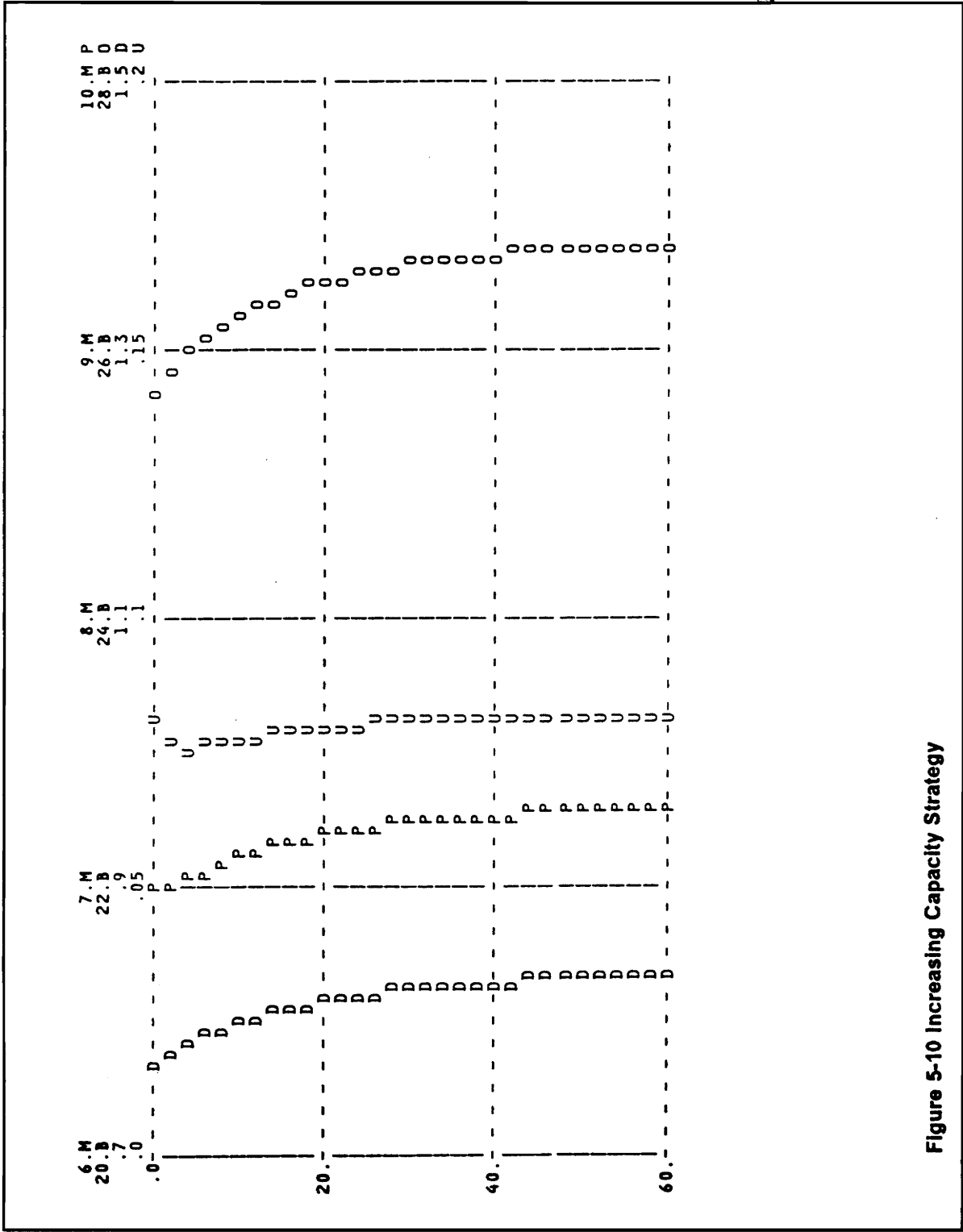
Figure 5-9

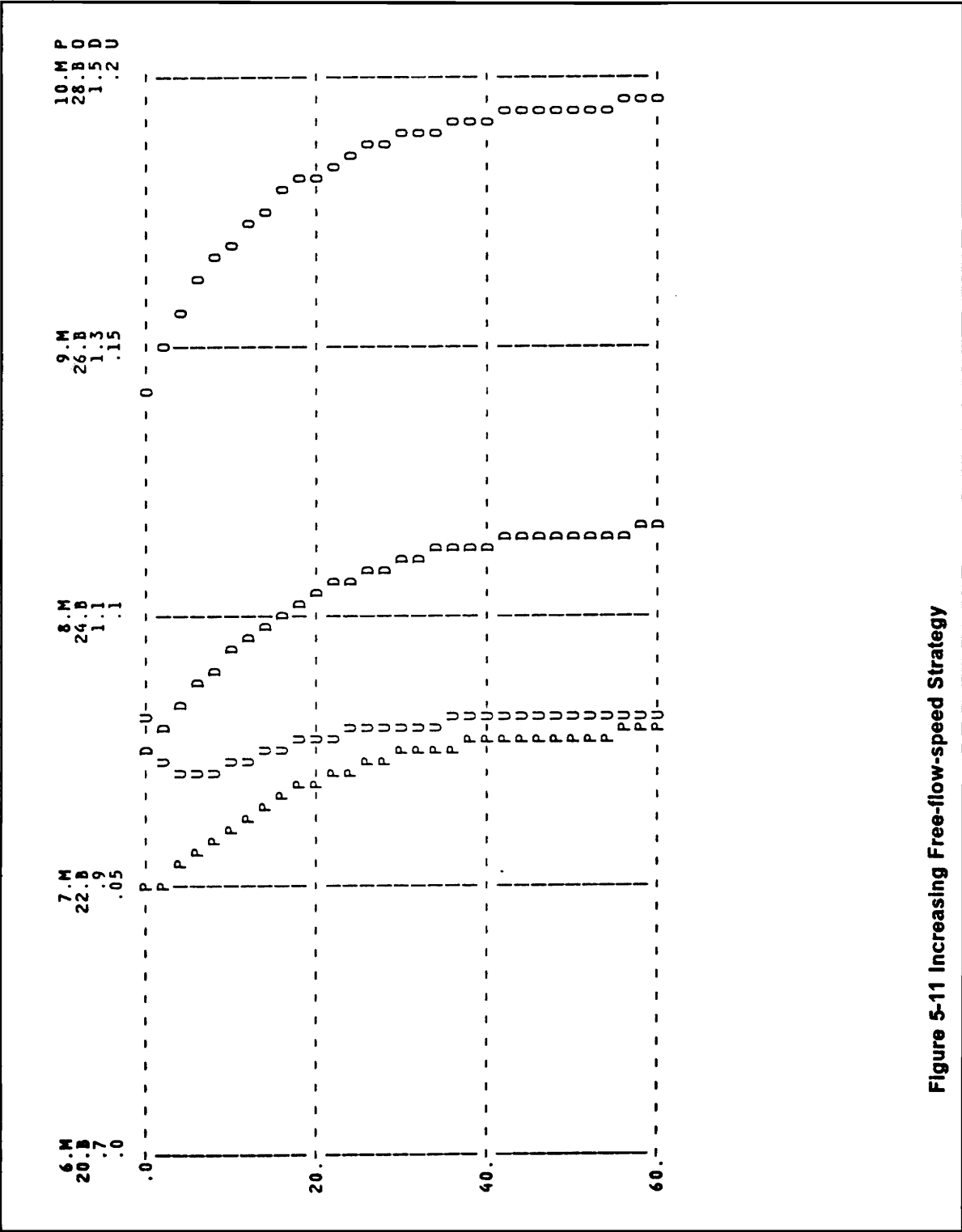Figure 5-10 Increasing Capacity Strategy

Figure 5-11 Increasing Free-flow-speed Strategy

It has to be recognized that these conclusions are circumstantial. For accurate projections, further investigation is needed, especially on the relative attractiveness of a region to population and economic activities.

Although this section focuses on regional analysis, the proposed methodology and modelling techniques may well be used for interregional analyses.

5.3   Summary

The stimulative role of transportation is no doubt positive both in the national and regional economies. At the national level, investments in transportation will not only channel the development of a nation but also stimulate the economic growth. At the regional level, transportation helps a region to achieve economic prosperity. In addition to enabling us to quantify the economic impact of transportation investments, this chapter concludes that: (1) congestion can only be alleviated, not solved, with transportation investments, (2) there is no once-for-all optimal scale for transportation systems, and (3) there is an optimal transportation investment strategy for each economy at each stage of development.

6.0　Conclusions and Recommendations

This Chapter presents a summary of this research, discusses the strengths and weaknesses of the methodology proposed, and identifies opportunities for future research.

6.1　Summary of Research

This research addresses two important issues facing transportation economists and planners: the relationship between transportation investment and economic development and the methodology for evaluating transportation projects and programs. Transportation is viewed as an important factor which enters the production functions of firms and the consumption functions of individuals. The demand for and the supply of transportation cannot be determined within the transportation system. Changes in the transportation system may have far-reaching and, most importantly, feedback impacts that not only generate secondary impacts, tertiary impacts, and so on; but also influence further decisions and, therefore, generate more changes further along in the system. The systems approach is crucial to the identification and

quantification of the impacts of transportation improvements and to the better understanding of the transportation/economic development relationships. System dynamics is used in this research as a tool for modeling and simulating transportation/economic interactions.

This research conceptualizes the role of transportation in a broad socioeconomic context and develops a framework for applying the systems approach to the evaluation of transportation investments. Five scenarios examined with the methodology are: highway improvement, corridor development, HOV lane provision, impacts of transportation in a closed economy, and regional impacts of transportation. Computer simulation programs were developed to evaluate the dynamic behavior of the system in response to changes in the transportation subsystem.

Problems with the current methodologies for user and nonuser benefit analysis were identified. New approaches to the determination of user and nonuser benefits from transportation improvements were developed.

6.2   Critical Analysis

This research has demonstrated a systems approach to the identification and quantification of user and nonuser benefits from transportation improvements. It features a methodology for systematically analyzing these benefits in a broad, dynamic, and causally related socioeconomic context. It concentrates exploring and modeling the causal structure of the socio-economic-transportation system and, therefore, facilitates the consideration not only of the ramification of impacts from transportation improvements but also of the feedback, that is, the self-reinforcing or self-neutralization of these impacts. The methodology was developed

in such a way that it takes into consideration, without double counting, the possible effects of changing transportation performance; that it makes possible the use of existing data bases and information systems; and that it is spatial-policy sensitive and compatible with current methodologies for transportation planning and economic forecasting, specifically the methodologies of Urban Transportation Planning Process and Input-Output Analysis.

The method suggested by this research for determining user benefits from transportation improvements has advantages over consumers' surplus theory in that it is causal, dynamic, and easy to use. The scenario analyses illustrate the modeling and simulation strategies with the simulation language DYNAMO while presenting insights into three typical highway transportation problems: highway improvements, corridor development, and HOV lane provision. The suggested methodology for nonuser benefit analysis makes possible the quantification of nonuser benefits.

The system dynamics methodology was applied to the analysis of the relationship between transportation investment and economic development. The scenario analysis has led to important transportation-related policy implications, for example, that a balanced transportation investment strategy, in terms of balancing travel speed and the capacity of transportation facilities, is most likely to alleviate congestion while enhancing economic development and transportation mobility.

Despite the strength of the systems approach in the solution to problems associated with general transportation investment strategies, this research on the transportation/economic development relationships represents only a first step towards an effective, efficient, and user-friendly transportation/development model system: a laboratory for transportation policy experiments. Further elaboration is necessary for this research to have practical significance to the question of an optimal transportation system. Opportunities for future research are discussed in the next section.

6.3   Recommendations for Future Research

There are a number of dimensions along which this research can be expanded, especially in the area of modeling transportation/development relationships. First of all, this research could be expanded to address additional transportation issues such as energy conservation and environmental protection. This could be accomplished by expanding the boundary of this research to include the additional sectors of interest, by incorporating additional system state variables, transportation policy variables, and causal interrelationships that exist among these and other variables. Second, the level of system disaggregation could be expanded to facilitate the examination of transportation problems at different geographic scale: national, regional, and local. Input-output analysis is a promising method that could be incorporated. Third, the strength of causal relationships between variables needs to be statistically verified for the area of study. Cross-classification and time-series analysis (including econometrics) are the basic techniques to be employed. And fourth, this research could be expanded to develop an integrated transportation/economic development model system that fully takes into consideration the possible effects of transportation changes.

References

1. Adler, H. A., *Economic Appraisal of Transport Projects*, The Johns Hopkins University Press, Baltimore and London, 1987.

2. Alfeld, L. E. and Graham, A. K., *Introduction to Urban Dynamics*, Wright-Allen Press, Inc., Cambridge, Massachusetts, 1976.

3. American Association of State Highway and Transportation Officials, *A Manual on User Benefit Analysis and Bus-Transit Improvement*, Washington D.C., 1977.

4. Ancot, J. P., *Analysing the Structure of Econometric Models*, Martinus Nijhoff Publishers, 1984.

5. Apogee Research, Inc., "Current Literature on Highway Investment and Economic Development", Prepared for FHWA, July 1989.

6. Blunden, W. R., *The Land-use Transport System*, Pergamon Press, 1971.

7. Burkhardte. Jon, E., " Socioeconomic Reactions to Highway Development" , Transportation Research Record 991.

8. Button, K. J. and Gillingwater, D, *Transport, Location, and Spatial Policy*, Gower Publishing Company Ltd., England, 1983.

9. Ciaschini, Maurizio, *Input-output analysis: current developments*, Chapman and Hall, New York, 1988.

10. Dickey, J. W., *Metropolitan Transportation Planning*, Hemisphare Publishing Company, 1983.

11. Drew, D. R. and Hsieh, C. H., *A Systems View of Development*, Cheng Yang Publishing Company, Taipei, 1984.

12. Drew, D. R., *Transportation Systems Planning*, CE 5644 Study Notes, Virginia Tech.

13. Drew, D. R., *System Dynamics: Modeling and Applications*, ENGR 5104 Study Notes, Virginia Tech.

14. Drew, D. R.; "Methodologies for Evaluating the Effects of Transportation Policies on the Economy", NCHRP Project 2-17(1), Virginia Polytechnic Institute and State University, 1989.

15. Drew, D. R. and Huang, "Transportation and Development Methodology", Proceedings of the Twentieth Annual Conference on Modeling and Simulation, Institute Society of America, Pittsburg, 1989.

16. Drew, D. R., "Methodology for Evaluating the Effects of Transportation Policies on the Economy", A Proposal submitted to NCHRP, Sept. 1989.

17. Drew, D. R., "Conference Summary Paper", TRB Conference on Transportation and Economic Devlopment, Williamsburg, Virginia, Nov 5-9, 1989.

18. Grossman, P. J., *Economic Base Analysis: Theory and Applications*, Tayloe Murphy Institute, Charlottesville, Virginia, 1984.

19. Harris, C. C. Jr., *Regional Economic Effects of Alternative Highway Systems*, Ballinger Publishing Company, Cambridge, Mass., 1974.

20. Harris, C. C. Jr., *The Urban Economies, 1985: A Multiregional Multi-industry Forecasting Model*, D.C. Heath and Company, Lexington, Mass., 1973.

21. Intriligator, M. D., *Econometric Models, Techniques, and Applications*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1978.

22. Huang, Guoxiong, "Traffic Assignment: Theory, Practice, and New Approach", Master's Thesis, Xian Highway Institute, Xian, 1988.

23. Kraft, G., *The Role of Transportation in Regional Economic Development*, D.C. Heath and Company, Lexington, Mass., 1971.

24. Liew, Chong K. and Liew, Chung J., "Measuring the Development Impact of a Proposed Transportation System", Regional Science and Urban Economics, 14 (1984), 175-198

25. Liew, Chong K. and Liew, Chung J., "Multi-modal, Multi-output, Multiregional Variable Input-output Model", Regional Science and Urban Economics, 14 (1984), 265-281

26. Liew, C. K. and Shim, J., "A Spatial Equilibrium Model: Another View", Journal of Urban Economics, 1982.

27. Lewis, J. A., *Economic Impact Analysis: A U.K. Literature Survey and Bibliography*, Pergamon Press, Oxford, 1988.

28. Miles, R. F.,Jr, *Systems Concepts: Lectures on Contemporary Approaches to Systems*, John Wiley & Sons, Inc, New York, 1973.

29. Mosbaek, E. J. and Cohen, H. S., "Methodology for Estimating the Impacts of Changes in Highway Performance", Jack Faucett Asso., Prepared for U.S. DOT, August, 1977.

30. O'connor, R. and Henry, E. W., *Input output Analysis and its Applications*, Charles Griffin and Company Ltd., London, 1975.

31. Palmquist, Raymond B., "Impact of Hihgway Improvements on Property Values in Washington State ", Transportation Research Record 887, 1982.

32. Pleeter, Saul, *Economic Impact Analysis: Methodology and Applications*, Martinus Nijhoff Publishing, Boston, 1980.

33. Polenske, Karen R., *The U.S. Multiregional Input-output Accounts and Model* , Lexington Books, Lexington, MA, 1980.

34. Prospt, Dennis B., "Assessing the Economic Impacts of Recreation and Tourism", Southeastern Forest Experiment Station, Asheville, NC, 1985.

35. Randers, Jorgen, *Elements of the System Dynamics Method*, The MIT Press, Cambridge, Massachusetts, 1980.

36. Richardson, G. P. and Pugh, A. L, *Introduction to system Dynamics Modeling with DYNAMO*, The MIT Press, Cambridge, Massachusetts, 1981.

37. Sage, A. P., *Methodology for Large-Scale Systems*, McGraw-Hill, Inc., 1977.

38. Roberts, Nancy, *Introduction to Computer Simulation: A System Dynamics Modeling Approach*, Addison-Wesley Publishing Company, Massachusetts, 1983.

39. Sheffi, Yosef, *Urban Transportation Network*, 1985.

40. Sohn, Ira, *Readings in Input-output Analysis: Theory and Application*, Oxford University Press, Oxford, 1986.

41. TBR, "Problem Statement", National Cooperative Highway Research Program, FY 1990.

42. Vlachos, E. C., "Secondary Impacts and Consequences of Highway Projects", Department of Sociology,Colorado State University, Report No. DOT-TST-77-24, October, 1976.

43. Wardrop, J. G., "Some Theorectical Aspects of Road Traffic Research" , Proceedings of Institute of Civil Engineering, Part II, P325, 1952.

44. Webber, M. J., *Explanation, Prediction and Planning: the Lowry Model* , Pion Limited, London, 1984.

45. Wilson, Tay and Neff, Charlotte, *The Social Dimention in Transportation Assessment*, Gower Publishing Company, Ltd., England, 1983.

Appendix A. Program Listing

A.1   Dynamic Input-Output Analysis

```
*         THREE SECTORS DYNAMIC INPUT-OUTPUT ANALYSIS
NOTE
NOTE ****************** CAPITAL FORMATION **********************
NOTE
NOTE AC-AGRICULTURE CAPITAL ($)
NOTE ACN-AGRICULTURE CAPITAL INITIAL ($)
NOTE ACI-AGRICULTURE CAPITAL INVESTMENT ($/YR)
NOTE ACD-AGRICULTURE CAPITAL DEPRECIATION ($/YR)
NOTE AP-AGRICULTURE PRODUCT ($/YR)
NOTE FAPC-FRACTION OF AGRICULTURE PRODUCT TO CAPITAL
NOTE ALAC-AVERAGE LIFETIME OF AGRICULTURE CAPITAL (YR)
NOTE
L AC.K = AC.J + (DT)(ACI.JK-ACD.JK)
N AC = ACN
C ACN = 3.5E9
R ACI.KL = AP.K*FAPC
C FAPC = 0.029
R ACD.KL = AC.K/ALAC
C ALAC = 20
NOTE
NOTE IC-INDUSTRY CAPITAL ($)
NOTE ICN-INDUSTRY CAPITAL INITIAL ($)
NOTE ICI-INDUSTRY CAPITAL INVESTMENT ($/YR)
NOTE ICD-INDUSTRY CAPITAL DEPRECIATION ($/YR)
NOTE IP-INDUSTRY PRODUCT ($/YR)
NOTE FIPC-FRACTION OF INDUSTRY PRODUCT TO CAPITAL
```

NOTE ALIC-AVERAGE LIFETIME OF INDUSTRY CAPITAL (YR)
NOTE
L IC.K = IC.J + (DT)(ICI.JK-ICD.JK)
N IC = ICN
C ICN = 5.44E10
R ICI.KL = IP.K*FIPC
C FIPC = 0.2708
R ICD.KL = IC.K/ALIC
C ALIC = 20
NOTE
NOTE SC-SERVICES CAPITAL ($)
NOTE SCN-SERVICES CAPITAL INITIAL ($)
NOTE SCI-SERVICES CAPITAL INVESTMENT ($/YR)
NOTE SCD-SERVICES CAPITAL DEPRECIATION ($/YR)
NOTE SP-SERVICES PRODUCT ($/YR)
NOTE FSPC-FRACTION OF SERVICES PRODUCT TO CAPITAL
NOTE ALSC-AVERAGE LIFETIME OF SERVICES CAPITAL (YR)
NOTE
L SC.K = SC.J + (DT)(SCI.JK-SCD.JK)
N SC = SCN
C SCN = 3.29E10
R SCI.KL = SP.K*FSPC
C FSPC = 0.0318
R SCD.KL = SC.K/ALSC
C ALSC = 20
NOTE
NOTE ******************* AGRICULTURE SECTOR *******************
NOTE
NOTE AO-AGRICULTURE OUTPUT ($)
NOTE AU-AGRICULTURE USAGE ($)
NOTE ACOR-AGRICULTURE CAPITAL OUTPUT RATIO
NOTE ACORN-AGRICULTURE CAPITAL OUTPUT RATIO NORMAL
NOTE ACORM-AGRICULTURE CAPITAL OUTPUT RATIO MULTIPLIER
NOTE AA-AGRICULTURE INPUT FROM AGRICULTURE ($)
NOTE AI-INDUSTRY INPUT FROM AGRICULTURE ($)
NOTE AS-SERVICES INPUT FROM AGRICULTURE ($)
NOTE FAA-FRACTION OF AGRICULTURE INPUT FROM AGRICULTURE
NOTE FAI-FRACTION OF INDUSTRY INPUT FROM AGRICULTURE
NOTE FAS-FRACTION OF SERVICES INPUT FROM AGRICULTURE
NOTE AV-AGRICULTURE VALUE-ADDED ($)
NOTE AII-AGRICULTURE INTERMEDIATE INPUT ($)
NOTE
A AP.K = AO.K-AU.K
A AO.K = AC.K/ACOR.K
A ACOR.K = ACORN*ACORM.K
C ACORN = 1.8

```
A ACORM.K = AC.K/ACN
A AU.K = AA.K + AI.K + AS.K
A AA.K = FAA.K*AO.K
A AI.K = FAI.K*IO.K
A AS.K = FAS.K*SO.K
A AV.K = AO.K-AII.K
A AII.K = AA.K + IA.K + SA.K
NOTE
NOTE ******************** INDUSTRY SECTOR **********************
NOTE
NOTE IO-INDUSTRY OUTPUT ($)
NOTE IU-INDUSTRY USAGE ($)
NOTE ICOR-INDUSTRY CAPITAL OUTPUT RATIO
NOTE ICORN-INDUSTRY CAPITAL OUTPUT RATIO NORMAL
NOTE ICORM-INDUSTRY CAPITAL OUTPUT RATIO MULTIPLIER
NOTE IA-AGRICULTURE INPUT FROM INDUSTRY ($)
NOTE II-INDUSTRY INPUT FROM INDUSTRY ($)
NOTE IS-SERVICES INPUT FROM INDUSTRY ($)
NOTE FIA-FRACTION OF AGRICULTURE INPUT FROM INDUSTRY
NOTE FII-FRACTION OF INDUSTRY INPUT FROM INDUSTRY
NOTE FIS-FRACTION OF SERVICES INPUT FROM INDUSTRY
NOTE IV-INDUSTRY VALUE-ADDED ($)
NOTE III-INDUSTRY INTERMEDIATE INPUT ($)
NOTE
A IP.K = IO.K-IU.K
A IO.K = IC.K/ICOR.K
A ICOR.K = ICORN*ICORM.K
C ICORN = 1.8
A ICORM.K = IC.K/ICN
A IU.K = IA.K + II.K + IS.K
A IA.K = FIA.K*AO.K
A II.K = FII.K*IO.K
A IS.K = FIS.K*SO.K
A IV.K = IO.K-III.K
A III.K = AI.K + II.K + SI.K
NOTE
NOTE ******************** SERVICES SECTOR **********************
NOTE
NOTE SO-SERVICES OUTPUT ($)
NOTE SU-SERVICES USAGE ($)
NOTE SCOR-SERVICES CAPITAL OUTPUT RATIO
NOTE SCORN-SERVICES CAPITAL OUTPUT RATIO NORMAL
NOTE SCORM-SERVICES CAPITAL OUTPUT RATIO MULTIPLIER
NOTE SA-AGRICULTURE INPUT FROM SERVICES ($)
NOTE SI-INDUSTRY INPUT FROM SERVICES ($)
NOTE SS-SERVICES INPUT FROM SERVICES ($)
```

NOTE FSA-FRACTION OF AGRICULTURE INPUT FROM SERVICES
NOTE FSI-FRACTION OF INDUSTRY INPUT FROM SERVICES
NOTE FSS-FRACTION OF SERVICES INPUT FROM SERVICES
NOTE SV-SERVICES VALUE-ADDED ($)
NOTE SII-SERVICES INTERMEDIATE INPUT ($)
NOTE
A SP.K = SO.K-SU.K
A SO.K = SC.K/SCOR.K
A SCOR.K = SCORN*SCORM.K
C SCORN = 1.8
A SCORM.K = SC.K/SCN
A SU.K = SA.K + SI.K + SS.K
A SA.K = FSA.K*AO.K
A SI.K = FSI.K*IO.K
A SS.K = FSS.K*SO.K
A SV.K = SO.K-SII.K
A SII.K = AS.K + IS.K + SS.K
NOTE
NOTE *** SOCIAL ACCOUNTING AND TECHNOLOGICAL CHANGES ***
NOTE
NOTE GDP-GROSS DOMESTIC PRODUCT ($)
NOTE FAAN,FIAN,ETC.-INITIAL TECHNOLOGICAL COEFFICIENTS
NOTE FAAM,FIAM,ETC.-TECHNOLOGICAL COEFFICIENT MULTIPLIERS
NOTE
A GDP.K = AP.K + IP.K + SP.K
A FAA.K = FAAN*FAAM.K
A FAAM.K = 1.0
C FAAN = 0.1425
A FIA.K = FIAN*FIAM.K
A FIAM.K = 1.0
C FIAN = 0.3020
A FSA.K = FSAN*FSAM.K
A FSAM.K = 1.0
C FSAN = 0.1214
A FAI.K = FAIN*FAIM.K
A FAIM.K = 1.0
C FAIN = 0.0147
A FII.K = FIIN*FIIM.K
A FIIM.K = 1.0
C FIIN = 0.3688
A FSI.K = FSIN*FSIM.K
A FSIM.K = 1.0
C FSIN = 0.0964
A FAS.K = FASN*FASM.K
A FASM.K = 1.0
C FASN = 0.0008

```
A FIS.K = FISN*FISM.K
A FISM.K = 1.0
C FISN = 0.1032
A FSS.K = FSSN*FSSM.K
A FSSM.K = 1.0
C FSSN = 0.0861
NOTE
SPEC DT = 1/LENGTH = 30/PRTPER = 10/PLTPER = 1
PRINT 1)'******'/2)'******'/3)'INPUT-'/4)'OUTPUT'/5)'TABLE'/6)'******'/
X    7)'******'
PRINT 1)*/2)'AGRI'/3)'INDU'/4)'SERV'/5)*/6)*/7)*
PRINT 1)*,'AGRI'/2)AA/3)AI/4)AS/5)AU/6)AP/7)AO
PRINT 1)*,'INDU'/2)IA/3)II/4)IS/5)IU/6)IP/7)IO
PRINT 1)*,'SERV'/2)SA/3)SI/4)SS/5)SU/6)SP/7)SO
PRINT 1)*,*/2)AII/3)III/4)SII
PRINT 1)*,*/2)AV/3)IV/4)SV
PRINT 1)*,*/2)AO/3)IO/4)SO
PLOT  GDP = G,AP = A,IP = I,SP = S
PLOT  AO = A,IO = I,SO = S
PLOT  AV = A,IV = I,SV = S
RUN
QUIT
```

A.2　Urban Transportation Planning Process

```
*    URBAN TRANSPORTATION PLANNING PROCESS
NOTE
NOTE THE PROJECTION OF POPULATION DISTRIBUTION AND TRAFFIC
NOTE FLOWS FOR A FOUR-ZONE URBAN AREA TO BE SERVED BY AN
NOTE EXISTING ARTERIAL AND A PROPOSED FREEWAY.
NOTE
NOTE ********** ALLOCATION OF RESIDENTIAL ACTIVITY **********
NOTE
NOTE TIJ-PEAK-HR TRAVEL TIME (MIN)
NOTE WTIJ-WEIGHT TRAVEL TIME (MIN)
NOTE JJ-JOBS IN ZONE J IN HORIZON YEAR (PERSON)
NOTE LI-LABORFORCE IN ZONE I IN HORIZON YEAR (PERSON)
NOTE ACI-ACCESSIBILITY TO EMPLOYMENT OF RESIDENTISL ZONE I
NOTE HI-HOLDING CAPACITY OF ZONE I
NOTE PI--POPULATION IN ZONE I
NOTE FLP-FRACT. LABOR PARTICIPATION
NOTE
L  T21.K = T21.J + (DT/ST)(WT21.J-T21.J)
N  T21 = T21N
C  T21N = 18
L  T22.K = T22.J + (DT/ST)(WT22.J-T22.J)
N  T22 = T22N
C  T22N = 13
L  T31.K = T31.J + (DT/ST)(WT31.J-T31.J)
N  T31 = T31N
C  T31N = 19
L  T32.K = T32.J + (DT/ST)(WT32.J-T32.J)
N  T32 = T32N
C  T32N = 14
L  T41.K = T41.J + (DT/ST)(WT41.J-T41.J)
N  T41 = T41N
C  T41N = 30
L  T42.K = T42.J + (DT/ST)(WT42.J-T42.J)
N  T42 = T42N
C  T42N = 25
A  AC2.K = (J1/T21.K) + (J2/T22.K)
A  AC3.K = (J1/T31.K) + (J2/T32.K)
A  AC4.K = (J1/T41.K) + (J2/T42.K)
C  J1 = 40000
C  J2 = 40000
A  L2.K = ((AC2.K*H2)/(AC2.K*H2 + AC3.K*H3 + AC4.K*H4))*(J1 + J2)
A  L3.K = ((AC3.K*H3)/(AC2.K*H2 + AC3.K*H3 + AC4.K*H4))*(J1 + J2)
A  L4.K = ((AC4.K*H4)/(AC2.K*H2 + AC3.K*H3 + AC4.K*H4))*(J1 + J2)
```

```
C H2 = 125000
C H3 = 38000
C H4 = 225000
A P2.K = L2.K/FLP
A P3.K = L3.K/FLP
A P4.K = L4.K/FLP
C FLP = 0.4
N ST = DT
NOTE
NOTE ****************** TRIP GENERATION ******************
NOTE
NOTE DJ-DESTINATIONS TO ZONE J
NOTE OI-ORIGINS IN ZONE I
A D1.K = BETA*J1
A D2.K = BETA*J2
A O2.K = ALPHA1*L2.K + ALPHA2*P2.K
A O3.K = ALPHA1*L3.K + ALPHA2*P3.K
A O4.K = ALPHA1*L4.K + ALPHA2*P4.K
A TTRIP.K = O2.K + O3.K + O4.K
C BETA = 1.0
C ALPHA1 = 1.0
C ALPHA2 = 0.0
NOTE
NOTE **************** TRIP DISTRIBUTION ******************
NOTE
NOTE BJ&AI-CONSTRAINT OF THE GRAVITY MODEL
NOTE VIJ-NO. OF TRIPS FROM I TO J
NOTE
A A21.K = 1/((B11.K*D1.K/T21.K) + (B21.K*D2.K/T22.K))
A A211.K = 1/((B111.K*D1.K/T21.K) + (B211.K*D2.K/T22.K))
A A2111.K = 1/((B1111.K*D1.K/T21.K) + (B2111.K*D2.K/T22.K))
A A31.K = 1/((B11.K*D1.K/T31.K) + (B21.K*D2.K/T32.K))
A A311.K = 1/((B111.K*D1.K/T31.K) + (B211.K*D2.K/T32.K))
A A3111.K = 1/((B1111.K*D1.K/T31.K) + (B2111.K*D2.K/T32.K))
A A41.K = 1/((B11.K*D1.K/T41.K) + (B21.K*D2.K/T42.K))
A A411.K = 1/((B111.K*D1.K/T41.K) + (B211.K*D2.K/T42.K))
A A4111.K = 1/((B1111.K*D1.K/T41.K) + (B2111.K*D2.K/T42.K))
A B11.K = 1.0
A B111.K = 1/((A31.K*O3.K/T31.K) + (A41.K*O4.K/T41.K)
X  + (A21.K*O2.K/T21.K))
A B1111.K = 1/((A311.K*O3.K/T31.K) + (A411.K*O4.K/T41.K)
X   + (A211.K*O2.K/T21.K))
A B21.K = 1.0
A B211.K = 1/((A21.K*O2.K/T22.K) + (A31.K*O3.K/T32.K)
X   + (A41.K*O4.K/T42.K))
A B2111.K = 1/((A211.K*O2.K/T22.K) + (A311.K*O3.K/T32.K)
```

```
X    +(A411.K*O4.K/T42.K))
A V21.K=A2111.K*B1111.K*O2.K*D1.K/T21.K
A V22.K=A2111.K*B2111.K*O2.K*D2.K/T22.K
A V31.K=A3111.K*B1111.K*O3.K*D1.K/T31.K
A V32.K=A3111.K*B2111.K*O3.K*D2.K/T32.K
A V41.K=A4111.K*B1111.K*O4.K*D1.K/T41.K
A V42.K=A4111.K*B2111.K*O4.K*D2.K/T42.K
NOTE
NOTE *************** TRIP END MODEL SPLIT *****************
NOTE
NOTE PICH-PERCENTAGE OF CHOICE RIDER IN ZONE I
NOTE PICA-PERCENTAGE OF CAPTIVE RIDER IN ZONE I
NOTE VIJCH-NO. OF TRIPS FROM I TO J BY CHOICE RIDER
NOTE VIJCA-NO. OF TRIPS FROM I TO J BY CAPTIVE RIDER
NOTE CI-CAR OWNERSHIP IN ZONE I
NOTE
C $=1
C C2=20000
C C3=10000
C C4=35000
A P2CH.K=CLIP(1.0,$*C2/L2.K,C2/L2.K,1.0)
A P3CH.K=CLIP(1.0,$*C3/L3.K,C3/L3.K,1.0)
A P4CH.K=CLIP(1.0,$*C4/L4.K,C4/L4.K,1.0)
A V21CH.K=P2CH.K*V21.K
A V22CH.K=P2CH.K*V22.K
A V31CH.K=P3CH.K*V31.K
A V32CH.K=P3CH.K*V32.K
A V41CH.K=P4CH.K*V41.K
A V42CH.K=P4CH.K*V42.K
A V21CA.K=(1-P2CH.K)*V21.K
A V22CA.K=(1-P2CH.K)*V22.K
A V31CA.K=(1-P3CH.K)*V31.K
A V32CA.K=(1-P3CH.K)*V32.K
A V41CA.K=(1-P4CH.K)*V41.K
A V42CA.K=(1-P4CH.K)*V42.K
NOTE
NOTE ************ TRIP INTERCHANGE MODEL SPLIT *************
NOTE
NOTE VIJC-NO. OF TRIPS FROM I TO J BY CAR
NOTE VIJB-NO. OF TRIPS FROM I TO J BY BUS
NOTE PIJC-FRACTION OF TRIPS FROM I TO J BY CAR
NOTE PIJB-FRACTION OF TRIPS FROM I TO J BY BUS
NOTE CCIJ-COST SPEND USING CAR FROM I TO J ($)
NOTE CBIJ-COST SPEND USING BUS FROM I TO J ($)
NOTE V-VALUE OF TRAVELERS TIME ($/MIN)
NOTE TIJC-TIME SPEND USING CAR FROM I TO J (MIN)
```

NOTE TIJB-TIME SPEND USING BUS FROM I TO J (MIN)
NOTE ZIJC-GENERALIZED COST USING CAR FROM I TO J ($)
NOTE ZIJB-GENERALIZED COST USING BUS FROM I TO J ($)
NOTE
L T21C.K = T21C.J + (DT/ST)(T21CF.J-T21C.J)
N T21C = T21CN
C T21CN = 18
L T22C.K = T22C.J + (DT/ST)(T22CF.J-T22C.J)
N T22C = T22CN
C T22CN = 13
L T31C.K = T31C.J + (DT/ST)(T31CF.J-T31C.J)
N T31C = T31CN
C T31CN = 19
L T32C.K = T32C.J + (DT/ST)(T32CF.J-T32C.J)
N T32C = T32CN
C T32CN = 14
L T41C.K = T41C.J + (DT/ST)(T41CF.J-T41C.J)
N T41C = T41CN
C T41CN = 30
L T42C.K = T42C.J + (DT/ST)(T42CF.J-T42C.J)
N T42C = T42CN
C T42CN = 25
L T21B.K = T21B.J + (DT/ST)(T21BA.J-T21B.J)
N T21B = T21BN
C T21BN = 37
L T22B.K = T22B.J + (DT/ST)(T22BA.J-T22B.J)
N T22B = T22BN
C T22BN = 27
L T31B.K = T31B.J + (DT/ST)(T31BA.J-T31B.J)
N T31B = T31BN
C T31BN = 44
L T32B.K = T32B.J + (DT/ST)(T32BA.J-T32B.J)
N T32B = T32BN
C T32BN = 36
L T41B.K = T41B.J + (DT/ST)(T41BA.J-T41B.J)
N T41B = T41BN
C T41BN = 66
L T42B.K = T42B.J + (DT/ST)(T42BA.J-T42B.J)
N T42B = T42BN
C T42BN = 58
A Z21C.K = CC21 + V*T21C.K
A Z22C.K = CC22 + V*T22C.K
A Z31C.K = CC31 + V*T31C.K
A Z32C.K = CC32 + V*T32C.K
A Z41C.K = CC41 + V*T41C.K
A Z42C.K = CC42 + V*T42C.K

```
A Z21B.K = CB21 + V*T21B.K
A Z22B.K = CB22 + V*T22B.K
A Z31B.K = CB31 + V*T31B.K
A Z32B.K = CB32 + V*T32B.K
A Z41B.K = CB41 + V*T41B.K
A Z42B.K = CB42 + V*T42B.K
A DZ21.K = Z21B.K-Z21C.K
A DZ22.K = Z22B.K-Z22C.K
A DZ31.K = Z31B.K-Z31C.K
A DZ32.K = Z32B.K-Z32C.K
A DZ41.K = Z41B.K-Z41C.K
A DZ42.K = Z42B.K-Z42C.K
A P21C.K = EXP(DZ21.K)/(1 + EXP(DZ21.K))
A P22C.K = EXP(DZ22.K)/(1 + EXP(DZ22.K))
A P31C.K = EXP(DZ31.K)/(1 + EXP(DZ31.K))
A P32C.K = EXP(DZ32.K)/(1 + EXP(DZ32.K))
A P41C.K = EXP(DZ41.K)/(1 + EXP(DZ41.K))
A P42C.K = EXP(DZ42.K)/(1 + EXP(DZ42.K))
C CC21 = 0.73
C CC22 = 0.23
C CC31 = 1.02
C CC32 = 0.75
C CC41 = 1.73
C CC42 = 1.45
C CB21 = 0.5
C CB22 = 0.25
C CB31 = 0.5
C CB32 = 0.5
C CB41 = 0.5
C CB42 = 0.5
N V = 6/60
A V21C.K = P21C.K*V21CH.K
A V22C.K = P22C.K*V22CH.K
A V31C.K = P31C.K*V31CH.K
A V32C.K = P32C.K*V32CH.K
A V41C.K = P41C.K*V41CH.K
A V42C.K = P42C.K*V42CH.K
A V21B.K = P21B.K*V21CH.K + V21CA.K
A V22B.K = P22B.K*V22CH.K + V22CA.K
A V31B.K = P31B.K*V31CH.K + V31CA.K
A V32B.K = P32B.K*V32CH.K + V32CA.K
A V41B.K = P41B.K*V41CH.K + V41CA.K
A V42B.K = P42B.K*V42CH.K + V42CA.K
A P21B.K = 1-P21C.K
A P22B.K = 1-P22C.K
A P31B.K = 1-P31C.K
```

```
A P32B.K = 1-P32C.K
A P41B.K = 1-P41C.K
A P42B.K = 1-P42C.K
NOTE
NOTE ************ LINK PEAK HR VEH. TRIP DEMAND ************
NOTE
NOTE QIJC-PEAK HR VEH.TRIP DEMAND FROM I TOJ USING CAR
NOTE QIJB-PEAK HR VEH.TRIP DEMAND FROM I TOJ USING BUS
NOTE FDTPH-FRACT. OF DAILY TRIPS DURING PEAK HOUR
NOTE AMO-AVERAGE VEHICLE OCCUPANCY OF MODE M
NOTE
C ACO = 2
C ABO = 40
C FDTPH = 0.4
A Q21C.K = (V21C.K + V31C.K + V41C.K)*FDTPH/ACO
A Q32C.K = (V31C.K + V32C.K + V41C.K + V42C.K)*FDTPH/ACO
A Q43C.K = (V41C.K + V42C.K)*FDTPH/ACO
A Q21B.K = (V21B.K + V31B.K + V41B.K)*FDTPH/ABO
A Q32B.K = (V31B.K + V32B.K + V41B.K + V42B.K)*FDTPH/ABO
A Q43B.K = (V41B.K + V42B.K)*FDTPH/ABO
NOTE
NOTE ***************** TRAFFIC ASSIGNMENT *****************
NOTE
NOTE NIJF-NO. OF LANES ON FREEWAY
NOTE NIJA-NO. OF LANES ON ARTERIAL
NOTE XIJF-DISTANCE FROM I TO J ON FREEWAY
NOTE XIJA-DISTANCE FROM I TO J ON ARTERIAL
NOTE QF-FREEWAY LANE CAPACITY (VEH/HR)
NOTE QA-ARTERIAL LANE CAPACITY (VEH/HR)
NOTE FSF-FREE SPEED ON FREEWAY (MPH)
NOTE FSA-FREE SPEED ON ARTERIAL (MPH)
NOTE TIJCF-TRAVEL TIME FROM I TO J USING CAR ON FREEWAY (MIN)
NOTE TIJCA-TRAVEL TIME FROM I TO J USING CAR ON ARTERIAL (MIN)
NOTE TIJBA-TRAVEL TIME FROM I TO J USING BUS ON ARTERIAL (MIN)
NOTE QIJCF-DEMAND OF CARS FROM I TO J ON ARTERIAL
NOTE QIJCA-DEMAND OF CARS FROM I TO J ON FREEWAY
NOTE BEF-BUS EQUIVALENT FACTOR TO CARS (CARS/BUS)
NOTE
C N21F = 4
C N32F = 5
C N43F = 4
C QF = 2000
C FSF = 80
C QA = 1500
C FSA = 60
C N21A = 2
```

```
C N32A = 2
C N43A = 2
C X21F = 5
C X32F = 5
C X43F = 7
C X21A = 5
C X32A = 5
C X43A = 7
C BEF = 3
NOTE
NOTE VA-VOLUME ON ARTERIAL (VEH/HR)
NOTE VF-VOLUME ON FREEWAY  (VEH/HR)
NOTE TDR-TRAFFIC DIVERSION RATE (VEH/HR)
NOTE TTR-TRAVEL TIME RATIO
NOTE TTF-TRAVEL TIME USING FREEWAY (MIN)
NOTE TTA-TRAVEL TIME USING ARTERIAL (MIN)
NOTE FFTTA-FREE FLOW TRAVEL TIME USING ARTERIAL (MIN)
NOTE FFTTF-FREE FLOW TRAVEL TIME USING FREEWAY (MIN)
NOTE LSFA-LEVEL OF SERVICE FACTOR FOR ARTERIAL
NOTE LSFF-LEVEL OF SERVICE FACTOR FOR FREEWAY
NOTE DOA-DISTANCE ON ARTERIAL (MILES)
NOTE DOF-DISTANCE ON FREEWAY (MILES)
NOTE VCRA-VOLUME TO CAPACITY RATIO FOR ARTERIAL
NOTE VCRF-VOLUME TO CAPACITY RATIO FOR FREEWAY
NOTE
MACRO VF(QB,QC,LSFA,DOA,FSA,CA,LSFF,DOF,FSF,CF,VA,TTA,TTF)
INTRN TDR,TTR,TTR1,FFTTA,FFTTF,VCRA,VCRF
A     VA.K = QB.K + TDR.K
A     VF.K = QC.K-TDR.K
A     TDR.K = (QC.K/4)*TTR.K
A     TTR1.K = (TTF.K-TTA.K)/TTF.K
A     TTR.K = MAX(TTR1.K,0)
A     TTA.K = FFTTA*(1.0-(1.0-LSFA)(VCRA.K))/(1.0-VCRA.K)
N     FFTTA = (DOA/FSA)*60
A     VCRA.K = QB.K/CA
A     TTF.K = FFTTF*(1.0-(1.0-LSFF)(VCRF.K))/(1.0-VCRF.K)
N     FFTTF = (DOF/FSF)*60
A     VCRF.K = QC.K/CF
MEND
C LSFA = 1.0
C LSFF = 0.5
NOTE              LINK 43
NOTE              *********
N CA43 = N43A*QA
N CF43 = N43F*QF
A Q43CF1.K = VF(BEF*Q43B.K,Q43C.K,LSFA,X43A,FSA,CA43,LSFF,X43F,
```

```
X   FSF,CF43,VA431,TTA431,TTF431)
A Q43CA1.K = VA431.K
A Q43CF2.K = VF(Q43CA1.K,Q43CF1.K,LSFA,X43A,FSA,CA43,LSFF,X43F,
X   FSF,CF43,VA432,TTA432,TTF432)
A Q43CA2.K = VA432.K
A Q43CF3.K = VF(Q43CA2.K,Q43CF2.K,LSFA,X43A,FSA,CA43,LSFF,X43F,
X   FSF,CF43,VA433,TTA433,TTF433)
A Q43CA3.K = VA433.K-BEF*Q43B.K
A T43CF3.K = TTF433.K
A T43BA3.K = TTA433.K
NOTE                LINK 32
NOTE                *********
N CA32 = N32A*QA
N CF32 = N32F*QF
A Q32CF1.K = VF(BEF*Q32B.K,Q32C.K,LSFA,X32A,FSA,CA32,LSFF,X32F,
X   FSF,CF32,VA321,TTA321,TTF321)
A Q32CA1.K = VA321.K
A Q32CF2.K = VF(Q32CA1.K,Q32CF1.K,LSFA,X32A,FSA,CA32,LSFF,X32F,
X   FSF,CF32,VA322,TTA322,TTF322)
A Q32CA2.K = VA322.K
A Q32CF3.K = VF(Q32CA2.K,Q32CF2.K,LSFA,X32A,FSA,CA32,LSFF,X32F,
X   FSF,CF32,VA323,TTA323,TTF323)
A Q32CA3.K = VA323.K-BEF*Q32B.K
A T32CF3.K = TTF323.K
A T32BA3.K = TTA323.K
NOTE                LINK 21
NOTE                *********
N CA21 = N21A*QA
N CF21 = N21F*QF
A Q21CF1.K = VF(BEF*Q21B.K,Q21C.K,LSFA,X21A,FSA,CA21,LSFF,X21F,
X   FSF,CF21,VA211,TTA211,TTF211)
A Q21CA1.K = VA211.K
A Q21CF2.K = VF(Q21CA1.K,Q21CF1.K,LSFA,X21A,FSA,CA21,LSFF,X21F,
X   FSF,CF21,VA212,TTA212,TTF212)
A Q21CA2.K = VA212.K
A Q21CF3.K = VF(Q21CA2.K,Q21CF2.K,LSFA,X21A,FSA,CA21,LSFF,X21F,
X   FSF,CF21,VA213,TTA213,TTF213)
A Q21CA3.K = VA213.K-BEF*Q21B.K
A T21CF3.K = TTF213.K
A T21BA3.K = TTA213.K
NOTE
NOTE **************** EQUILIBRIUM CHECK *****************
NOTE
A T21CF.K = T21CF3.K + 13
A T22CF.K = 13
A T32CF.K = T32CF3.K + 9
```

```
A T21BA.K = T21BA3.K + 32
A T22BA.K = 27
A T32BA.K = T32BA3.K + 31
A T31CF.K = T32CF3.K + T21CF3.K + 9
A T41CF.K = T43CF3.K + T32CF3.K + T21CF3.K + 13
A T42CF.K = T43CF3.K + T32CF3.K + 13
A T31BA.K = T32BA3.K + T21BA3.K + 34
A T41BA.K = T43BA3.K + T32BA3.K + T21BA3.K + 49
A T42BA.K = T43BA3.K + T32BA3.K + 46
A WT21.K = ((T21CF.K*V21C.K) + (T21BA.K*V21B.K))/V21.K
A WT22.K = ((T22CF.K*V22C.K) + (T22BA.K*V22B.K))/V22.K
A WT31.K = ((T31CF.K*V31C.K) + (T31BA.K*V31B.K))/V31.K
A WT32.K = ((T32CF.K*V32C.K) + (T32BA.K*V32B.K))/V32.K
A WT41.K = ((T41CF.K*V41C.K) + (T41BA.K*V41B.K))/V41.K
A WT42.K = ((T42CF.K*V42C.K) + (T42BA.K*V42B.K))/V42.K
NOTE
SPEC DT = 1/LENGTH = 10/PRTPER = 5/PLTPER = 1
PRINT 1)'SOCIAL',*/2)*,*/3)'ACTIV',*/4)'ITY',*/5)*,*
PRINT 1)T21,T31,T41/2)T22,T32,T42/3)AC2,AC3,AC4/4)L2,L3,L4
X      /5)P2,P3,P4
PRINT 1)*,'GENERA',*/2)*,'TION-D',*/3)*,'ISTRIB',*/4)*,'UTION',*
PRINT 1)V21,V31,V41,D1/2)V22,V32,V42,D2/3)O2,O3,O4,TTRIP/
X      4)*,*,*,*,*,*,*,*
PRINT 1)*,'MODAL',*/2)*,*,*/3)*,'SPLIT',*/4)*,*,*
PRINT 1)V21B,V31B,V41B/2)V22B,V32B,V42B/3)V21C,V31C,V41C
X      /4)V22C,V32C
PRINT 1)Q21C,Q21B/2)Q32C,Q32B/3)Q43C,Q43B
PRINT 1)*,'ASSIGN',*/2)*,'MENT',*/3)*,*,*
PRINT 1)Q21CF3,Q21CA3/2)Q32CF3,Q32CA3/3)Q43CF3,Q43CA3
PRINT 1)T21CF3,T21BA3/2)T32CF3,T32BA3/3)T43CF3,T43BA3
PRINT 1)T21CF,T31CF,T41CF/2)T22CF,T32CF,T42CF
X      /3)T21BA,T31BA,T41BA
PRINT 1)T22BA,T32BA,T42BA/2)WT21,WT31,WT41/3)WT22,WT32,WT42
PLOT  L2 = 2,L3 = 3,L4 = 4
PLOT  P2 = 2,P3 = 3,P4 = 4
PLOT  Q21CF3 = 1,Q32CF3 = 2,Q43CF3 = 3
RUN
QUIT
```

A.3 Highway Improvement Scenario

```
NOTE ******** HIGHWAY IMPROVEMENT SCENARIO ********
NOTE
L    T21.K = T21.J + (DT/ST)(CT21.JK)
N    T21 = 53.47
N    ST = DT
NOTE T21-TRAVEL TIME FROM SUBURB TO CENTRAL CITY (MIN)
R    CT21.KL = UT21.K-T21.K
NOTE CT21-CHANGES IN TRAVEL TIME (MIN)
A    UT21.K = (2*FFTT/(1 + SQRT(1-DCR.K))) + CDT
NOTE UT21-UPDATED TRAVEL TIME (MIN)
C    CDT = 10
NOTE CDT-COLLECTION-DISTRIBUTION TIME (MIN)
C    FFTT = 30
NOTE FFTT-FREE FLOW TRAVEL TIME (MIN)
A    DCR.K = Q21.K/CA
NOTE DCR-DEMAND CAPACITY RATIO (DIM)
N    CA = LC*NL*DPP
NOTE CA-CAPACITY (VEH/HR)
C    LC = 1800
NOTE LC-LANE CAPACITY (VEH/HR)
C    NL = 3
NOTE NL-NUMBER OF LANES IN EACH DIRECTION (LANES)
C    DPP = 2
NOTE DPP = DURATION OF PEAK PERIOD (HR)
A    Q21.K = V21.K/ACO
NOTE Q21-TRAF DEMAND FROM SUBURB TO CENTR CITY
(VEH/PERIOD)
C    ACO = 1
NOTE ACO-AVERAGE CAR OCCUPANCY (PERSON/CAR)
A    V21.K = A2.K*B1.K*O2.K*D1.K/T21.K
NOTE V21-TRIP DEMAND (PERSONS/PERIOD)
A    A2F.K = 1/((D1.K/T21.K) + (D2.K/T22))
A    A1F.K = 1/((D1.K/T11) + (D2.K/T12.K))
A    B1.K = 1/((A1F.K*O1.K/T11) + (A2F.K*O2.K/T21.K))
A    B2.K = 1/((A1F.K*O1.K/T12.K) + (A2F.K*O2.K/T22))
A    A2.K = 1/((B1.K*D1.K/T21.K) + (B2.K*D2.K/T22))
NOTE AI,BJ-TRIP DISTRIBUTION PARAMETERS (DIM)
C    T11 = 30
A    T12.K = T21.K
C    T22 = 15
NOTE TIJ-ZONAL TRAVEL TIME (MIN)
A    O1.K = SMOOTH(UO1.K,LRT)
A    O2.K = TJ-O1.K
```

NOTE OI-NUMBER OF TRIPS ORIGINATED AT ZONE I (TRIPS/PERIOD)
C   LRT = 3
NOTE LRT-LABOR RELOCATION TIME (YEARS)
A   UO1.K = ILF1.K + THSL1.K
NOTE UO1-UPDATED O1 (TRIPS/PERIOD)
A   D1.K = SMOOTH(UD1.K,BRT)
A   D2.K = TJ-D1.K
NOTE DJ-NUMBER OF TRIPS DESTINATED AT ZONE J (TRIPS/PERIOD)
C   BRT = 5
NOTE BRT-BUSINESS RELOCATION TIME (YEARS)
A   UD1.K = BJ1 + BSJ1.K + THSJ1.K
NOTE UD1-UPDATED D1 (TRIPS/PERIOD)
C   BJ1 = 10000
NOTE BJ1-BASIC JOBS IN CENTRAL CITY (JOBS)
A   BSJ1.K = TBSJ*ASI1.K*ZSI1/(ASI1.K*ZSI1 + ASI2.K*ZSI2)
A   BSJ2.K = TBSJ-BSJ1.K
NOTE BSJI-ZONE I BUSINESS SERVICE JOBS (JOBS)
N   TBSJ = BJ1*S
NOTE TBSJ-TOTAL BUSINESS SERVICE JOBS (JOBS)
C   S = 1
NOTE S-BUSINESS SERVICE EMPLOYMENT MULTIPLIER (DIM)
C   ZSI1 = 20
C   ZSI2 = 10
NOTE ZSII-ZONE I HOLDING CAP OF SERV INDUS (THOUSAND JOBS)
A   ASI1.K = BJ1/T11
A   ASI2.K = BJ1/T21.K
NOTE ASII-ZONE I ACCESSIBILITY TO SERVICE JOBS
A   ILF1.K = TILF*ARIJ1.K*ZR1/(ARIJ1.K*ZR1 + ARIJ2.K*ZR2)
A   ILF2.K = TILF-ILF1.K
NOTE ILFI-ZONE I INDUSTRAIL LABORFORCE (PERSONS)
N   TILF = (BJ1 + TBSJ)
NOTE TILF-TOTAL INDUSTRIAL LABORFORCE (PERSONS)
C   ZR1 = 100
C   ZR2 = 100
NOTE ZRI-ZONE I HOLDING CAP OF RESIDENTS (THOUSAND PERSONS)
A   ARIJ1.K = ((BJ1 + BSJ1.K)/T11) + (BSJ2.K/T12.K)
A   ARIJ2.K = ((BJ1 + BSJ1.K)/T21.K) + (BSJ2.K/T22)
NOTE ARIJI-ACCESSIBILITY OF RESIDENTIAL ZONE I TO INDUS JOBS
A   THSJ1.K = THSJ*AHP1.K*ZHS1/(AHP1.K*ZHS1 + AHP2.K*ZHS2)
A   THSJ2.K = THSJ-THSJ1.K
NOTE THSJI-ZONE I TOTAL HOUSEHOLD SERVICE JOB (JOBS)
N   THSJ = TJ-BJ1-TBSJ
NOTE THSJ-TOTAL HOUSEHOLD SERVICE JOBS (JOBS)
C   TJ = 36000
NOTE TJ-TOTAL JOBS OF THE METROPOLITAN AREA (JOBS)
C   ZHS1 = 20

```
C    ZHS2 = 20
NOTE ZHSI-ZONE I HOLDING CAP OF H.S. INDUS. (THOUS PERSONS)
A    AHP1.K = (ILF1.K/T11) + (ILF2.K/T12.K)
A    AHP2.K = (ILF1.K/T21.K) + (ILF2.K/T22)
NOTE AHPI-ZONE I ACCESSIBILITY OF H.S. TO POPULATION
A    THSL1.K = THSJ*ARHJ1.K*ZR1/(ARHJ1.K*ZR1 + ARHJ2.K*ZR2)
NOTE THSLI-ZONE I TOTAL H.S. LABORFORCE (PERSONS)
A    ARHJ1.K = (THSJ1.K/T11) + (THSJ2.K/T12.K)
A    ARHJ2.K = (THSJ1.K/T21.K) + (THSJ2.K/T22)
NOTE ARHJI-ACCESSIBILITY OF RESIDENTIAL ZONE I TO H.S. JOBS
A    P2.K = O2.K/F
NOTE P2-SUBURBAN POPULATION (PERSONS)
C    F = 0.4
NOTE F-LABOR PARTICIPATION FACTOR (DIM)
L    CUB.K = CUB.J + (DT)(AUB.JK)
N    CUB = 0
R    AUB.KL = 0.5*VT*(V21.K + 9238)(53.47-T21.K)*600/((1 + IR)**TIME.K)
C    VT = 0.10
C    IR = 0.07
NOTE
SPEC DT = 1/LENGTH = 20/PRTPER = 1/PLTPER = 1
PRINT T21,Q21,O1,O2,D1,D2,CUB
PLOT T21 = T(0,60)/Q21 = Q(0,20000)
PLOT D2 = E(11000,16000)/P2 = P(45000,55000)
RUN BASE
C DPP = 3
RUN STAGGERED WORKING HOUR
C ACO = 1.5
RUN INCREASE VEHICLE OCCUPANCY
C NL = 4
C LC = 2000
C FFTT = 22
RUN HIGHWAY UPGRADING
QUIT
```

A.4   *Corridor Development Scenario I*

```
NOTE ******** CORRIDOR DEVELOPMENT SCENARIO I ********
NOTE
L   T21.K = T21.J + (DT/ST)(CT21.JK)
N   T21 = 67.49
N   ST = DT
NOTE T21-TRAVEL TIME FROM SUBURB TO CENTRAL CITY (MIN)
R   CT21.KL = UT21.K-T21.K
NOTE CT21-CHANGES IN TRAVEL TIME (MIN)
A   UT21.K = TA.K
NOTE UT21-UPDATED TRAVEL TIME (MIN)
A   TA1.K = (2*FFTTA/(1 + SQRT(1-DCRA1.K))) + CDT
A   TA2.K = 2*FFTTA + 30*(DCRA.K-1.0) + CDT
A   TA.K = CLIP(TA1.K,TA2.K,1,DCRA.K)
NOTE TA-TRAVEL TIME ON THE ARTERIAL ROAD (MIN)
C   CDT = 10
NOTE CDT-COLLECTION-DISTRIBUTION TIME (MIN)
C   FFTTA = 30
NOTE FFTTA-FREE FLOW TRAVEL TIME ON THE ARTERIAL ROAD (MIN)
A   DCRA.K = QA.K/CAA
A   DCRA1.K = MIN(DCRA.K,1)
NOTE DCRA-DEMAND CAPACITY RATIO OF THE ARTERIAL ROAD (DIM)
N   CAA = LCA*NLA*DPP
NOTE CAA-CAPACITY OF THE ARTERIAL ROAD (VEH/HR)
C   LCA = 1800
NOTE LCA-LANE CAPACITY OF THE ARTERIAL ROAD (VEH/HR)
C   NLA = 3
NOTE NLA-NUMBER OF LANES IN EACH DIREC OF ART.RD. (LANES)
C   DPP = 2
NOTE DPP = DURATION OF PEAK PERIOD (HR)
A   QA.K = Q21.K-QF.K
NOTE QA-TRAFFIC FLOWS ON THE ARTERIAL ROAD (VEH/PERIOD)
L   QF.K = QF.J + (DT/ST)(TDR.JK)
N   QF = 0
NOTE QF-FREEWAY TRAFFIC FLOWS (VEH/PERIOD)
R   TDR.KL = QA.K*(TTR.K-1)
NOTE TDR-TRAFFIC DIVERSION RATE (VEH/PERIOD)
A   TTR.K = MAX(TA.K/TF.K,1)
NOTE TTR-TRAFFIC TIME RATION (DIM)
A   TF.K = (2*FFTTF/(1 + SQRT(1-DCRF.K))) + CDT
NOTE TF-TRAVEL TIME ON THE FREEWAY (MIN)
C   FFTTF = 10000
NOTE FFTTF-FREE FLOW TRAVEL TIME ON THE FREEWAY (MIN)
A   DCRF.K = QF.K/CAF
```

NOTE DCRF-DEMAND CAPACITY RATIO OF THE FREEWAY (DIM)
N   CAF=LCF*NLF*DPP
NOTE CAF-CAPACITY OF THE FREEWAY (VEH/HR)
C   LCF=2000
NOTE LCF-LANE CAPACITY OF THE FREEWAY (VEH/HR)
C   NLF=4
NOTE NLF-NUMBER OF LANES OF THE FREEWAY (LANES/DIRECTION)
A   Q21.K=V21.K/ACO
NOTE Q21-TRAF DEMAND FROM SUBURB TO CENTR CITY (VEH/PERIOD)
C   ACO=1
NOTE ACO-AVERAGE CAR OCCUPANCY (PERSON/CAR)
A   V21.K=SMOOTH(UV21,1)
A   UV21.K=A2.K*B1.K*O2.K*D1.K/T21.K
NOTE V21-TRIP DEMAND (PERSONS/PERIOD)
A   A2F.K=1/((D1.K/T21.K)+(D2.K/T22))
A   A1F.K=1/((D1.K/T11)+(D2.K/T12.K))
A   B1.K=1/((A1F.K*O1.K/T11)+(A2F.K*O2.K/T21.K))
A   B2.K=1/((A1F.K*O1.K/T12.K)+(A2F.K*O2.K/T22))
A   A2.K=1/((B1.K*D1.K/T21.K)+(B2.K*D2.K/T22))
NOTE AI,BJ-TRIP DISTRIBUTION PARAMETERS (DIM)
C   T11=30
A   T12.K=T21.K
C   T22=15
NOTE TIJ-ZONAL TRAVEL TIME (MIN)
A   O1.K=SMOOTH(UO1.K,LRT)
A   O2.K=TJ-O1.K
NOTE OI-NUMBER OF TRIPS ORIGINATED AT ZONE I (TRIPS/PERIOD)
C   LRT=3
NOTE LRT-LABOR RELOCATION TIME (YEARS)
A   UO1.K=ILF1.K+THSL1.K
NOTE UO1-UPDATED O1 (TRIPS/PERIOD)
A   D1.K=SMOOTH(UD1.K,BRT)
A   D2.K=TJ-D1.K
NOTE DJ-NUMBER OF TRIPS DESTINATED AT ZONE J (TRIPS/PERIOD)
C   BRT=5
NOTE BRT-BUSINESS RELOCATION TIME (YEARS)
A   UD1.K=BJ1+BSJ1.K+THSJ1.K
NOTE UD1-UPDATED D1 (TRIPS/PERIOD)
C   BJ1=20000
NOTE BJ1-BASIC JOBS IN CENTRAL CITY (JOBS)
A   BSJ1.K=TBSJ*ASI1.K*ZSI1/(ASI1.K*ZSI1+ASI2.K*ZSI2)
A   BSJ2.K=TBSJ-BSJ1.K
NOTE BSJI-ZONE I BUSINESS SERVICE JOBS (JOBS)
N   TBSJ=BJ1*S
NOTE TBSJ-TOTAL BUSINESS SERVICE JOBS (JOBS)

```
C    S=1
NOTE S-BUSINESS SERVICE EMPLOYMENT MULTIPLIER (DIM)
C    ZSI1=30
C    ZSI2=15
NOTE ZSII-ZONE I HOLDING CAP OF SERVICE INDUS (THOUS JOBS)
A    ASI1.K=BJ1/T11
A    ASI2.K=BJ1/T21.K
NOTE ASII-ZONE I ACCESSIBILITY TO SERVICE JOBS
A    ILF1.K=TILF*ARIJ1.K*ZR1/(ARIJ1.K*ZR1+ARIJ2.K*ZR2)
A    ILF2.K=TILF-ILF1.K
NOTE ILFI-ZONE I INDUSTRAIL LABORFORCE (PERSONS)
N    TILF=(BJ1+TBSJ)
NOTE TILF-TOTAL INDUSTRIAL LABORFORCE (PERSONS)
.C   ZR1=200
C    ZR2=100
NOTE ZRI-ZONE I HOLDING CAP OF RESIDENTS (THOUS PERSONS)
A    ARIJ1.K=((BJ1+BSJ1.K)/T11)+(BSJ2.K/T12.K)
A    ARIJ2.K=((BJ1+BSJ1.K)/T21.K)+(BSJ2.K/T22)
NOTE ARIJI-ACCESSIBILITY OF RESID ZONE I TO INDUSTIAL JOBS
A    THSJ1.K=THSJ*AHP1.K*ZHS1/(AHP1.K*ZHS1+AHP2.K*ZHS2)
A    THSJ2.K=THSJ-THSJ1.K
NOTE THSJI-ZONE I TOTAL HOUSEHOLD SERVICE JOB (JOBS)
N    THSJ=TJ-BJ1-TBSJ
NOTE THSJ-TOTAL HOUSEHOLD SERVICE JOBS (JOBS)
C    TJ=70000
NOTE TJ-TOTAL JOBS OF THE METROPOLITAN AREA (JOBS)
C    ZHS1=40
C    ZHS2=20
NOTE ZHSI-ZONE I HOLDING CAP OF H.S. INDUS. (THOUS PERSONS)
A    AHP1.K=(ILF1.K/T11)+(ILF2.K/T12.K)
A    AHP2.K=(ILF1.K/T21.K)+(ILF2.K/T22)
NOTE AHPI-ZONE I ACCESSIBILITY OF H.S. TO POPULATION
A    THSL1.K=THSJ*ARHJ1.K*ZR1/(ARHJ1.K*ZR1+ARHJ2.K*ZR2)
NOTE THSLI-ZONE I TOTAL H.S. LABORFORCE (PERSONS)
A    ARHJ1.K=(THSJ1.K/T11)+(THSJ2.K/T12.K)
A    ARHJ2.K=(THSJ1.K/T21.K)+(THSJ2.K/T22)
NOTE ARHJI-ACCESSIBILITY OF RESIDENTIAL ZONE I TO H.S. JOBS
A    P2.K=O2.K/F
NOTE P2-SUBURBAN POPULATION (PERSONS)
C    F=0.4
NOTE F-LABOR PARTICIPATION FACTOR (DIM)
NOTE
SPEC DT=0.125/LENGTH=20/PRTPER=1/PLTPER=1
PRINT TA,QA,TF,QF,O2,D1
PLOT TA=T(10,70)/QA=Q(0,15000)
PLOT TF=C(10,70)/QF=F(0,15000)
```

```
PLOT D2 = E(10000,30000)/P2 = P(30000,70000)
RUN BASE
C    FFTTF = 22
RUN FREEWAY CONSTRUCTION
QUIT
```

A.5 Corridor Development Scenario II

```
NOTE ***** CORRIDOR DEVELOPMENT SENARIO II *****
NOTE
L    T21.K=T21.J+(DT/ST)(CT21.JK)
N    T21=67.49
N    ST=DT
NOTE T21-TRAVEL TIME FROM SUBURB TO CENTRAL CITY (MIN)
R    CT21.KL=UT21.K-T21.K
NOTE CT21-CHANGES IN TRAVEL TIME (MIN)
A    UT21.K=TA.K
NOTE UT21-UPDATED TRAVEL TIME (MIN)
A    TA1.K=(2*FFTTA/(1+SQRT(1-DCRA1.K)))+CDT
A    TA2.K=2*FFTTA+30*(DCRA.K-1.0)+CDT
A    TA.K=CLIP(TA1.K,TA2.K,1,DCRA.K)
NOTE TA-TRAVEL TIME ON THE ARTERIAL ROAD (MIN)
C    CDT=10
NOTE CDT-COLLECTION-DISTRIBUTION TIME (MIN)
C    FFTTA=30
NOTE FFTTA-FREE FLOW TRAVEL TIME ON THE ARTERIAL ROAD (MIN)
A    DCRA.K=QA.K/CAA
A    DCRA1.K=MIN(DCRA.K,1)
NOTE DCRA-DEMAND CAPACITY RATIO OF THE ARTERIAL ROAD (DIM)
N    CAA=LCA*NLA*DPP
NOTE CAA-CAPACITY OF THE ARTERIAL ROAD (VEH/HR)
C    LCA=1800
NOTE LCA-LANE CAPACITY OF THE ARTERIAL ROAD (VEH/HR)
C    NLA=3
NOTE NLA-NUMBER OF LANES IN EACH DIREC OF ART.RD. (LANES)
C    DPP=2
NOTE DPP=DURATION OF PEAK PERIOD (HR)
A    QA.K=Q21.K-QF.K
NOTE QA-TRAFFIC FLOWS ON THE ARTERIAL ROAD (VEH/PERIOD)
L    QF.K=QF.J+(DT/ST)(TDR.JK)
N    QF=0
NOTE QF-FREEWAY TRAFFIC FLOWS (VEH/PERIOD)
R    TDR.KL=QA.K*(TTR.K-1)
NOTE TDR-TRAFFIC DIVERSION RATE (VEH/PERIOD)
A    TTR.K=MAX(TA.K/TF.K,1)
NOTE TTR-TRAFFIC TIME RATION (DIM)
A    TF.K=(2*FFTTF/(1+SQRT(1-DCRF.K)))+CDT
NOTE TF-TRAVEL TIME ON THE FREEWAY (MIN)
C    FFTTF=10000
NOTE FFTTF-FREE FLOW TRAVEL TIME ON THE FREEWAY (MIN)
A    DCRF.K=QF.K/CAF
```

NOTE DCRF-DEMAND CAPACITY RATIO OF THE FREEWAY (DIM)
N   CAF = LCF*NLF*DPP
NOTE CAF-CAPACITY OF THE FREEWAY (VEH/HR)
C   LCF = 2000
NOTE LCF-LANE CAPACITY OF THE FREEWAY (VEH/HR)
C   NLF = 4
NOTE NLF-NUMBER OF LANES OF THE FREEWAY (LANES/DIRECTION)
A   Q21.K = V21.K/ACO
NOTE Q21-TRAF DEMAND FROM SUBURB TO CENTR CITY
(VEH/PERIOD)
C   ACO = 1
NOTE ACO-AVERAGE CAR OCCUPANCY (PERSON/CAR)
A   V21.K = SMOOTH(UV21,1)
A   UV21.K = A2.K*B1.K*O2.K*D1.K/T21.K
NOTE V21-TRIP DEMAND (PERSONS/PERIOD)
A   A2F.K = 1/((D1.K/T21.K) + (D2.K/T22))
A   A1F.K = 1/((D1.K/T11) + (D2.K/T12.K))
A   B1.K = 1/((A1F.K*O1.K/T11) + (A2F.K*O2.K/T21.K))
A   B2.K = 1/((A1F.K*O1.K/T12.K) + (A2F.K*O2.K/T22))
A   A2.K = 1/((B1.K*D1.K/T21.K) + (B2.K*D2.K/T22))
NOTE AI,BJ-TRIP DISTRIBUTION PARAMETERS (DIM)
C   T11 = 30
A   T12.K = T21.K
C   T22 = 15
NOTE TIJ-ZONAL TRAVEL TIME (MIN)
A   O1.K = SMOOTH(UO1.K,LRT)
A   O2.K = TJ-O1.K
NOTE OI-NUMBER OF TRIPS ORIGINATED AT ZONE I (TRIPS/PERIOD)
C   LRT = 3
NOTE LRT-LABOR RELOCATION TIME (YEARS)
A   UO1.K = ILF1.K + THSL1.K
NOTE UO1-UPDATED O1 (TRIPS/PERIOD)
A   D1.K = SMOOTH(UD1.K,BRT)
A   D2.K = TJ-D1.K
NOTE DJ-NUMBER OF TRIPS DESTINATED AT ZONE J (TRIPS/PERIOD)
C   BRT = 5
NOTE BRT-BUSINESS RELOCATION TIME (YEARS)
A   UD1.K = BJ1 + BSJ1.K + THSJ1.K
NOTE UD1-UPDATED D1 (TRIPS/PERIOD)
C   BJ1 = 20000
NOTE BJ1-BASIC JOBS IN CENTRAL CITY (JOBS)
A   BSJ1.K = TBSJ*ASI1.K*ZSI1/(ASI1.K*ZSI1 + ASI2.K*ZSI2)
A   BSJ2.K = TBSJ-BSJ1.K
NOTE BSJI-ZONE I BUSINESS SERVICE JOBS (JOBS)
N   TBSJ = BJ1*S
NOTE TBSJ-TOTAL BUSINESS SERVICE JOBS (JOBS)

```
C    S=1
NOTE S-BUSINESS SERVICE EMPLOYMENT MULTIPLIER (DIM)
C    ZSI1=30
C    ZSI2=15
NOTE ZSII-ZONE I HOLDING CAP OF SERV INDUS (THOUSAND JOBS)
A    ASI1.K=BJ1/T11
A    ASI2.K=BJ1/T21.K
NOTE ASII-ZONE I ACCESSIBILITY TO SERVICE JOBS
A    ILF1.K=TILF*ARIJ1.K*ZR1/(ARIJ1.K*ZR1+ARIJ2.K*ZR2)
A    ILF2.K=TILF-ILF1.K
NOTE ILFI-ZONE I INDUSTRAIL LABORFORCE (PERSONS)
N    TILF=(BJ1+TBSJ)
NOTE TILF-TOTAL INDUSTRIAL LABORFORCE (PERSONS)
C    ZR1=200
C    ZR2=100
NOTE ZRI-ZONE I HOLDING CAP OF RESIDENTS (THOUSAND PERSONS)
A    ARIJ1.K=((BJ1+BSJ1.K)/T11)+(BSJ2.K/T12.K)
A    ARIJ2.K=((BJ1+BSJ1.K)/T21.K)+(BSJ2.K/T22)
NOTE ARIJI-ACCESSIBILITY OF RESIDENTIAL ZONE I TO INDUS JOBS
A    THSJ1.K=THSJ*AHP1.K*ZHS1/(AHP1.K*ZHS1+AHP2.K*ZHS2)
A    THSJ2.K=THSJ-THSJ1.K
NOTE THSJI-ZONE I TOTAL HOUSEHOLD SERVICE JOB (JOBS)
N    THSJ=TJ-BJ1-TBSJ
NOTE THSJ-TOTAL HOUSEHOLD SERVICE JOBS (JOBS)
C    TJ=70000
NOTE TJ-TOTAL JOBS OF THE METROPOLITAN AREA (JOBS)
C    ZHS1=40
C    ZHS2=20
NOTE ZHSI-ZONE I HOLDING CAP OF H.S. INDUS. (THOUS PERSONS)
A    AHP1.K=(ILF1.K/T11)+(ILF2.K/T12.K)
A    AHP2.K=(ILF1.K/T21.K)+(ILF2.K/T22)
NOTE AHPI-ZONE I ACCESSIBILITY OF H.S. TO POPULATION
A    THSL1.K=THSJ*ARHJ1.K*ZR1/(ARHJ1.K*ZR1+ARHJ2.K*ZR2)
NOTE THSLI-ZONE I TOTAL H.S. LABORFORCE (PERSONS)
A    ARHJ1.K=(THSJ1.K/T11)+(THSJ2.K/T12.K)
A    ARHJ2.K=(THSJ1.K/T21.K)+(THSJ2.K/T22)
NOTE ARHJI-ACCESSIBILITY OF RESIDENTIAL ZONE I TO H.S. JOBS
A    P2.K=O2.K/F
NOTE P2-SUBURBAN POPULATION (PERSONS)
C    F=0.4
NOTE F-LABOR PARTICIPATION FACTOR (DIM)
NOTE
SPEC DT=0.125/LENGTH=20/PRTPER=1/PLTPER=1
PRINT TA,QA,TF,QF,O2,D1
PLOT TA=T(10,70)/QA=Q(0,15000)
PLOT TF=C(10,70)/QF=F(0,15000)
```

A.6   HOV Lane Provision Scenario

```
NOTE ******** HOV LANE PROVISION SCENARIO ********
NOTE
L    T21.K = T21.J + (DT/ST)(CT21.JK)
N    T21 = 44.12
N    ST = DT
NOTE T21-TRAVEL TIME FROM SUBURB TO CENTRAL CITY (MIN)
R    CT21.KL = UT21.K-T21.K
NOTE CT21-CHANGES IN TRAVEL TIME (MIN)
A    UT21.K = TA.K
NOTE UT21-UPDATED TRAVEL TIME (MIN)
A    TA1.K = (2*FFTTA/(1 + SQRT(1-DCRA1.K))) + CDT
A    TA2.K = 2*FFTTA + 30*(DCRA.K-1.0) + CDT
A    TA.K = CLIP(TA1.K,TA2.K,1,DCRA.K)
NOTE TA-TRAVEL TIME ON THE ARTERIAL ROAD (MIN)
C    CDT = 10
NOTE CDT-COLLECTION-DISTRIBUTION TIME (MIN)
C    FFTTA = 30
NOTE FFTTA-FREE FLOW TRAVEL TIME ON THE ARTERIAL ROAD (MIN)
A    DCRA.K = QA.K/CAA
A    DCRA1.K = MIN(DCRA.K,1)
NOTE DCRA-DEMAND CAPACITY RATIO OF THE ARTERIAL ROAD (DIM)
N    CAA = LCA*NLA*DPP
NOTE CAA-CAPACITY OF THE ARTERIAL ROAD (VEH/HR)
C    LCA = 1800
NOTE LCA-LANE CAPACITY OF THE ARTERIAL ROAD (VEH/HR)
C    NLA = 3
NOTE NLA-NUMBER OF LANES IN EACH DIREC OF ART.RD. (LANES)
C    DPP = 2
NOTE DPP = DURATION OF PEAK PERIOD (HR)
A    QA.K = Q21.K-QF.K
NOTE QA-TRAFFIC FLOWS ON THE ARTERIAL ROAD (VEH/PERIOD)
L    QF.K = QF.J + (DT/ST)(TDR.JK)
N    QF = 0
NOTE QF-FREEWAY TRAFFIC FLOWS (VEH/PERIOD)
R    TDR.KL = QA.K*(TTR.K-1)
NOTE TDR-TRAFFIC DIVERSION RATE (VEH/PERIOD)
A    TTR.K = MAX(TA.K/TF.K,1)
NOTE TTR-TRAFFIC TIME RATION (DIM)
A    TF.K = (2*FFTTF/(1 + SQRT(1-DCRF.K))) + CDT
NOTE TF-TRAVEL TIME ON THE FREEWAY (MIN)
C    FFTTF = 10000
NOTE FFTTF-FREE FLOW TRAVEL TIME ON THE FREEWAY (MIN)
A    DCRF.K = QF.K/CAF
```

```
NOTE DCRF-DEMAND CAPACITY RATIO OF THE FREEWAY (DIM)
N    CAF=LCF*NLF*DPP
NOTE CAF-CAPACITY OF THE FREEWAY (VEH/HR)
C    LCF=2000
NOTE LCF-LANE CAPACITY OF THE FREEWAY (VEH/HR)
C    NLF=4
NOTE NLF-NUMBER OF LANES OF THE FREEWAY (LANES/DIRECTION)
A    Q21.K=V21.K/ACO
NOTE Q21-TRAF DEMAND FROM SUBURB TO CENTR CITY
(VEH/PERIOD)
C    ACO=1
NOTE ACO-AVERAGE CAR OCCUPANCY (PERSON/CAR)
A    V21.K=SMOOTH(UV21,1)
A    UV21.K=A2.K*B1.K*O2.K*D1.K/T21.K
NOTE V21-TRIP DEMAND (PERSONS/PERIOD)
A    A2F.K=1/((D1.K/T21.K)+(D2.K/T22))
A    A1F.K=1/((D1.K/T11)+(D2.K/T12.K))
A    B1.K=1/((A1F.K*O1.K/T11)+(A2F.K*O2.K/T21.K))
A    B2.K=1/((A1F.K*O1.K/T12.K)+(A2F.K*O2.K/T22))
A    A2.K=1/((B1.K*D1.K/T21.K)+(B2.K*D2.K/T22))
NOTE AI,BJ-TRIP DISTRIBUTION PARAMETERS (DIM)
C    T11=30
A    T12.K=T21.K
C    T22=15
NOTE TIJ-ZONAL TRAVEL TIME (MIN)
A    O1.K=SMOOTH(UO1.K,LRT)
A    O2.K=TJ-O1.K
NOTE OI-NUMBER OF TRIPS ORIGINATED AT ZONE I (TRIPS/PERIOD)
C    LRT=3
NOTE LRT-LABOR RELOCATION TIME (YEARS)
A    UO1.K=ILF1.K+THSL1.K
NOTE UO1-UPDATED O1 (TRIPS/PERIOD)
A    D1.K=SMOOTH(UD1.K,BRT)
A    D2.K=TJ-D1.K
NOTE DJ-NUMBER OF TRIPS DESTINATED AT ZONE J (TRIPS/PERIOD)
C    BRT=5
NOTE BRT-BUSINESS RELOCATION TIME (YEARS)
A    UD1.K=BJ1+BSJ1.K+THSJ1.K
NOTE UD1-UPDATED D1 (TRIPS/PERIOD)
C    BJ1=20000
C    BJ2=1000
NOTE BJI-BASIC JOBS IN ZONE I (JOBS)
A    BSJ1.K=TBSJ*ASI1.K*ZSI1/(ASI1.K*ZSI1+ASI2.K*ZSI2)
A    BSJ2.K=TBSJ-BSJ1.K
NOTE BSJI-ZONE I BUSINESS SERVICE JOBS (JOBS)
N    TBSJ=(BJ1+BJ2)*S
```

NOTE TBSJ-TOTAL BUSINESS SERVICE JOBS (JOBS)
C   S=1
NOTE S-BUSINESS SERVICE EMPLOYMENT MULTIPLIER (DIM)
C   ZSI1=60
C   ZSI2=10
NOTE ZSII-ZONE I HOLDING CAP OF SERV INDUS (THOUSAND JOBS)
A   ASI1.K=(BJ1/T11)+(BJ2/T12.K)
A   ASI2.K=(BJ1/T21.K)+(BJ2/T22)
NOTE ASII-ZONE I ACCESSIBILITY TO SERVICE JOBS
A   ILF1.K=TILF*ARIJ1.K*ZR1/(ARIJ1.K*ZR1+ARIJ2.K*ZR2)
A   ILF2.K=TILF-ILF1.K
NOTE ILFI-ZONE I INDUSTRAIL LABORFORCE (PERSONS)
N   TILF=(BJ1+BJ2+TBSJ)
NOTE TILF-TOTAL INDUSTRIAL LABORFORCE (PERSONS)
C   ZR1=400
C   ZR2=50
NOTE ZRI-ZONE I HOLDING CAP OF RESIDENTS (THOUSAND PERSONS)
A   ARIJ1.K=((BJ1+BSJ1.K)/T11)+(BJ2+BSJ2.K/T12.K)
A   ARIJ2.K=((BJ1+BSJ1.K)/T21.K)+(BJ2+BSJ2.K/T22)
NOTE ARIJI-ACCESSIBILITY OF RESIDENTIAL ZONE I TO INDUS JOBS
A   THSJ1.K=THSJ*AHP1.K*ZHS1/(AHP1.K*ZHS1+AHP2.K*ZHS2)
A   THSJ2.K=THSJ-THSJ1.K
NOTE THSJI-ZONE I TOTAL HOUSEHOLD SERVICE JOB (JOBS)
N   THSJ=TJ-BJ1-TBSJ
NOTE THSJ-TOTAL HOUSEHOLD SERVICE JOBS (JOBS)
C   TJ=70000
NOTE TJ-TOTAL JOBS OF THE METROPOLITAN AREA (JOBS)
C   ZHS1=80
C   ZHS2=10
NOTE ZHSI-ZONE I HOLDING CAP OF H.S.INDUS. (THOUS PERSONS)
A   AHP1.K=(ILF1.K/T11)+(ILF2.K/T12.K)
A   AHP2.K=(ILF1.K/T21.K)+(ILF2.K/T22)
NOTE AHPI-ZONE I ACCESSIBILITY OF H.S. TO POPULATION
A   THSL1.K=THSJ*ARHJ1.K*ZR1/(ARHJ1.K*ZR1+ARHJ2.K*ZR2)
NOTE THSLI-ZONE I TOTAL H.S. LABORFORCE (PERSONS)
A   ARHJ1.K=(THSJ1.K/T11)+(THSJ2.K/T12.K)
A   ARHJ2.K=(THSJ1.K/T21.K)+(THSJ2.K/T22)
NOTE ARHJI-ACCESSIBILITY OF RESIDENTIAL ZONE I TO H.S. JOBS
A   P2.K=O2.K/F
NOTE P2-SUBURBAN POPULATION (PERSONS)
C   F=0.4
NOTE F-LABOR PARTICIPATION FACTOR (DIM)
NOTE
SPEC DT=0.125/LENGTH=20/PRTPER=1/PLTPER=1
PRINT TA,QA,TF,QF,O2,D1
PLOT TA=T(10,70)/QA=Q(0,15000)

```
PLOT TF = C(10,70)/QF = F(0,15000)
PLOT D2 = E(10000,30000)/P2 = P(30000,70000)
RUN BASE
C    FFTTF = 22
RUN FREEWAY CONSTRUCTION
QUIT
```

A.7   Impacts of Transportation in a Closed Economy

```
NOTE *** IMPACTS OF TRANSPORTATION IN A CLOSED ECONOMY ***
NOTE
L    IC.K = IC.J + (DT)(CI.JK-CD.JK)
N    IC = ICN
NOTE IC-INDUSTRIAL CAPITAL ($)
C    ICN = 84E9
NOTE ICN-INDUSTRIAL CAPITAL INITIAL VALUE ($)
R    CD.KL = IC.K/ALC
NOTE CD-CAPITAL DEPRECIATION ($/YR)
C    ALC = 16
NOTE ALC-AVERAGE LIFETIME OF CAPITAL (YR)
R    CI.KL = GNP.K*FGNPI + TF.K
NOTE CI-CAPITAL INVESTMENT ($/YR)
C    FGNPI = 0.2
NOTE FGNPI-FRACTION OF GNP INVESTED (DIM)
A    GNP.K = IO.K*(1-FIOI.K)
NOTE GNP-GROSS NATIONAL PRODUCT ($/YR)
A    IO.K = IC.K/COR
NOTE IO-INDUSTRIAL OUTPUT ($/YR)
C    COR = 1.68
NOTE COR-CAPITAL OUTPUT RATIO (YR)
A    FIOI.K = FIOO + FIOT.K
NOTE FIOI-FRACTION OF INDUSTRIAL OUTPUT TO INPUT (DIM)
C    FIOO = 0.4
NOTE FIOO-FRACTION OF INDUSTRIAL OUTPUT TO OTHER INPUTS
A    FIOT.K = FIOTN*TCM.K
NOTE FIOT-FRACTION OF INDUSTRIAL OUTPUT TO TRANSPORTATION
C    FIOTN = 0.1
NOTE FIOTN-INITIAL VALUE FOR FIOT (DIM)
A    TCM.K = 1/TMI.K
NOTE TCM-TRANSPORTATION COST MULTIPLIER (DIM)
A    TMI.K = (1 + FFSR.K)(1 + DCRN)/(1 + DCR.K)
NOTE TMI-TRANSPORTATION MOBILITY INDEX (DIM)
A    FFSR.K = (FFSRH/TS)*TU.K
NOTE FFSR-PERSENTAGE INCREASE IN FREE-FLOW-SPEED
C    FFSRH = 0
NOTE FFSRH-HORIZEN YEAR FFSR (DIM)
C    TS = 10
NOTE TS-TIME SPAN OF THE TRANSPORTATION INVESTMENT (YR)
A    TU.K = CLIP(TIME.K,TS,TS,TIME.K)
NOTE TU-TIME USED FOR THE PROGRAM (YR)
A    DCR.K = DCRN*IO.K/(ION*(1 + CAR.K))
NOTE DCR-DEMAND CAPACITY RATIO (DIM)
```

```
C    DCRN = 1.0
NOTE DCRN-INITIAL DEMAND-CAPACITY RATIO
N    ION = ICN/COR
NOTE ION-INDUTRAIAL OUTPUT INITIAL VALUE ($/YR)
A    CAR.K = (CARH/TS)*TU.K
NOTE CAR-PERCENTAGE INCREASE IN CAPACITY (DIM)
C    CARH = 0
NOTE CARH-HORIZEN YEAR CAR (DIM)
A    TF.K = FGNPT*GNP.K-TI.K
NOTE TF-TRANSPORTATION FUNDS ($)
C    FGNPT = 0.01
NOTE FGNPT-FRACTION OF GNP TO TRANSPORTATION FUNDS
A    TI.K = CLIP(TIP.K,0,TIME.K,SPT)
A    TIP.K = CLIP(0,TI1.K,TIME.K,TS + SPT)
A    TI1.K = (CFFSR + CCAR)/TS
NOTE TI-TRANSPORTATION INVESTMENT ($/YR)
C    SPT = 0
NOTE SPT-STARTING PAYBACK TIME (YR)
N    CFFSR = C1*GNPN*FFSRH
NOTE CFFSR-COST ASSO WITH INCREASING FREE-FLOW-SPEED ($)
C    C1 = 0.05
NOTE C1-COST OF DOUBLING FFS (AS A MULTIPLE OF GNP)
N    GNPN = ION*(1-FIOO-FIOTN)
NOTE GNPN-INITIAL GNP ($)
N    CCAR = C2*GNPN*CARH
NOTE CCAR-COST ASSOCIATED WITH INCREASING CAPACITY ($)
C    C2 = 0.05
NOTE C2-COST OF DOUBLING CAPACITY (AS A MULTIPLE OF GNP)
SPEC DT = 1/LENGTH = 35/PRTPER = 1/PLTPER = 1
PRINT IC,IO,DCR,TMI,TF
PLOT IO = O(48E9,60E9)/DCR = R(0.5,1.3)/TMI = M(0.4,1.6)
RUN
C    FFSRH = 0.15
C    C1 = 0.4
C    C2 = 0.4
C    CARH = 0.15
RUN  SENSITIVITY ANALYSIS
QUIT
```

A.8 Regional Impacts of Transportation

```
NOTE ********* REGIONAL IMPACTS OF TRANSPORTATION *********
NOTE
L    POP.K = POP.J + (DT)(NPG.JK + NIM.JK)
N    POP = POPN
NOTE POP-POPULATION (PERSONS)
C    POPN = 7E6
NOTE POPN-INITIAL POPULATION (PERSONS)
R    NPG.KL = POP.K*NGF
NOTE NPG-NATURAL POPULATION GROWTH (PERSONS)
C    NGF = 0.005
NOTE NGF-NATURAL POPULATION GROWTH FACTOR (DIM)
R    NIM.KL = POP.K*NIMN*APOP.K
NOTE NIM-NET INMIGRATION (PERSONS)
C    NIMN = 0.02
NOTE NIMN-NET INMIGRATION NORMAL
A    APOP.K = TABLE(APOPT,LFJR.K,0,2,0.2)
T    APOPT = 5/4.8/4.2/3.4/2.4/1/-1.8/-2.0/-2.2/-2.4/-2.6
NOTE APOP-ATTRACTIVENESS OF THE REGION TO POPULATION (DIM)
A    LFJR.K = LF.K/J.K
NOTE LFJR-LABORFORCE JOB RATIO (DIM)
A    LF.K = POP.K*LPF
NOTE LF-LABORFORCE (PERSONS)
C    LPF = 0.4
NOTE LPF-LABOR PARTICIPATION FACTOR (DIM)
A    J.K = IC.K/CLR
NOTE J-NUMBER OF JOBS (PERSONS)
C    CLR = 20000
NOTE CLR-CAPITAL LABOR RATIO ($/JOB)
L    IC.K = IC.J + (DT)(CI.JK-CD.JK)
N    IC = ICN
NOTE IC-INDUSTRIAL CAPITAL ($)
C    ICN = 51.41E9
NOTE ICN-INDUSTRIAL CAPITAL INITIAL ($)
R    CD.KL = IC.K/ALC
NOTE CD-CAPITAL DEPRECIATION ($/YR)
C    ALC = 16
NOTE ALC-AVERAGE CAPITAL LIFETIME (YR)
R    CI.KL = CIN*AC.K
NOTE CI-CAPITAL INVESTMENT ($/YR)
C    CIN = 2.779E9
NOTE CIN-CAPITAL INVESTMENT INITIAL ($/YR)
A    AC.K = AC1.K*AC2.K
A    AC1.K = TABLE(AC1T,LFJR.K,0,2,0.2)
```

```
T    AC1T = .2/.25/.35/.5/.7/1/1.35/1.6/1.8/1.95/2
A    AC2.K = TABLE(AC2T,FIOT.K,0,0.2,0.02)
T    AC2T = 1.5/1.4/1.3/1.2/1.1/1/.9/.8/.7/.6/.5
NOTE AC-ATTRACTIVENESS OF THE REGION TO CAPITAL (DIM)
A    FIOT.K = FIOTN*TCM.K
NOTE FIOT-FRACTION OF INDUSTRIAL OUTPUT TO TRANSPORT (DIM)
C    FIOTN = 0.1
NOTE FIOTN-NORMAL VALUE FOR FIOT
A    TCM.K = (1 + DCR.K)/(FFSM*(1 + DCRN))
NOTE TCM-TRANSPORTATION COST MULTIPLIER (DIM)
C    DCRN = 1.0
NOTE DCRN-DEMAND CAPACITY RATIO NORMAL (DIM)
C    FFSM = 1.0
NOTE FFSM-FREE FLOW SPEED MULTIPLIER (DIM)
A    DCR.K = DCRN*((IC.K/ICN) + (POP.K/POPN)-1)/CAM
NOTE DCR-DEMAND CAPACITY RATIO
C    CAM = 1.0
NOTE CAM-CAPACITY MULTIPLIER (DIM)
A    UR.K = 1-(J.K/LF.K)
NOTE UR-UNEMPLOYMENT RATE (DIM)
A    IO.K = IC.K/COR
NOTE IO-INDUSTRIAL OUTPUT ($)
C    COR = 2
NOTE COR-CAPITAL OUTPUT RATIO (YR)
SPEC DT = 1/LENGTH = 60/PRTPER = 2/PLTPER = 2
PRINT POP,IO,DCR,UR,TCM
PLOT POP = P(6E6,10E6)/IO = O(20E9,28E9)/DCR = D(0.7,1.5)/UR = U(0,0.2)
RUN
C CAM = 1.3
RUN INCREASING CAPACITY
C FFSM = 1.3
RUN INCREASING SPEED
QUIT
```

VITA

Guoxiong Huang was born on November 10, 1962. He received the Bachelor of Science degree from Tongji University in Shanghai in 1982 and became a faculty member of the Wuhan Urban Construction Institute where he served as a researcher and then a lecturer. He joined Xian Highway Institute and earned a Master of Science degree in Traffic Engineering in 1988.

He has taught Traffic and Transportation Engineering to undergraduate students in several universities, including Virginia Polytechnic Institute and State University and Xian Highway Institute. He is a member of the Institute of Transportation Engineers and the Phi Kappa Phi Honor Society.