

**Methodology for Evaluating Transportation-Induced Regional Development**

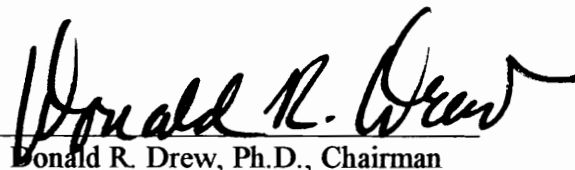
by

Seung B. Ahn

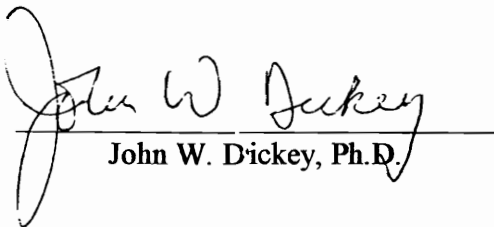
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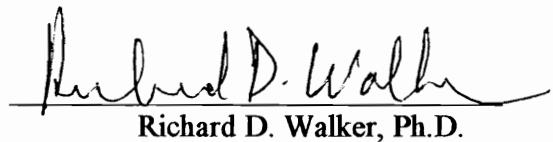
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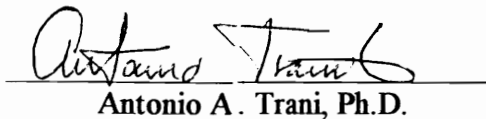
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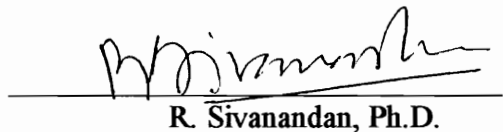
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# **Methodology for Evaluating Transportation-Induced Regional Development**

by

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**Civil Engineering**

**(ABSTRACT)**

There has long been a recognition that efficient transport plays a key role in supporting a dynamic economy and a high quality of life. However, traffic increases along with population and income, and traffic congestion and accidents are negative results of this increase, as is environmental damage. There has been a need for a methodology to evaluate user, nonuser benefits and the environmental impacts of transportation investments and policies through rational, objective scientific analysis.

This research aims to develop a methodology, termed the Transportation/Development Methodology, for evaluating transportation policies and projects, and also, to clarify the relationships between transportation investment and economic productivity. Transportation/Development Methodology, or TDM, conceptualizes the role of transportation in a broad socioeconomic and environmental context and enables scenario analysis.

In addition to the development of the TDM, this research comprises a critique and discussion of the primary methodologies used for evaluating transportation effects. In both transportation and development management, policy processes tend to proceed in nearly total isolation from ongoing planning activities in estimating impacts induced by transportation investments and policies. To overcome that imbalance for current models, TDM uses a system dynamics approach and adopts concepts from other methodologies, such as Input-Output analysis, the Lowry Model, and the Urban Transportation Planning Process (UTPP).

Finally, this research demonstrates the TDM by applying it in an analysis of a “real-life” situation, the Interstate 81 corridor, which goes through six states of the United States as a backbone of both passenger and freight transport. Development scenarios for improving regional economies, as well as for giving better service and reducing congestion, are analyzed by the TDM in order to evaluate their effectiveness. Application of the TDM to the I-81 corridor generates significant conclusions that would not have been possible using existing methodologies.



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## 1.0 INTRODUCTION

There has long been a recognition that efficient transportation systems play a key role in supporting the economy and society, sometimes acting as catalysts for regional and national economies (Drew et al., 1996). In the U.S., an increase in real income and a great wave of suburbanization following the general prosperity since World War II enabled more people to own automobiles (Levy, 1991). The accelerated urbanization of societies increases the demands of both passenger and freight transport (Banister and Button, 1993). Although transportation systems are essential to the efficient functioning of national and regional economies, they can have negative impacts such as traffic congestion, accidents, and environmental damage (Drew, 1994a).

Papacostas and Prevedouros (1993) indicated that nationally, nearly 2 billion potentially productive hours are wasted annually due to traffic congestion, and a substantial portion of delays are due to unpredictable events such as disabled vehicles, accidents, and bad weather conditions. They also estimated that these delays cost over \$16 billion in 1989 in lost productivity, and by the turn of the century this estimate may reach \$90 billion if nothing is done to reverse the causes of congestion. Roadway accidents' costs reached \$65 billion in 1989 and the costs are the result of 45,450 deaths and hundreds of thousands of injured, and includes medical expenses, property damage, lost time, and so forth (Papacostas and Prevedouros, 1993).



Transportation has taken on new dimension because of modal shifts to aviation and automobile travel, both of which are environmentally intrusive, and on the freight side, the increased dominance of trucking is due to the nature of the goods transported and the increased sophistication of logistics and inventory management (Drew et al., 1996). Vehicles with internal combustion engines are major contributors to air pollution. In 1992, transportation emissions in the U.S. accounted for 77 percent of carbon monoxide (CO), 36 percent of Volatile Organic Compounds (VOCs), 45 percent of nitrogen oxides (NO<sub>x</sub>), and 31 percent of lead (Pb), and 28 percent of carbon dioxide (CO<sub>2</sub>). (Bureau of Transportation Statistics, 1995)

In 1993, GDP (Gross Domestic Product) was about \$6.3 trillion, and the portion of GDP attributed to transportation was about \$680 billion in current dollars, accounting for approximately 11 percent of GDP. In 1993, the total spending on transportation was on average \$5,453 for American households, representing about 17.8 percent of total household expenditures (Bureau of Transportation Statistics, 1995). Lack of sufficient transportation facilities can also produce negative effects, and a reduction of the true cost of transport will increase the total amount of goods and services available (Drew, 1994a). On the other hand, over-capitalization of transportation investments, which often never materialize, will be also a burden to society.

The development of highway systems affects transportation, industry, urban development, and environments not only of the region in the system but also of the adjacent regions. A given geographic area needs to discover the appropriate level of transportation facilities in order to maximize its economic potential. It is obvious that highway improvements will improve the level of service (L.O.S) and that the activities of construction will increase jobs, but it is difficult to estimate the extent of the direct, indirect, and induced economic activities and adverse impacts resulting from the flow of development over time. Thus, there has been a need for a methodology to evaluate user, non-user benefits and the environmental impacts of transportation investments and policies through rational, objective scientific analysis. A large scale highway investment requires

carefully-designed impact studies, which need to be done with consideration for the distribution of labor, capital, industry, and other factors. In other words, although improvements in transportation infrastructure directly reduce travel time and travel costs between regions and places, concerns cannot exclude other factors, such as economy, land use, the environment, equity, and distributional effects.

### 1.1. Problem Statement

There has been a need for a new methodology showing relationships among transportation, development, and environments. Recently, the National Cooperative Highway Research Program of the National Research Council announced a request for proposals for Innovations Deserving Exploratory Analysis (IDEA). The primary concern is to evaluate new transportation products and techniques for user, non-user and environmental impacts.

In its preliminary announcement about transportation research projects for FY 1995, the NCHRP (National Cooperative Highway Research Program) points out:

Transportation-infrastructure investment has played a key role in the development of the nation's economy. The manner in which transportation investment affects economic productivity has been the subject of many studies, and although the relationship between these investments and productivity is not well understood, the output of these studies provides decision-makers with the information needed to make choices in determining which transportation investments should be supported. .... Therefore, research is needed to identify stakeholders; analyze, describe, and critique pertinent research; identify gaps, contradictions, and inconsistencies in information.

Suggested research areas covering theoretical approaches, and applied techniques are the following (TRB, 1994): "1. Macro-level national investment analysis; 2.

Regional and state investment analysis; 3. Economic productivity impacts of project-level investments; 4. Intermodal investment comparisons; 5. The economic productivity consequences of (a) tradeoffs between urban livability, environmental impacts, and transportation-user benefits; (b) community settlement patterns; (c) telecommuting; (d) technological improvements; and (e) international trade and NAFTA; and 6. Impact of governmental policy on the private sector.” The research by NCHRP addresses two important issues: 1) the relationship between transportation investment, economic development, and environmental impacts; and 2) the methodology for evaluating transportation projects and programs.

Many models have been developed and applied to transportation investments and policies. Tools for estimating the effects of different transportation improvements tend to fall into two classes (Drew, 1994a): “(1) models of national and regional economies with a component being the transportation system, and (2) traditional models of various aspects of the development process such as land use models, population models, location models, economic base models and input-output models, which are linked in some way to transportation.” In both transportation and development management, policy processes tend to proceed in nearly total isolation from ongoing planning activities (Drew et al., 1996).

Transportation engineers and planners focus on accurate estimations of travel time, reduction of travel costs, and ultimately user benefits based on the reduction of these. However, transport models neither include nor emphasize socio-economic factors, market analysis, and other factors such as pollution and limited resources. Meanwhile, economists’ interests include industry, products, income, capital and price changes in national, regional, and local economies. They concentrate more on the economic aspect of construction activities because their models are not sensitive to reductions in travel time.

The relationship between transportation investment and regional development has always been a critical issue in various levels of governments and departments of transportation. Recently, sustainability has emerged as a crucial factor in transportation invest-

ment and policies because transportation imposes environmental costs and because of the diminishing availability of land. Besides user benefits, nonuser and environmental impacts need to be considered over time.

## 1.2. Research Objectives and Scope

The primary purpose of this dissertation is the development of a methodology for evaluating transportation policies and projects. This research also aims to clarify the relationships between transportation investment and economic productivity. Transportation/Development Methodology, which will be developed in this research, will conceptualize the role of transportation in a broad socioeconomic and environmental context so as to perform trade-off analysis. Transportation/Development Methodology (TDM), is an attempt to answer the following question: What would be the economic impact A, the social impact B, the demographic impact C, the land use impact D, the environmental impact E, and the user-benefit F over the geographic scale G for a transportation investment H on mode I at time T? (Drew et al., 1996)

TDM will be modeled on a System Dynamics approach, because of its strength in dealing with feedback between transportation, economic and environmental linkages. A conventional System Dynamics approach provides backgrounds for several sectors in a regional economic analysis. Concepts of other related methodologies also need to be considered and adopted in TDM where appropriate. Multiregional Transportation/Development Methodology (MTDM) will be developed for multiregional analysis, covering distributional effects and equity among regions. TDM, including MTDM, will be illustrated using simulation results of various transportation scenarios and policies.

In addition to the development of TDM. This research will comprise a critique and discussion of promising methodologies used for evaluating transportation effects for

consideration for inclusion in TDM. Components of these methodologies will be used both directly and indirectly in developing TDM.

Finally, this research aims to demonstrate TDM by applying it in an analysis of the Interstate 81 corridor. Interstate highway 81 (I-81, hereafter) goes through six states of the U.S., as a backbone of both passenger and freight transport. The I-81 corridor council and committee are currently engaged in planning the future development of highway system and regional development along the I-81 corridor. Subjects for debate are: opposition by residents, environmental deterioration, and distributional effects and budget problems. In addition, Intelligent Transportation Systems (ITS) has been debated in the context of the corridor. It has the potential of “improving safety, reducing congestion, enhancing mobility, minimizing environmental impact, saving energy, and promoting economic productivity in transport systems (ITS America, 1994).”

Development scenarios with transportation policies are needed in order to make the proper decisions to improve regional economies as well as to give better service and reduce congestion along the I-81 corridor. The study of the transportation effects in the I-81 corridor requires a broad examination of regional growth, distributional effects and environmental impacts among regions along the corridor, including investment opportunities. Analyses of scenarios and policies can supply information for the decision maker and the society. TDM will offer a methodology for testing and evaluating scenarios of transportation policy and investment in the I-81 corridor.

### 1.3. Dissertation Overview

This dissertation is comprised of seven chapters. Following the introductory first chapter, Chapter 2 provides the theoretical backgrounds of regional and multiregional I-O analyses, including how they have been applied to transportation problems. In Chapter 3,

the systems approach is introduced. It covers the concepts of the system, system dynamics, and feedback structures. The system dynamics approach is explored and compared to other methodologies related to transportation impacts, and it is shown how it can be incorporated into the following methodologies: UTPP, the Lowry model, and input-output analysis. Chapter 4 provides tools for analyzing transportation impacts. Cost-benefit analysis is used to assess user benefits. Sensitivity analysis with dynamic behavior and time effects is used for non-user benefits and environmental impacts concerning pollution.

Chapter 5 explores and simulates the causal structure of Transportation /Development Methodology (TDM). TDM is developed to estimate the regional socio-economic and environmental effects of transportation induced development. TDM is modeled in a System Dynamics approach, which includes several sectors from “urban socio-economic structure” and “urban technological systems” in a regional economic analysis: 1) demographic sector, 2) regional economy sector, 3) employment sector, 4) land use sector, 5) transportation sector, and 6) environment sector. Multiregional TDM is based on the concept of interregional flows such as migration, capital flow, accessibility to transportation, and interregional trade flow in economics.

In Chapter 6, scenarios for the interstate-81 corridor are established and simulated based on TDM. The purpose of simulation is to show scenarios of how Intelligent Transportation Systems (ITS) technologies affect regions along the corridor. The scenarios are based on the following: expansion of lanes, exclusive truckways (CVO), ATMS deployment, and AVCS technologies (Hybrid Personal Maglev). The final chapter reviews conclusions and points out areas for further research.

## 2.0. INPUT OUTPUT ANALYSIS

During the International Conference on Transportation and Economic Development, held by the Transportation Research Board (TRB) in 1989, several models were introduced. Among these, input-output analysis was often adopted by researchers. Input-output analysis (I-O analysis, hereafter) shows the behavior of an economic system by demonstrating the interrelationships among industry sectors. RIMS II (Regional Industrial Multiplier System) and regional coefficients in a practical section were introduced to measure transportation impacts. Compared to econometrics and general equilibrium analysis, I-O analysis has merit in that it covers detailed information about industry and easily identifies regional coefficients and multipliers for output, earnings and employment, supported by the Bureau of Economic Analysis. Thus transportation planners can easily use I-O analysis for measuring regional impacts of construction activities.

This chapter comprises three sections: the foundations of input-output analysis, regional input-output analyses, and input-output analysis of transportation impacts. The first section covers the theoretical backgrounds of static, dynamic, social accounting, linear programming, and environmental considerations. The second section shows the practical use of regional input-output analysis and many-region models such as interregional and multiregional models. The final section covers how the regional input-output analysis has been applied to transportation impacts.

## 2.1. Foundations of Input Output Analysis

The empirically based theoretical work of Leontief and some experimental extensions of this work into regional applications by others have resulted in the development of “input-output analysis” for measuring interindustry relationships in a given spatial setting - localized, regional, or national (Chapin and Kaiser, 1979). Leontief (1986) characterizes Input-Output analysis as “a method of systematically quantifying the mutual interrelationships among the various sectors of a complex economic system.” Input-output analysis (I-O analysis) has been one of the most typical approaches to the understanding of the secondary impacts of public development projects and programs as well as the structure of regional economies (Chapin and Kaiser, 1979).

Initially, Leontief developed the I-O model for a closed national economy for the U.S. Regional and multiregional I-O models were developed later, and are more open as small scale versions than the national model. Direct survey data are ideal for those models, but this is a time-consuming and expensive process. Available alternatives can be found through the national planning commission or the economic ministry when direct survey data are not available (Dickey and Miller, 1984).

### 2.1.1. Static I-O Analysis

The computational procedure in I-O analysis is based on matrix algebra. The advent of the computer has made it possible to calculate matrix inversion, multiplication, addition and subtraction in a very short time. In doing an input-output study, it is necessary to produce input-output tables and technical coefficients.



The input-output table of the U.S. economy was published by Leontief in 1936. It describes “the flow of goods and services between all the individual sectors of a national economy over a stated period of time” (Leontief, 1986). In other words, it shows the interrelations among sectors which purchase goods and services from other sectors and which in turn produce goods and services which are sold to others. The input coefficient of the product of sector  $i$  into sector  $j$  as a technical coefficient is:

$$a_{ij} = \frac{x_{ij}}{x_i} \quad (2.1)$$

where  $x_i$  is the physical output of sector  $i$  and

$x_{ij}$  is the amount of the product of sector  $i$  absorbed by sector  $j$

The static I-O model for a single region is well explained by Wilson (1974), as follows. The structure of the total product of industry  $i$  in some time period for a single region,  $x_i$ , is

$$\sum_{j=1}^n x_{ij} + y_i = x_i \quad (2.2)$$

where  $x_i$  is the total product of industry  $m$  in some time period,

$y_i$  is the amount consumed by the final demand sector,

$n$  is the total number of sectors.

As stated in equation (2.1), the coefficient, which is a constant, is as follows:

$$a_{ij} = \frac{x_{ij}}{x_i} \quad (2.3)$$

Then the equation (2.3) enables replacing  $x_{ij}$  by  $a_{ij}x_j$ ,

$$\sum_{j=1}^n a_{ij}x_j + y_i = x_i \quad (2.4)$$

This can be rewritten as

$$\sum_{i=1}^n (\delta_{ij} - a_{ij})x_j = y_i \quad (2.5)$$

where  $\delta_{ij}$  is a kronecker delta ( $\delta_{ij} = 1$  if  $i = j$ ,  $0$  otherwise).

Then the equation (2.5) can be expressed in matrix notation as

$$(I - a)X = Y \quad (2.6)$$

and the equation (2.6) can be replaced by

$$X = (I - a)^{-1}Y \quad (2.7)$$

If we expand the equation (2.7), then we get

$$X = (I + a + a^2 + a^3 + \dots)Y \quad (2.8)$$

where  $aY$  is the amount of products directly demanded by the intermediate demand sector.

To satisfy the equilibrium, each price needs to be:

$$p_j x_j = \sum_{i=1}^n p_i x_{ij} + w_j \quad (2.9)$$

where  $p_j$  is the price of commodity  $j$ , and  $w_j$  total value added of industry  $j$  (Toyomane, 1988). We have the following by dividing (2.9) by  $x_j$ :

$$p = \sum_{i=1}^n p_i a_{ij} + v_j \quad (2.10)$$

where  $v_j = w_j / x_j$ , which means value added per unit of commodity  $j$ . Equation (2.10) can be rewritten:

$$p = pA + v \quad (2.11)$$

where  $p$  and  $v$  are the row vector of  $p_i$ 's and  $v_i$ 's respectively.

Chiang (1984) indicates that some assumptions are necessary to simplify the problem for an input-output model. These assumptions are critical limitations in real world problems: 1) Each industry produces only one homogeneous commodity; 2) Each industry uses a fixed input ratio; 3) Production in every industry is subject to constant returns to scale.

### 2.1.2. Dynamic I-O Analysis

Leontief and others' work extended to dynamic I-O analysis from static I-O analysis. The ordinary input-output equations are

$$x_{it} - \sum_{j=1}^n a_{ij} x_{jt} - \sum_{j=1}^n b_{ij} (x_{j,t+1} - x_{jt}) = y_{it} \quad (i = 1, \dots, n) \quad (2.12)$$

where  $n$  = number of sectors

$x_{it}$  = total output for sector  $i$  in period  $t$ ,

$y_{it}$  = final demand for sector  $i$  in period  $t$ ,

$a_{ij}$  = the current input coefficients for capital stock produced in sector  $i$

and used in sector  $j$ , and

$b_{ij}$  = the coefficients for capital stock produced in sector  $i$  and used in

sector  $j$ .

For a dynamic approach, a growth rate  $\lambda$  is added.

$$x_{it} = x_{it-1}(1 + \lambda) \quad (2.13)$$

According to Johansen (1986), the following equations must be satisfied:

$$x_{it} - \sum_{j=1}^n a_{ij} x_{jt} - \lambda \sum_{j=1}^n b_{ij} x_{jt} = 0 \quad (i = 1, \dots, n) \quad (2.14)$$

The value of  $\lambda$  is determined as the real positive root of the equation

$$|I - A - \lambda B| = 0 \quad (2.15)$$

where  $I$  is the unit matrix,

$A$  is the matrix of  $a_{ij}$ ,

$B$  is the matrix of  $b_{ij}$ .

Equation (2.12) can be written in the following equation:

$$X(t) = AX(t) + B(X(t+1) - X(t)) + f(t) \quad (2.16)$$

where  $f(t)$  is the portion of output  $X(t)$  that goes to final consumption. If we let

$$X(t+1) - X(t) = F(D(t) - f(t)) \quad (2.17)$$

where  $D(t)$  represents consumer demand and  $F$  the adjustment factor of production to demand-supply discrepancy (Sohn, 1986). Then,

$$f(t) = (I - BF)^{-1}(I - A)X(t) - (I - BF)^{-1}BFD(t) \quad (2.18)$$

In dynamic equilibrium, if an steady state solution exists, equation (2.18) gives us the following

$$X(t) = (I - A)^{-1}D(t) \quad (2.19)$$

If inventories are negligible ( $B = 0$ ), then equation (2.19) can be

$$X(t) = (I - A)^{-1}f(t) \quad (2.20)$$

As the dynamic I-O model portrays the time path behavior, it is more policy sensitive than the static I-O model. However, “dynamic” formulations cannot be automatically used for long-term forecasting because input and capital coefficients are constant in the dynamic I-O model (Toyomane, 1988). In other words, it does not include any change of industry structure by interacting with demographic, social, and environmental systems as well as technological changes.

### 2.1.3. Multiplier Analysis

From the static I-O analysis, the total output,  $X$ , is

$$X = (I - A)^{-1}Y \quad (2.21)$$

When we consider the household sector as endogenous, the multiplier can be exaggerated; therefore, we need to adjust the output multiplier properly. Various kinds of multipliers can be obtained based on the above equation, including employment, total income, resource use, and pollution. For example, employment can be estimated by:

$$E = eX = e(I - A)^{-1}Y \quad (2.22)$$

where  $X$  is a vector of economic outputs,  $Y$  is a vector of final demands,  $E$  is total employment,  $A$  is a matrix of technological coefficients,  $e$  is a vector of employment per

dollar output by industry. By the same token, we can estimate resource use  $R$ , pollution  $P$ , and total income  $I$ :

$$R = r(I - A)^{-1}Y \quad (2.23)$$

$$P = p(I - A)^{-1}Y \quad (2.24)$$

$$I = i(I - A)^{-1}Y \quad (2.25)$$

where  $i$  is a vector of income per dollar output by industry,  $r$  is a matrix of coefficients for resource use, and  $p$  is a matrix of pollution in various types of sectors.

Sectoral multipliers can be estimated in an input-output model. Several multipliers can be obtained for each sector, among which output (sales), income, value added, and employment are common. Other multipliers such as energy and pollution can be added with additional data. There are several types of multipliers: type I multipliers, type II multipliers, and truncated multipliers (Miller and Blair, 1985). The differences among several types of multipliers are based on the effects they cover.

There can be direct effects, indirect effects and induced effects. Direct effects come from the original, exogenous, change in a level. Indirect effects represent the subsequent changes in the economy due to backward linkages among industrial sectors, and induced effects represent the subsequent changes in the economy due to changes in household spending “induced” by the direct and indirect effects. Type I multipliers measure the multiplier effects of industrial sectors only, which include direct and indirect effects. Type II multipliers measure the multiplier effects of the industrial sector and household spending. Truncated multipliers (Type III multipliers) are used to eliminate double-counting of the multiplier effects from income change and household spending.

The final demand as well as the total outputs can cause the multiplier effect (or the externalities). For example, Sage (1977) differentiated taxes as two types: a function of total output (an industrial tax) and total demand (a sales taxes on the consumer). Thus, the general equations for the I-O analysis can be (Sage, 1977):

$$X = AX + BY \quad (2.26)$$

The equation (2.23) can be rewritten as:

$$X = (I - A)^{-1}BY \quad (2.27)$$

#### 2.1.4. Linear Programming, Environmental Considerations, and Social Accounting

J. Cumberland placed monetary values on environmental effects, which was the first application in an extended interindustry model (Richardson, 1972). Isard and Langford (1971) suggested environmental quality and standardization using input-output analysis. Economic activities, ecologic processes, and economic and ecologic commodities are used for the I-O matrix. To discover various pollutants and their levels, economic activities, and the ecologic processes for land, air, and marine contexts can be collected for I-O analysis.

Leontief (1986) provided a structural matrix of a national economy with pollution output. Including the anti-pollution sector as endogenous, he tested several anti-pollution scenarios. He (1986) also showed multiplier impacts of air pollution by SIC (Standard Industrial Classification) industries empirically. Hamada (1991) made a long-term projection for the industrial and environmental aspects of the Hokkaido economy based on the input-output model with a small-scale macroeconometric model. Emissions by the industrial activities are considered, such as: biological oxygen demand (BOD), nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>), and carbon dioxide (COD).

Multiplier effects in I-O analysis can be easily exaggerated in two ways: the endogenous household sector, and no constraints for more demand. Although conventional I-O analysis assumes unlimited supplies of intermediate inputs, resources, labor, capital, and pollution can be restraining factors. A linear programming approach to input-output analysis has been developed in both static and dynamic models.

Based on the objective function, the following equations are required:

$$(I - A)X - Y = 0, \quad (2.28)$$

$$Y \leq Y', \quad (2.29)$$

$$cX \leq c' \quad (2.30)$$

where  $Y'$  is a vector of final demand and  $c$  and  $c'$  are vectors of a constraint requirement matrix and constraint availability, respectively. The equation (2.30) applies for special cases of constraints such as: resources, energy, and water availability (Hewings, 1985 and Richardson, 1972). The constraints can be a function of both  $X$  and  $Y$ , and various approaches can be made with concepts of linear programming.

The development of a “social accounting system”, including input-output analysis as a subset of the system, is needed to trace impacts on a firm-by-firm or consumer-by-consumer basis (Hewings, 1985). Social accounting covers demography, economics, and capital. Social Accounting Matrices (SAM, thereafter) are different from I-O analysis in that a multiplier matrix, known as the Leontief inverse, links all endogenous income levels (Pyatt and Round, 1985). Hewings and Maden (1995) indicates the importance of Social Accounts Matrices in generating Computable General Equilibrium models (CGE).

Although I-O models, SAM, and General Equilibrium models have somewhat different theoretical backgrounds and tables, analyses in practice are quite similar. Most models include demography, price, capital, income, and others, regardless of whether they are endogenous or exogenous, particularly for a long-run simulation. For example, the structure of the simulation model for Indonesia by Toyomane (1988) includes public and private investment plans, income, housing, education, population, labor and interregional traffic flow based on multiregional I-O analysis.

## 2.2. Regional I-O Analysis

### 2.2.1. Regional I-O Analysis

Because a survey-based regional I-O model involves a burden in expenditures, the development of I-O tables on regional levels has relied on non-survey and partial survey techniques.

In non-survey techniques, the major efforts have been directed toward the modification of national tables (Hewings, 1985). As one of the successful non-survey techniques, the simple location quotient approach is rooted in an economic-based model (or basic and non-basic technique). The location quotient for industry  $i$  in region  $r$  is:

$$lq_i = \frac{[X_i(r) / \sum_i X_i(r)]}{[X_i(n) / \sum_i X_i(n)]} \quad (2.31)$$

the proportionate share of industry  $i$  in the region  $r$  is compared to the share of  $i$  in the nation. The data used for the  $X$ 's usually constitute either employment or output figures:

$$\begin{aligned} r_{ij} &= a_{ij}(n) && \text{if } lq_i \geq 1 \\ r_{ij} &= a_{ij}(n)lq_i && \text{if } lq_i < 1 \end{aligned} \quad (2.32)$$

The Bureau of Economic Analysis (BEA) developed a method for estimating regional I-O multipliers, known as RIMS (Regional Industrial Multiplier System) in the mid-1970's, and RIMS II in the mid-1980's (BEA, 1992). RIMS and RIMS II were based on Garnick's and Drake's works. Two data sources are mainly used in RIMS II (BEA, 1992): (1) BEA's national I-O table for U.S. industries and, (2) BEA's four-digit Standard Industrial Classification (SIC) county wage-and-salary data to adjust the national I-O table to show a region's industrial structure and trading patterns. I-O multipliers from RIMS II can be used to estimate the impacts of project and program expenditures by industry on regional output, earnings, and employment (BEA, 1992).



Stevens et al. (1980) have developed a technique for modifying national technical coefficients using Regional Purchase Coefficients (RPCs), which can be obtained from various quotients such as the wages in the region. They (1980, 1981) applied this technique to highway investment in several states.

As non-survey techniques are rather unreliable, partial survey techniques have been developed. The RAS or Biproportional technique, developed by Stone, can be used for the regional level by incorporating regional surveys to the national coefficient matrix. The survey includes two questions: “the volume of sales made to other firms within the region, and the volume of purchases made from other firms within the region (Hewings, 1985).” By adjusting the fabrication effect and the substitution effect, regional technical coefficients can be obtained in the RAS technique. The rows-only method, the exports-only method and hybrid methods are also partial techniques.

### 2.2.2. Interregional I-O Model

In an open economy, e.g., a regional economy, additional demands are expected as feedback effects. Interregional and multiregional models were developed to consider the interregional feedback effects in two or more regions. The accounting balance equations can be given by the following (Toyomane, 1988):

$$x_i^r = \sum_{s=1}^R \sum_{j=1}^N x_{ij}^{rs} + y_i^r \quad r = 1, 2, \dots, R \text{ and } i = 1, 2, \dots, N \quad (2.33)$$

where  $x_i^r$  denotes total output of industry  $i$  in region  $r$ . In the same pattern of static I-O analysis, we can get

$$\Delta X = (I - R)^{-1} \Delta Y \quad (2.34)$$

The interregional model can be presented for the two-region case (Hewings, 1985).

$$\begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \quad (2.35)$$

The solution is as follows where B matrices are the partitioned components of the Leontief inverse matrix of the solution.

$$\begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \quad (2.36)$$

Then the inverse matrix of B is:

$$B^{-1} = \begin{bmatrix} [B_{11} - B_{12}B_{22}^{-1}B_{21}]^{-1} & -B_{11}^{-1}B_{12}[B_{22} - B_{21}B_{11}^{-1}B_{12}]^{-1} \\ -B_{22}^{-1}B_{21}[B_{11} - B_{12}B_{22}^{-1}B_{21}]^{-1} & [B_{22} - B_{21}B_{11}^{-1}B_{12}]^{-1} \end{bmatrix} \quad (2.37)$$

If we produce the solution for  $X_1$ , we have:

$$\begin{aligned} X_1 &= B_{11}Y_1 + B_{12}Y_2 \\ &= [(I - R_{11}) - R_{12}(I - R_{22})^{-1}R_{21}]^{-1}Y_1 + [(I - R_{11}) - R_{12}(I - R_{22})^{-1}R_{21}]^{-1}R_{12}(I - R_{22})^{-1}Y_2 \end{aligned} \quad (2.38)$$

$$\begin{aligned} X_2 &= B_{22}Y_2 + B_{21}Y_1 \\ &= [(I - R_{22}) - R_{21}(I - R_{11})^{-1}R_{12}]^{-1}Y_2 + [(I - R_{22}) - R_{21}(I - R_{11})^{-1}R_{12}]^{-1}R_{21}(I - R_{11})^{-1}Y_1 \end{aligned} \quad (2.39)$$

The IRIO model has limitations in two respects (Toyomane, 1988): 1) it requires very detailed data, and; 2) a fixed supply pattern which does not allow any substitution between regions.

### 2.2.3. Multiregional I-O Analysis

To overcome the problems of the IRIO model, Multiregional I-O (MRIO) models have been developed. The column coefficient MRIO (Chenery-Moses) model, the row coefficient MRIO model by Polenske, and the gravity model by Leontief and Strout are frequently used. Other MRIO models include the linear programming model by Moses

and the entropy maximizing model (Wilson, 1974). Table 2.1 brings the comparison of three MRIO models.

Table 2.1. Summary of the Multiregional Input-Output Models

	<i>Row coefficient model</i>	<i>column coefficient model</i>	<i>Gravity model</i>
Trade coefficient equation	$x_i^{gh} = r_i^{gh} x_i^{g0}$	$x_i^{gh} = c_i^{gh} x_i^{0h}$	$x_i^{gh} = \frac{x_i^{g0} x_i^{0h}}{x_i^{00}} q_i^{gh}$
Equation system in matrix form	$R' \Delta X = \hat{A} \Delta X + \Delta Y$ $(R' - \hat{A}) \Delta X = \Delta Y$ $\Delta X = (R' - \hat{A})^{-1} \Delta Y$	$\Delta X = C(\hat{A} \Delta X + \Delta Y)$ $(I - C\hat{A}) \Delta X = C \Delta Y$ $\Delta X = (I - C\hat{A})^{-1} C \Delta Y$ or $\Delta X = (C^{-1} - \hat{A})^{-1} \Delta Y$	$T' \Delta X = S(\hat{A} \Delta X + \Delta Y)$ $(T' - S\hat{A}) \Delta X = S \Delta Y$ $\Delta X = (T' - S\hat{A})^{-1} S \Delta Y$ or $\Delta X = (S^{-1} T' - \hat{A})^{-1} \Delta Y$

Source: Polenske, 1989.

In addition to the gravity model in Table 2.1., the elements S and T' in the gravity model are defined as:

$$s_i^{gh} = x_i^{g0} \left[ 1 - \frac{x_i^{00} x_i^{gh}}{x_i^{g0} x_i^{0h}} \right] \quad \text{for } g \neq k, \quad s_i^{gh} = 1 \quad \text{for } g = k \quad (2.40)$$

$$t_i^{gh} = x_i^{0g} \left[ 1 - \frac{x_i^{00} x_i^{hg}}{x_i^{h0} x_i^{0g}} \right] \quad \text{for } h \neq k, \quad t_i^{gh} = 1 \quad \text{for } h = k \quad (2.41)$$

where k can be assigned arbitrarily (Polenske, 1989).

Two sets of data are required for the column-coefficient multiregional I-O model: (1) a set of regional input output tables by each region (regional technical coefficients), and (2) a set of interregional trade flow tables by each commodity. A set of final demands for each industry in each region is also needed to estimate future impacts.

$$X = (I - C\hat{A})^{-1} CY \quad (2.42)$$

Where X and Y are vectors of dimension  $mn \times 1$  and C and A matrices of  $mn \times mn$ .

The estimated level of intermediate demands,  $D$ , is:

$$D = \hat{A}cmX^t \quad (2.43)$$

where  $cm$  stands for matrix column multiplication and  $t$  is the transpose of the matrix.

Then, a vector of intermediate demands,  $D^*$ , is the sum of the elements in each row of the intermediate demand matrix. Finally, the estimated interregional trade flows,  $T$ , can be obtained (Polenske, 1980).

$$T = CcmG^t \quad \text{where } G = D^* + Y \quad (2.44)$$

Miller and Blair (1985) give an example of a column-coefficient MRIO model for two regions and two sectors. Trade tables are necessary in the analysis:

Table 2.2. Trade coefficients table

<i>Destination (D)</i> <i>Origin (O)</i>	<i>Region 1</i>	<i>Region 2</i>
Region 1	$Z_i^{11}$	$Z_i^{12}$
Region 2	$Z_i^{21}$	$Z_i^{22}$

Column sum of  $i$ th industry means the input from all the regions. For region 2:

$$T_i^2 = Z_i^{12} + Z_i^{22} \quad (2.45)$$

Interregional trade coefficients are as follows:

$$C_i^{12} = \frac{Z_i^{12}}{T_i^2} \quad (2.46)$$

The column vector:

$$C^{12} = \begin{bmatrix} C_1^{12} \\ C_2^{12} \end{bmatrix} \quad (2.47)$$

It can be rewritten as follows:

$$\hat{C}^{12} = \begin{bmatrix} C_1^{12} & | & 0 \\ \hline 0 & | & C_2^{12} \end{bmatrix} \quad (2.48)$$

The tables required for the MRIO analysis are the following:

$$A^L = \begin{bmatrix} a_{11}^L & a_{12}^L \\ a_{21}^L & a_{22}^L \end{bmatrix}, \quad A^M = \begin{bmatrix} a_{11}^M & a_{12}^M \\ a_{21}^M & a_{22}^M \end{bmatrix} \quad (2.49)$$

$$\hat{C}^{LL} = \begin{bmatrix} C_1^{LL} & 0 \\ 0 & C_2^{LL} \end{bmatrix}, \quad \hat{C}^{LM} = \begin{bmatrix} C_1^{LM} & 0 \\ 0 & C_2^{LM} \end{bmatrix}$$

$$\hat{C}^{ML} = \begin{bmatrix} C_1^{ML} & 0 \\ 0 & C_2^{ML} \end{bmatrix}, \quad \hat{C}^{MM} = \begin{bmatrix} C_1^{MM} & 0 \\ 0 & C_2^{MM} \end{bmatrix} \quad (2.50)$$

From the Interregional I-O Model:

$$(I - \hat{C}^{LL} A^L) X^L - \hat{C}^{LM} A^M X^M = \hat{C}^{LL} Y^L + C^{LM} Y^M,$$

$$-\hat{C}^{ML} A^L X^L + (I - \hat{C}^{MM} A^M) X^M = \hat{C}^{ML} Y^L + C^{MM} Y^M \quad (2.51)$$

For a two-by-two matrix:

$$\hat{A} = \begin{bmatrix} A^L & 0 \\ 0 & A^M \end{bmatrix}, \quad C = \begin{bmatrix} \hat{C}^{LL} & \hat{C}^{LM} \\ \hat{C}^{ML} & \hat{C}^{MM} \end{bmatrix} \quad (2.52)$$

$$X = \begin{bmatrix} X^L \\ X^M \end{bmatrix}, \quad Y = \begin{bmatrix} Y^L \\ Y^M \end{bmatrix} \quad (2.53)$$

Therefore:

$$(I - C\hat{A})X = CY$$

$$X = (I - C\hat{A})^{-1}CY \quad \text{or} \quad X = (C^{-1} - \hat{A})^{-1}Y \quad (2.54)$$

### 2.3. Input-Output Analysis of Transportation Impacts

In dealing with economic impacts by transportation investments and improvements, several aspects can be considered: construction and maintenance activities, reduction of intraregional and interregional travel time, and changes in interregional trade flows and final demand due to better accessibility and market strength. Measuring the economic impacts of construction activities is quite straightforward compared to other aspects, although a determination must be made about which method to use. However, a problem always exists if we only consider the construction activities of transportation

facilities; in fact, it is almost impossible to do scenario and policy analysis, for example, as to whether to build one more lane, or two or more highway lanes. And further, if we only consider construction and maintenance activities, we can easily ignore the main purpose for the development of infrastructure. The main purpose of transportation improvements should be better accessibility between regions and places in order to reduce congestion or travel time for either passengers or trucking, or both.

Apogee Research, Inc. (1989) refers to production-function models and input-output models as promising methodologies for highway investment and economic development. Production function is used effectively for global analysis, but is not the ideal form for an infrastructure investment due to the difficulty in collecting data on infrastructure capital stock (Apogee Research, Inc., 1989).

The Florida Department of Transportation uses RIMS II to estimate the regional impacts of constructing and operating transportation facilities (The BEA, 1992). Stevens et al. (1980) developed RPCs (Regional Purchase Coefficients) to adjust the national coefficients and estimated direct, indirect and induced effects of transportation investments. They identified “a demand disturbance” as exogenous or discontinuous change, and indicated three kinds of disturbances caused by a new transportation facility: capital formation of the construction of public as well as private facilities, a new facility considered as a new export demand, and the effect on the comparative advantage of the region as a location for economic activity. Polenske and Levy (1975) used a multiregional I-O model to analyze energy and transportation policies. In the above studies, travel costs between regions are not considered.

Using an input-output model by linear programming, Hilewick et al. (1980) investigated highway cost, and investments such as truck travel costs, finally determining industrial locations by costs and agglomeration effects based on the Harris model. The Harris model, also known as the multiregional, multi-industry forecasting (MRMI) model,

was an multiregional econometric model for the U.S. to use in evaluating transportation impacts (Harris Associates Inc., 1974). Politano and Roadifer (1988) developed the modified version of the original model, the BEA RIMS II. By integrating highway data, they estimated transportation costs, savings, and benefits in their model.

Liew and Liew (1984) introduced a Multiregional Variable I-O (MRVIO) model as a case study of the proposed Coosa River Navigation Project. They investigated how reduction in shipping costs affects the economies of four different regions. Based on the RAS-Adjusted-Gravity model, they used concepts of MRIO with modified theoretical backgrounds. Recently, Liew (1995) describes a dynamic Variable Input-Output (VIO2) Model in the proposal for Innovations Deserving Exploratory Analysis (IDEA) of the National Research Council, which computes a long-run transportation cost-related dynamic price and output elasticities as well as dynamic final demand multipliers. Although the above modified I-O analyses considered travel time and costs, they still lack dynamic feedback between transportation systems, economy, population, and environments.

To deal with transportation problems, concepts and ideas may be used from modified or extended input-output analyses such as dynamic, multiregional, and linear-programming input-output analyses. Dynamic I-O analysis introduces flexibility with respect to time and is often used to include the capital formation effects of long-run changes in final demand (Pratt et al., 1976). In highway development, construction activities continue for several years and maintenance activities will go on after construction, which needs to be treated as dynamic. Interregional trade flows are significantly affected by transportation services and costs, which can be treated in multiregional I-O analysis. However, it is not an easy task to discover and change values affected by travel time. Concepts of a linear programming approach seem attractive because there are limited resources, and environmentalists force governments to adopt stricter laws, regulations, and policies towards environments. Costs for pollution are to be

considered when environmental measures such as air pollution and noise caused by traffic exceed states' or cities' regulatory levels.

Although the conventional I-O analysis has a simple theoretical background, it also has some drawbacks. Harris Associated Inc. (1974) points out the limitations of I-O analysis in the following:

In an input-output model, it is necessary to predetermine levels of final demand for each region and then use interdependence coefficients to produce the changes in output. .... In tracing out impacts with an input-output model, all trade and technical coefficients are assumed to remain constant, and the effect of changes in final demand, such as government expenditures, are fed through the model to determine the effects of output, income and employment.

Although Harris Associates Inc. (1974) used the multiregional, multi-industry forecasting (MRMI) model to overcome shortcomings, econometrics requires that most relationships be linear or log-linear, an approach which excludes non-linear relationships essential for long-term forecasting. Thus, econometricians are confined both by disciplinary boundaries and by observability (Drew, 1994a). Econometrics is often criticized as "being measurements without theory".

Drew (1990a) points out the limitation of the analysis, saying "The conventional I-O system can hardly be used for projection purposes because of their inability to express explicitly the feedback relationships between producers and the transportation systems. Without a proper micro analysis of the transportation sector, it will be impossible to compare several transportation scenarios and decide how they affect regional economy and environments."



### 3.0. SYSTEM DYNAMICS VIS-À-VIS OTHER METHODOLOGIES

The transportation/economic 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 (Drew et al., 1996). All these characteristics preclude predicting systems behavior by partitioning the problem along disciplinary lines and assembling the component solutions (Drew, 1994a). Therefore, transportation effects can only be understood in a large system of interactions among transportation, economy, environment and social structure. A systems approach is the key to success in analyzing transportation policy-related problems.

Transportation engineers and planners focus on accurate estimations of travel time, reduction of travel costs, and ultimately user benefits based on the reduction of travel time and costs. The four-step urban transportation planning process (UTPP) has been used to find future travel times based on numbers in the labor force, distances from residential areas to industrial ones, modes, cost of time, and other factors. However, the UTPP and other transport models do not include nor emphasize socio-economic factors, market analysis, and other constraints such as pollution and limited resources.

Economists' interests include industry, products, income, capital and price changes in national, regional, and local economies. They have primarily used econometrics, input-output (I-O) analysis, and general equilibrium analysis when investigating the impacts of

transportation investments. Economists tend to overemphasize the economic factors, and usually underestimate the limits of natural and physical resources such as land, environments and housing. In addition, travel time and travel costs are rarely considered in their models. They concentrate more on the economic aspect of construction activities because their models are not sensitive to reductions in travel time.

Meanwhile, urban and regional planners emphasize land use associated with population, industry and accessibility. In the 1960s, the Lowry model and the Penn-state model, an econometrics model, were cornerstones for urban comprehensive models. Although econometrics has many variables in its models, it is generally criticized for its complex relationships and its assumption of independence among variables. The Lowry model as a land-use model was a pioneer work for a comprehensive model, but it was criticized due to the volume of data needed to validate a model with so few variables (Sage, 1977).

Forrester's models generated much attention as comprehensive models based on systems behavior in the 1970s. Forrester indicated that several sectors affect population in *World Dynamics* (1971) and also manifested the growth and decline of cities in *Urban Dynamics* (1969). These models were successful in showing the behavior in large scale social systems, but were criticized due to limitations in data collection and validation. The programming language, DYNAMO (for DYNAMIC MOdels), furnished a time-dependent simulation package applicable for engineering problems and macro-economic analyses. Drew and his associates have developed several system dynamics models related to transportation and economic development.

In this chapter, concepts and ideas of system dynamics will be introduced, including feedback, steady-state and transient analysis, sensitivity analysis and scenario analysis. Next, system dynamics models will be covered with respect to 'sustainability'. The three famous models related to transportation impacts, UTPP (Urban Transportation Planning Process), the Lowry model, and the I-O model will be introduced with a system dynamics approach to these models. In each section, examples will be given, and further

applications with system dynamics will be explored. An understanding of the limitations and strengths of the models can be gained through these comparisons.

### 3.1. System Dynamics Approach

The concepts of System Dynamics have been initiated and directed by Jay Forrester. Forrester's works enabled the urban and regional planning process to overcome "static" or "one-shot" approaches, and to use causal relationships with a view of the goals as a comprehensive model (Chadwick, 1971). Ideas of "systems" come from the engineering or scientific process. Forrester (1968) identifies 'system' as "a grouping of parts that operate together for a common purpose." The philosophical background can be found in the classical approaches to the pursuit of the scientific truth, including the Leibnizian, the Lockean, the Kantian, and the Hegelian Approaches (Drew, 1994b). These philosophers considered society as a huge system, whose parts affect each other continuously. However, there was no tool to show this kind of process. Drew (1981) suggests that the systems approach will provide the ship, and computer modeling will serve as the instrument of navigation. In engineering, the "feedback" concept is introduced, and Forrester has applied this concept to various areas, which include industrial, urban, and world dynamics.

Chadwick (1971) characterized Forrester's dynamic simulation as a mixed-programming strategy, based on a mixed scanning approach. A mixed scanning approach or a mixed programming strategy provides both a realistic description of the strategy used by actors in a large variety of fields and the strategy for effective actors to follow; (1) A higher-order fundamental policy - making process which sets basic directions; (2) An incremental process which prepares for fundamental decisions and reviews them after they have been made (Etzioni, 1967).

### 3.1.1. System Dynamics

The human mind is not adapted to interpreting the behavior of social systems (Forrester, 1971). Over the long history of evolution it has not been necessary for man to understand these systems until very recent historical times (Forrester, 1971). Forrester (1971) warns of the danger of mental models, saying “If we follow intuition, the trends of the past will continue into deepening difficulty”, which is true in that in the future, degradation of environments will be accelerated by the trends of the past without treatment.

Models can be developed in two ways: knowledge-oriented, and problem-oriented. Traditional science, which is knowledge-oriented, has evolved into “disciplines”, but the world and its metaproblems are transdisciplinary (Drew, 1994b). Drew (1994b) also indicates three reasons why metaproblems remain outside any formal problem discipline: (1) normal science’s conceit, (2) bureaucratic arrogance, and (3) technocratic apprehension.

System dynamics is a problem-oriented technique for applying the scientific methods to the dynamic tendencies of complex systems. It is based on the foundations of decision making, feedback systems analysis, and simulation (Drew, 1994b). First, decision making states the actions to be taken. Second, feedback systems deal with the causal relationships among sectors for decision making. Finally, by simulation, planners and decision makers view the implications of their decisions for the future.

The systems approach 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 (Huang, 1990). Thus, the basic characteristics of the systems approach are objective, multidisciplinary, interactive, and primarily quantitative.

In difference equation terminology, any level variable  $L_i$  is expressed as a function of rate variables  $R_j$  and the previous value of the level.

$$L_i(t + dt) = L_i(t) + (dt) \sum_{j=1}^n R_j(t) \quad i = 1, \dots, m, \quad (3.1)$$

with the  $R_j$  is assumed to be constant over the interval from  $t$  to  $t+dt$ . Sage (1977) indicates an expression of level variables as a Markov process, saying “A process is a Markov process if the probability of an event occurring at time  $t$  conditioned upon events occurring at time  $t-1, t-2, \dots$  is equal to the probability of the event occurring at time  $t$  conditioned only upon the events occurring at the most recent time  $t-1$ .”

The rate variables are of the form:

$$R_j(t) = F[L_i(t), E_k(t), A_{ij}(t), A_{kj}(t)] \quad (3.2)$$

where  $E_k$  are the set of exogenous inputs that affect  $R_j$  directly and  $A_{ij}$  and  $A_{kj}$  are the impacts of auxiliary variables in the causal streams from the  $i$ th variable and  $k$ th exogenous input, respectively (Drew et al., 1996).

### 3.1.2. System Behavior and Feedback Structure

Forrester (1968) classifies system into “open” systems and “feedback” systems. In an open system, outputs are isolated from inputs and do not affect inputs. Feedback loops are basic blocks of a system and a feedback system, or a “closed” system, is influenced by its past behavior (Forrester, 1968). Feedback analysis deals with the way information is to be used for decision making, or the transmission and return of information (Forrester, 1968). Feedback can occur in two ways: 1) from one time period to the next time period in a closed system; 2) change of exogenous variables such as policies in different starting times and changes in values, for example, changes in industrial structures in the future.

The modeling procedure with system dynamics is sequential and iterative. System dynamics approach consists of three models: verbal, visual, and mathematical models. 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. (Huang, 1990).

Drew (1994b) identifies simulation models as a special class of mathematical model, which involve changes in the state of the system through time except in rare instances. The modified system dynamics methodology uses all the relevant parameter classes employed in system dynamics--level variables, auxiliary variables, supplementary variables, and constants. To identify a problem, a verbal description is done first. As a mental model, verbal description needs to thoroughly cover the causal relationships among variables, and also to follow the desired level of detail. Second, causal diagrams can be made based on the verbal description.

The steps are the following: 1) identifying key variables for the system according to the desired level of detail, 2) connecting variables with solid or dashed arrows showing the relationships, and 3) assigning a positive or negative sign to each arrow.

As example is in Fig 3.1.

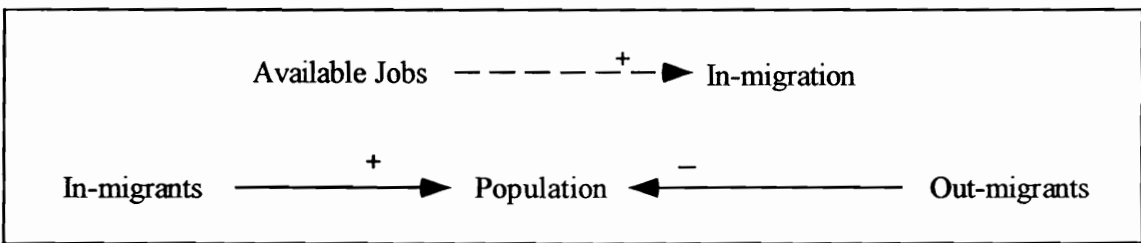


Fig 3.1. Arrows and signs in a causal diagram.

Two types of arrows were used in developing a causal diagram: solid and dashed arrows. Solid arrows indicate physical flows, connecting rate variables to level variables. Level variables, or state variables, represent the accumulation of resources in the system, such as population and capital. Dashed arrows represent the flow of information between

any other pairs of variables. Rates of flow represent the activities or decision functions in the system, such as population movement, capital investment, and capital depreciation.

Any intermediate variable on the path from a level variable, or from an exogenous input, to a rate variable is called an auxiliary variable. The signs on dashed arrows have the following interpretations: a + means that an increase in the parameter at the tail of the arrow will cause an increase in the parameter at the head of the arrow; a - means that an increase in the parameter at the tail of the arrow will cause a decrease in the parameter at the head of the arrow. Exogenous inputs are easily identified on a causal diagram since they have no arrows leading to them, but have one or more dashed arrows emanating from them. Supplementary variables, in contrast, do not form part of the system itself, but merely indicate its performance, and therefore are always identifiable as being at the head of a dashed arrow, and having no arrows emanating from them (Drew et al, 1996).

There is positive and negative feedback. Fig. 3.2. represents positive and negative feedback relationships in causal diagram.

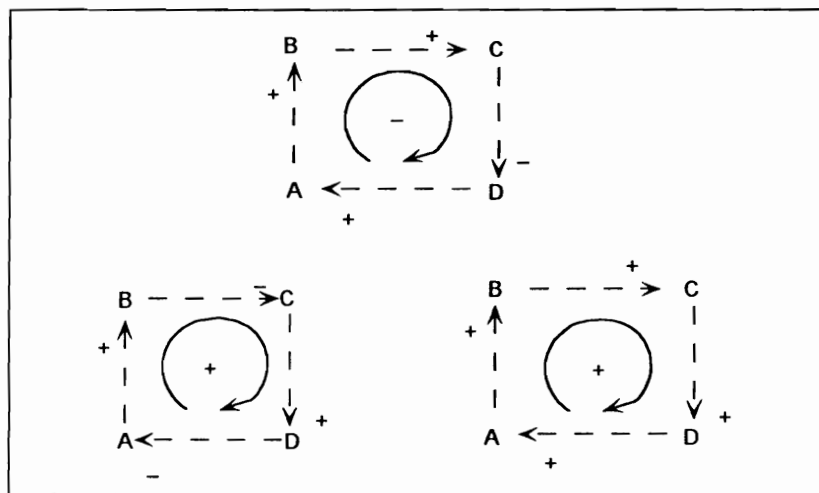


Fig. 3.2. Positive and negative feedback in a causal diagram

### 3.1.3. Programming in DYNAMO

The methodology utilizes the DYNAMO computer language associated with system dynamics. Therefore, computer simulation is necessary for complicated solution. DYNAMO is a computer program which compiles and executes continuous simulation models. It is designed to be an effective aid in simulating system dynamics models whose behaviors depend more on aggregate flows than upon the occurrence of discrete events.

A DYNAMO compiler facilitates a modeler in using up to seven types of equations and six types of control statements. 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
- P parameter
- T tables (values for independent 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
- SAVE followed by variables to be printed
- NOTE comment
- ^ continuation of previous line

Mathematically, the level equations at any time can be written as:

$$\text{Quantity } (t) = \text{Quantity } (t-1) + (\Delta t)(\text{Rate of Change})$$



where  $\Delta t$  is the incremental simulation time interval. In DYNAMO, the present time is indicated by the postscript .K, and the preceding time instant is represented by the postscript .J following the variable name. The incremental simulation time interval,  $\Delta t$ , is written as DT. Thus, a level equation can be written as:

$$LV.K = LV.J + (DT) * (RATE.JK) \quad \text{or} \quad LV.K = LV.J + (DT/TC) * (RATE.J)$$

where JK denotes the time from past to present. A rate equation can be written as, for example:

$$RATE.KL = AUX.K/CONS$$

where KL denotes the time from present to future, AUX.K is an auxiliary variable at present, and CONS is a constant.

Of the built-in functions, the DELAYs, SMOOTH, TABLEs, PULSE, RAMP, and SAMPLE are macros. There are two classes of delays: material and information. The example of delay is DELAY1(IN,DEL) where DEL is a period of delay. CLIP function has the form CLIP(P,Q,R,S) and returns the value:

$$CLIP = P \text{ if } R \geq S \text{ and } CLIP = Q \text{ if } R < S$$

The table function can be used when the relationships cannot be written in mathematical equations, but when the arbitrary relationship to another variable is known. TABLE, TABHL, and TABXT are used in different functions. NOISE and NORMRN are random-number functions. An “array” variable is a collection (or set) of ordinary variables that is given a single name. The ordinary variables can be designated individually by adding subscripts to the array name. A maximum of eight dimensions is used (Pugh-Roberts Associates, 1991 & 1994).

#### 3.1.4. Steady State and Transient Analyses

System dynamics come from differential equations. As it contains many non-linear relationships, the result can demonstrate exponential growth, steady-state (a threshold), and fluctuations over time. In a closed systems, such as the world model and the urban

model, there are always constraints against growths, such as pollution and limited resources. Therefore, in most cases in macroeconomics or urban models, there will be a steady state or equilibrium.

When a system is at its equilibrium, or steady state, all level variables stay constant over time. In other words, rates of flow 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.

Mathematical analysis may be applied to the solution of simple feedback systems by integrating each level equation in the system. In general, it is difficult to analyze social systems or models through transient analysis because they contain many non-linear relationships and table functions, which make it impossible to solve in one equation.

### 3.1.5. Sensitivity Analysis and Scenario Analysis

Sensitivity analysis involves the examination of the behavior of models by slightly changing the model parameters and the 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 establish relationships among data (Huang, 1990). In a forecasting model, the sensitivity of one variable may result in quite different results. Any model is based on assumptions and follows the trends of the past, which can be critical in forecasting. A slight change in one value can show a wholly different result. This can be viewed as 'elasticity' in the micro-economy.

The purpose of policy or scenario analysis is to investigate why particular policies have the effects they do, and further, 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.

### 3.2. System Dynamics Modeling

Forrester's work originated in industrial dynamics, where he searched for changes in industrial growth, fluctuation and business cycles. He expanded the idea of industrial dynamics to system dynamics, resulting in urban dynamics and world dynamics. Although Forrester's models have been criticized because of their basis on expert opinion and untested assumptions rather than real data (Sage, 1977), they have generated a great deal of new activity in urban modeling and great concern for the future through world modeling.

In *Urban Dynamics* (Forrester, 1969), several policies were tested for a hypothetical city. The sectors considered were housing, labor, industry, employment, land use, and others. Among the policies, Forrester suggested which were more effective. In *World Dynamics*, population was controlled by crowding, food supply, pollution, and natural resources. Quality of life depends on material standard of living, food supply, crowding, and pollution (Forrester, 1971). The research was conducted under the sponsorship of The Club of Rome. Of great concern in Forrester's models was the contemporary urgency of the problems they discuss (Sage, 1977). However, the lack of a technology sector has been one of the major criticisms of the Forrester's world and urban dynamics model.

During the 1970s and 1980s, Drew's works related to system dynamics used examples from various regions (Drew, 1994a & 1994b). He worked on developing proper policies in Bicol Rasin River, a model for Taiwan, a model for Lebanon, and several others. His works basically were involved in infrastructure development for national and regional economies. Concerning infrastructure, he especially concentrated the

transportation sector and tried to find both user benefits and non-user benefits in his models.

A second great concern for system dynamics nationally and internationally probably derives from the “sustainable development” debate. Most scholars have used the term “sustainable development” in smaller contexts. Meadows and Meadows (1991), and others’ work in *World Dynamics III*, have given a background for sustainable development for the world from the Club of Rome. The system dynamics model provides a powerful result, although it has limitations. No other methodology has been able to warn of future world problems in such an understandable way. Based on such concepts as ‘overshoot’ and ‘collapse’, Meadows and Meadows (1991) warned about problems in the world’s future, and gave several scenarios. They also explained in detail several air pollutants affecting ozone and health.

As for its limitations, the system dynamics model has a very poor level of spatial resolution (Wilson, 1974) and it includes untested assumptions (Sage, 1977). However, its assumptions could be tested and the submodels and assumptions could be improved in relation to other work in the field (Wilson, 1974). Therefore, the next sections in this chapter are meaningful in terms of the submodels or base-line information and data for a national and a regional system dynamics model.

Sage (1977) indicates the essential differences between the system dynamics model and the econometrics model, saying “the econometrics model is basically a static model with many linear terms used for short-term (1- or 2-year) predictions utilizing parameters precisely determined from detailed statistical tests, whereas the system dynamics model would be a dynamic model with many nonlinear multipliers operating over a much longer term (10 to 100 years) utilizing parameters determined much more from expert opinion than from analytical testing.”

Drew (1994a and 1994b) compared several other methods with system dynamics: queuing theory, catastrophe theory, and a linear programming approach. The expression

of one model in a different system may not appear to be significantly different, but actually is meaningful. Combining methodologies may reduce the disadvantages and result in a hybrid model, or at least provide a method which adopts some of the principal concepts of other methods.

### 3.3. System Dynamics Approach to UTPP

The Urban Transportation Planning Process (UTPP), in its more specifically focused aspect, was initiated for modeling purposes by economists and has been used at all levels of government as a response to the Post World War II Interstate Highway System. The microeconomic paradigm of demand and supply was articulated by economists to include transportation, providing the theoretical foundation for the “Four-Step (Generation, Distribution, Modal Split, Network Assignment) Transportation Planning Process” (Drew, 1994a). Four steps in the UTPP were used as a long-term comprehensive plan or as a short-range system analysis (Pas, 1986).

With the passage of the 1962 Federal Aid Highway Act, it was necessary for urban areas to employ a continuing, comprehensive, and cooperative planning process. The UTPP was oriented toward long-term, capital-intensive expansions of the transportation system (Pas, 1986). The UTPP can be used based on the labor force, the distance from residential areas to industrial ones, modes of transportation, cost of time, and others, to find future travel time. Based on future travel time, user benefits can be discovered easily. However, the UTPP does not rely primarily on economic factors, market analysis and other constraints; it also has been often used as a component of a larger model.

In 1975, the Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (UMTA) issued joint regulations, encompassing both the traditional long-range element as well as a short-range Transportation System

Management (TSM) element (Pas, 1986). Without significant changes in its basic structure established as a result of practice in the sixties and seventies, the UTPP is still widely used in academic and professional environments.

The UTPP has enlarged its areas with various techniques and methodologies. The following are the four steps in the UTPP, and techniques and application tools. The UTPP comprises an application of economic theory based on the flows which will result from a particular transportation system  $T$  and the pattern of socio-economic activities (Drew, 1994a). The equations of supply and demand for the UTPP are the following (Drew, 1994a):

$$F^* = (V^*, L^*) \text{ where } L = S(V, T) \text{ and } V = D(L, A) \quad (3.3)$$

where  $V$  = volume of flow,

$L$  = level of service experienced by that volume,

$F = f(V, L)$  is the flow pattern,

$S$  = a supply function  $S$ , and

$D$  = a demand function.

With the dynamic nature and spatial orientation of the phenomena, the UTPP is conceptualized as follows:

$$\text{Find } F^*(t)_{ij}^{mr} = f[V^*(t)_{ij}^{mr}, L^*(t)_{ij}^{mr}]: \text{ the flow pattern at equilibrium,} \quad (3.4)$$

$$V(t)_{ij}^{mr} = D[L(t)_{ij}^{mr}, A(t)_{ij}] \quad : \text{ the Demand Function,} \quad (3.5)$$

$$L(t)_{ij}^{mr} = S[V(t)_{ij}^{mr}, T(t)_{ij}^{mr}] \quad : \text{ the Supply Function} \quad (3.6)$$

where  $(t)_{ij}^{mr}$  means at time  $t$ , from zone  $i$  to zone  $j$ , by mode  $m$ , using route  $r$  and

$T(t)_{ij}^{mr}$  refers to the elements of the entire transportation system at time  $t$ .

where  $Y(O)$ ,  $L(O)$ ,  $A(O)$ ,  $T(O)$  describe Base Year conditions.

A four step procedure can be used for the Demand function as follows. (The UTPP has emphasized the Demand Function.) A brief explanation of the four step process is introduced before system dynamics approach.

- Trip Generation

The main function of trip generation is to process and estimate the total number of trips generated and attracted by each area unit (zone) in conjunction with the land use and the socio-economic characteristics of that area. The function of trip generation can be the following:

$$O_i(H) = f[A(H)_i] \text{ and } D_j = f[A(H)_j] \quad (3.7)$$

where  $O_i$  is the origin of home-based trip (commuter) and  $D_j$  is the destination of the trip.

There are three approaches commonly used in trip generation analysis: regression analysis, land-area trip rate analysis, and cross classification analysis. Dickey (1975) indicated that regression analysis is commonly used for residential trip generation and cross-classification summaries of rates of tripmaking are used for non-residential trip generation.

- Trip Distribution

In trip distribution, each zone is taken one at a time and a determination is made of the zones to which its produced trips will be attracted. The trip pattern within a study area is usually represented by means of a trip table. The distribution of trips are assumed to be dependent upon factors such as the availability of jobs, transportation facilities and travel times (value of in-vehicle time). The trip distribution subfunction can be defined:

$$V(H)_{ij} = \alpha_i \beta_j O_i(H) D_j(H) z(t_{ij}^x) \quad (3.8)$$

where  $\alpha_i, \beta_j$  are determined from the Base Year conditions.

Many mathematical models have been developed for trip distribution. The growth factor model, the gravity model, the intervening opportunity, and linear programming approach are usually used. The equations of double-constrained gravity models are:

$$A_i = [\sum_j B_j D_j / t_{ij}^x]^{-1} \quad (3.9)$$

$$B_j = [\sum_i A_i O_i / t_{ij}^x]^{-1} \quad (3.10)$$

$$\log \left( \frac{V_{ij} \sum_i \sum_j V_{ij}}{O_i D_j} \right) = -x \log t_{ij} \quad (3.11)$$

$$V_{ij} = A_i B_j O_i D_j / t_{ij}^x \quad (3.12)$$

where  $V_{ij}$  = trip interchange from zone i to zone j

$O_i$  = total trip production in zone i

$D_j$  = total attraction to zone j

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

$x$  = travel time exponent.

- **Modal Split**

The modal split is concerned primarily with the attempt to assign person-trips to the various alternative modes available. Factors found significant in determining the modal split have been grouped into three categories: characteristics of the trip, those of the trip-makers, and those of the transportation system. Three types of Modal Split models are usually used in transportation planning: the trip-end model, the trip interchange model, and individual mode choice model.

First, a Trip-End Model is one that allocates a portion of the total person trip origins and destinations to alternate modes of transportation prior to trip distribution. Second, a Trip-Interchange is one that allocates portions of given person-trip movements resulting from trip distribution to alternate transportation. Third, an Individual Mode Choice Model, which is known as a disaggregate behavioral model, is one based on individual observation, and reflects the actual choice process at the level the choice is made.

The modal split subfunction is:

$$V(H)_{ij}^m = \alpha_{ij}^m \times V(H)_{ij} \quad (3.13)$$

where  $m$  is mode and  $\alpha_{ij}^m$  are determined from the Base Year conditions.



The percentage of choice riders may be determined by the Logit model as follows:

$$P_{ij}^c = \frac{e^{\delta z}}{1 + e^{\delta z}} \quad (3.14)$$

where  $\delta z = Z_{ij}^b - Z_{ij}^c$ , the difference in generalized cost.

Adjusted factors for each mode can be used according to different criteria, such as convenience besides travel times and travel costs.

- **Traffic Assignment**

Traffic Assignment involves the assignment of the distributed volumes of trips, by mode, to an individual network link. According to Dickey (1975), four factors are identified as important by the researchers: travel times, travel costs, comfort, and level of service. Traffic assignment techniques include iterative assignment, incremental assignment, user equilibrium assignment, and stochastic user equilibrium assignment. The network assignment subfunction can be:

$$V(H)_{ij}^{mr} = \delta_{ij}^{mr} \times V(H)_{ij}^m \quad (3.15)$$

where  $r$  is route and  $\delta_{ij}^{mr}$  are determined from the Base Year conditions.

Wardrop assumed that all trip-makers have identical perceptions of travel costs, which then became the basic premise in traffic assignment. Based on that assumption, two principles for route choices for network equilibrium were proposed: a user-optimized equilibrium and a system-optimized equilibrium. The first principle, user-optimized equilibrium, requires that all feasible paths between an origin and a destination have the same travel costs (usually travel times). The second principle, system-optimized equilibrium, requires that the average travel costs in a network be minimal. The factors which affect route selection are travel times, level of service, etc.

Sheffi (1985) regarded as a reasonable assumption that every motorist will try to minimize his or her own travel time when traveling from origin to destination, which is based on the principle of a user-optimized equilibrium. He suggested two conditions

based on that assumption, the user-equilibrium (UE) condition and the stochastic-user-equilibrium (SUE) condition.

The UTPP is an essential concept for the TDM (transportation/development model), especially multiregional TDM (MTDM), covered in Chapter 5. The example of UTPP, i.e., allocation of residential activity using the accessibility model, was developed for three hypothetical residential and two hypothetical industrial areas. The example was programmed, using the DYNAMO computer simulation language, which can be found in Appendix A.

The land use gravity model, the double-constrained gravity model, the logit model, and user equilibrium analysis are used for trip generation, trip distribution, modal split, and traffic assignment, respectively. The modeling process is in Fig. 3.3. Changes of industrial jobs, changes in AVO (Average Vehicle Occupancy), an increase in highway lanes, and other policy implications can be tested, based on the programming.

It is important to understand the hypotheses upon which those studies are based. Some of them are:

- Human travel behavior is rational, describable and measurable.
- Traffic loads in the networks (volumes, densities, etc.) are functions of human characteristics and activities, and land use.
- The relationships derived under current conditions remain stable over time.

Thus, the UTPP has many limitations in its assumptions and applications for long-term forecasting. In addition, it does not explain supply-demand relationships and feedback relationships over time. Socio-economic data for the future are inconsistent because they do not have continuous feedback effects from transportation facilities over time. Still, the UTPP can provide very reliable travel times if the values of exogenous variables are correct in the system.

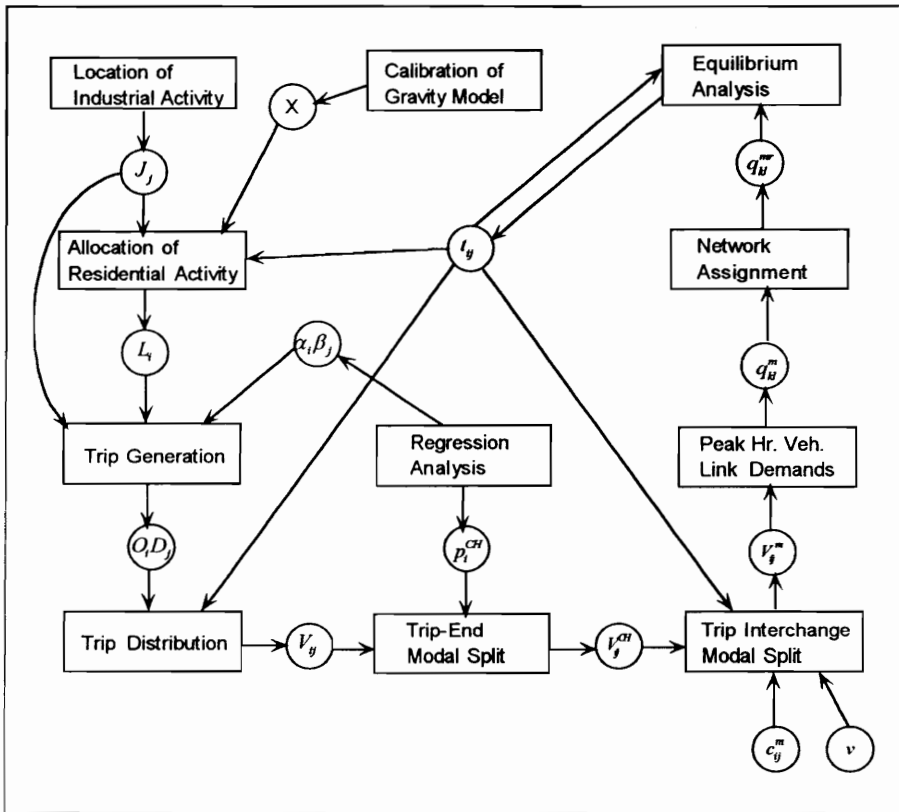


Fig. 3.3. Modeling sequence in the UTPP (Drew, 1993)

### 3.4. System Dynamics Approach to the Lowry Model

In the 1960s, there were massive federal efforts to make rational the project of urban and regional development. Based on previous partial models, a comprehensive model, or a general model could be developed to overcome the limitations of previous models by incorporating many possible interdependencies (Wilson, 1974). Lowry (1968) indicated that most model-builders of theoretical models omit substantial portions of adequate systems of interdependence, although the art of model-building is that of simplifying complicated problems.

Based on his experiences in the Pittsburgh region from 1960 to 1963, Lowry (1964) developed and implemented a model for allocating employment and residential activities over urban space to predict the equilibrium mix of housing, population, and industry in a large city. The Pittsburgh Model as a hybrid (Lowry, 1968) or the Lowry Model as a spatial interaction model (Wilson, 1974) is formulated as “a series of distributional algorithm, one for each activity (Lowry, 1968)”.

A region’s activity is divided into three pertinent groups: basic employment activity, business serving activity, and household activity. Basic employment activity refers to employment in the export industry, and the business serving activity refers to the service sector. Work-related trips and shopping trips are treated separately. Lowry (1964) suggested a differentiated product model for trip distribution, comparing it to the classical gravity model, the random travel-path model, and Schneider’s differentiated product model. A weighted average of values for each distance  $r$  can be calculated by aggregating work trip and employment variables for all residence zones. The equations can be:

$$\frac{dP}{dr} = ar^{-x} \quad , \quad T_{ij} = \frac{2\pi r^{1+x}}{a} \quad (3.16)$$

or reciprocals of quadratic functions,

$$\frac{dP}{dr} = (a - br + cr^2)^{-1}, \quad T_{ij} = 2\pi r(a - br + cr^2) \quad (3.17)$$

The equations for the allocation of socio-economic activity using the Lowry model include the following:

- Allocation of business serving jobs:

$$J_i^s = \frac{A_i^s Z_i^s}{\sum_i A_i^s Z_i^s} \sum_j J_j^b \times s \quad (3.18)$$

$$\text{where } A_i^s = \frac{\sum_j J_j^b}{t_{ij}^{x^s}} \quad (3.19)$$

$A_i^s$  = accessibility of service to basic industry

$J_j^b$  = jobs in basic industries

$J_i^s$  = jobs in service industries

$Z_i^s$  = land zoned for service industry

$s$  = service industry multiplier

$t_{ij}$  = zone-to-zone travel times

$x^s$  = importance of proximity for service industry

- Allocation of industrial labor force:

$$L_i^s = \frac{A_i^r Z_i^r}{\sum_i A_i^r Z_i^r} \sum_j (J_j^b \times J_j^s) \quad (3.20)$$

$$\text{where } A_i^r = \frac{\sum_j (J_j^b \times J_j^s)}{t_{ij}^{x^r}} = \frac{\sum_j J_j^i}{t_{ij}^{x^r}} \quad (3.21)$$

$A_i^r$  = accessibility of residential zone  $i$  to jobs

- Allocation of household serving jobs:

$$J_i^h = \frac{A_i^h Z_i^h}{\sum_i A_i^h Z_i^h} \sum_j L_j^b \times (p/f) \quad (3.22)$$

$$\text{where } A_i^h = \frac{\sum_j L_j^i}{t_{ij}^{x^h}} \quad (3.23)$$

$A_i^h$  = accessibility of household establishments to population

$Z_i^h$  = zone  $i$  holding capacity of household service

$p$  = household jobs per person

$f$  = labor participation fraction

- Allocation of household serving labor force

$$L_i^h = \frac{A_i^{r'} Z_i^r}{\sum_i A_i^{r'} Z_i^r} \sum_j J_j^b \quad (3.24)$$

where  $A_i^{r'} = \frac{\sum_j J_j^h}{t_{ij}^{x^h}}$  (3.25)

$A_i^{r'}$  is accessibility of residential zone i to household service

- Allocation of household serving jobs:

$$J_i^h = \frac{A_i^{h'} Z_i^h}{\sum_i A_i^{h'} Z_i^h} \sum_j L_j^b \times (P/f) \quad (3.26)$$

where  $A_i^{h'} = \frac{\sum_j L_j^h}{t_{ij}^{x^h}}$  (3.27)

- Find

$$L_i^h = \frac{A_j^{r''} Z_i^r}{\sum_i A_j^{r''} Z_i^r} \sum_j J_j^{b'} \quad (3.28)$$

where  $A_i^{r''} = \frac{\sum_j J_j^{h'}}{t_{ij}^{x^h}}$  (3.29)

Extrapolation of  $J_i^h$  and  $L_i^h$  to obtain  $J_i^{\sum h}$  and  $L_i^{\sum h}$

where  $J_i^{\sum h} = J_i^h + J_i^{h'} + \dots$  and  $L_i^{\sum h} = L_i^h + L_i^{h'} + \dots$

A steady state equilibrium will be achieved after the model is iterated (Drew, 1994a). A simplified flow chart is in Fig. 3.4.

As the Lowry model is highly spatially oriented using tracts in a city, it is useful in estimating impacts concerning land use, population, and travel time among tracts or zones. Several concepts can be adopted for regional systems, but primarily this model can be incorporated into a system dynamics model when building urban and suburban models.

Three examples are given in Appendix B. First, programming without time effects is introduced, and then the variables of industrial activities and transportation systems in a certain future are considered. In the third example, capital formation and depreciation of the basic industry are considered and spatial relocation of industries and population is forecasted.

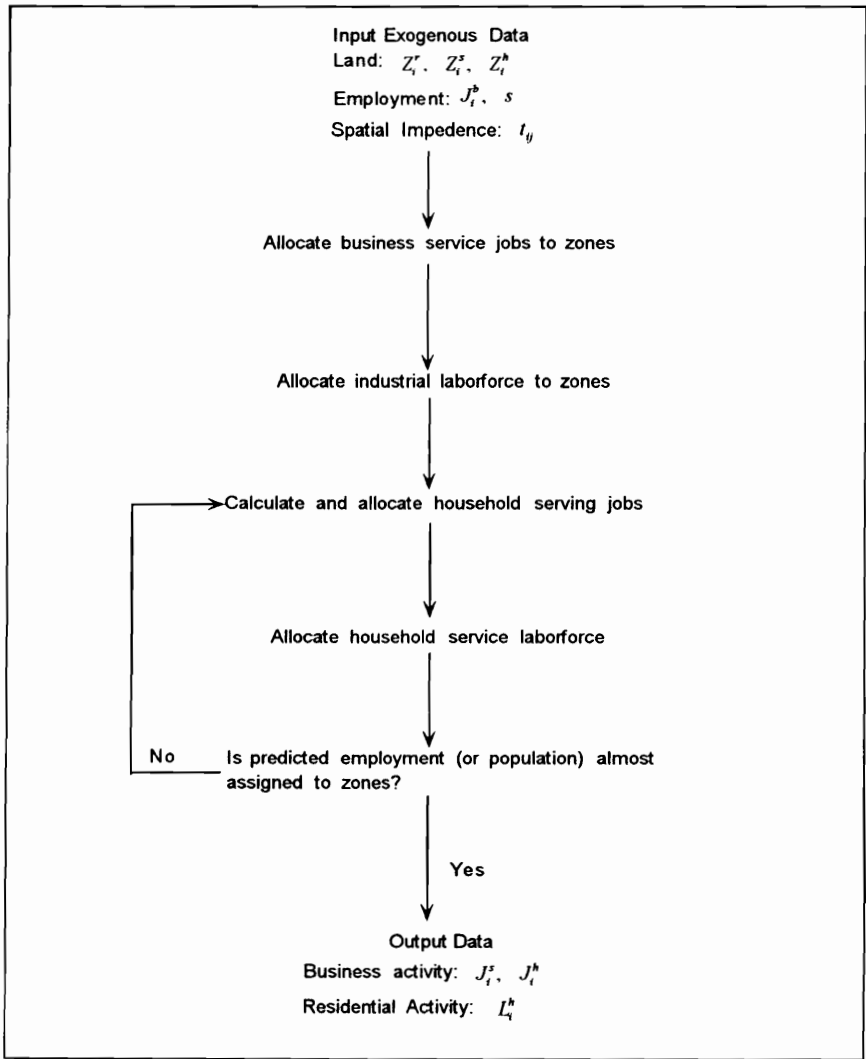


Fig. 3.4. A simplified flowchart of the Lowry Model

### 3.5. System Dynamics and Input-Output Analysis

Input-Output analysis basically comes from static relationships in a given period of time. To incorporate input-output analysis with the systems approach, two major factors need to be considered. The first is how the dynamic behavior of economic activities may be incorporated into the analysis, and the second is how to establish input-output tables for long-range forecasting.

Many people have tried to use I-O analysis for long-term forecasting, but is very doubtful as to whether the results are reliable. As input-output basically originated in static and partial models used only for the purpose of economic analysis, its use for transportation analysis raises some questions.

#### 3.5.1. Regional I-O Analysis

In Chapter 2, the theoretical background of this research was covered extensively. It is now necessary to consider how the coefficient table is constructed, and which sectors are included. Regional I-O analysis is a general term for an open model with partial coefficients derived from a national model. If we consider a region as a closed model with primary data, the structure will be the same in the table.

There are three sectors in the input-out table: the processing sector, the payment sector, and the final demand sector. Processing sectors produce goods and services. Payment sectors consume no output, but provide inputs to the processing sectors. Final demand sectors are the ultimate consumers of output, but provide no inputs to the processing sectors: the demand for goods and services by sectors other than the endogenous industrial sectors (consumption, government expenditures, investment, and exports). Values added are payments to inputs other than intermediate inputs and imports, which are labor  $L$  and capital  $N$ . Fig. 3.5. shows how an input-output table is structured.



Items	Processing Sector				C	I	G	E	Output
	Agri.	Manuf.	Trans.	Service -----					
Agriculture									
Manufacturing									
Transportation									
Services									
:									
:									
:									
:									
Value-Added									
Imports									
Total Sales									

Fig. 3.5. Structure of an Input-Output table.

Input-output coefficients and interdependency coefficients can be made based on the table. A causal diagram for two-sector dynamic input-output analysis is introduced in Fig. 3.6, which is a special case. In a dynamic input-output model, capital is used as an input with a fixed coefficient. In Fig. 3.6., capital-output ratios for each industry can be altered based on other factors, and capital is used for production activities. A detailed explanation is given in chapter 5.

Examples of regional input-output analysis is introduced in Appendix C.1., where a hypothetical regional input-output transactions matrix is offered, and the direct requirement matrix and interdependency coefficient matrix are found using MATLAB programming. Employment multipliers of each sector are found using labor/output ratios. In the same patterns, pollution generation multipliers, value-added multipliers, required land multipliers, and others can be found.

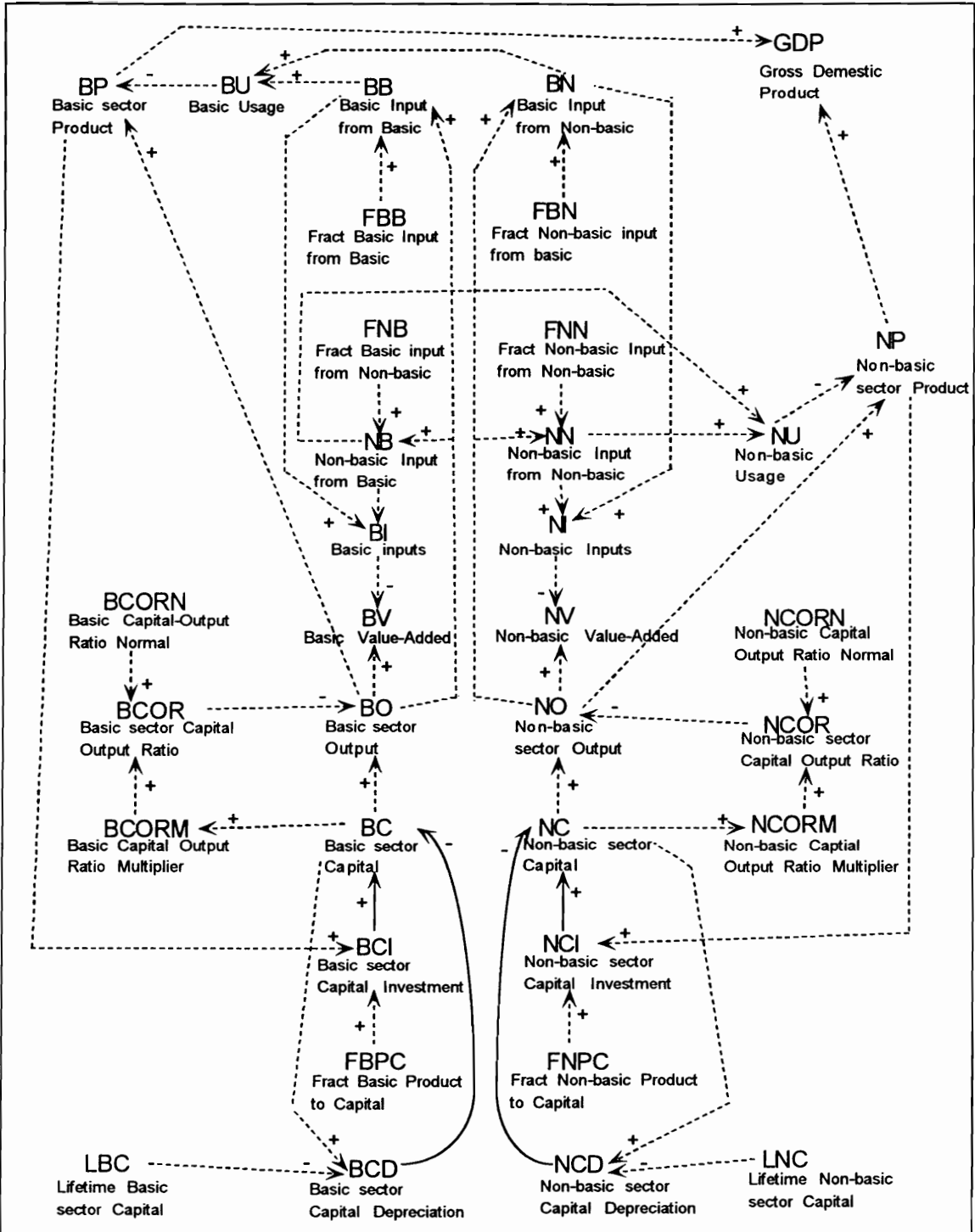


Fig. 3.6. A special case for two-sector dynamic Input-Output analysis

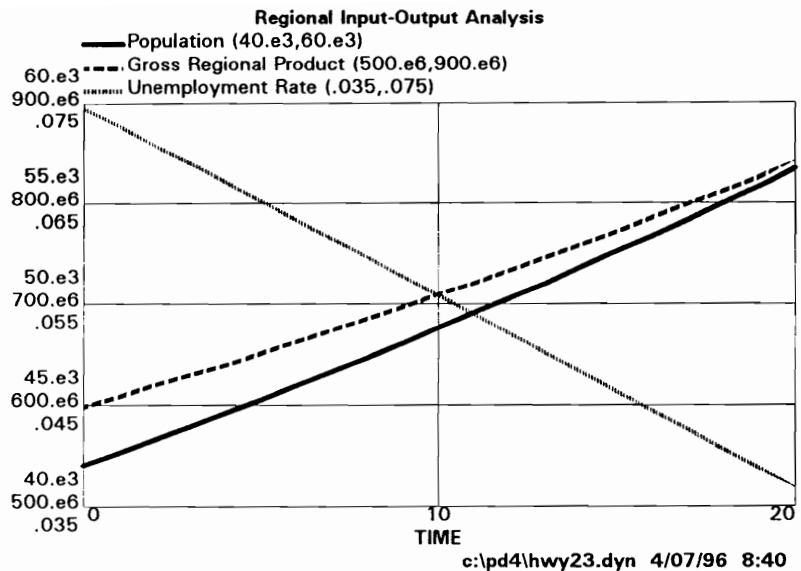


Fig. 3.7. Computer output of regional I-O analysis without constraints

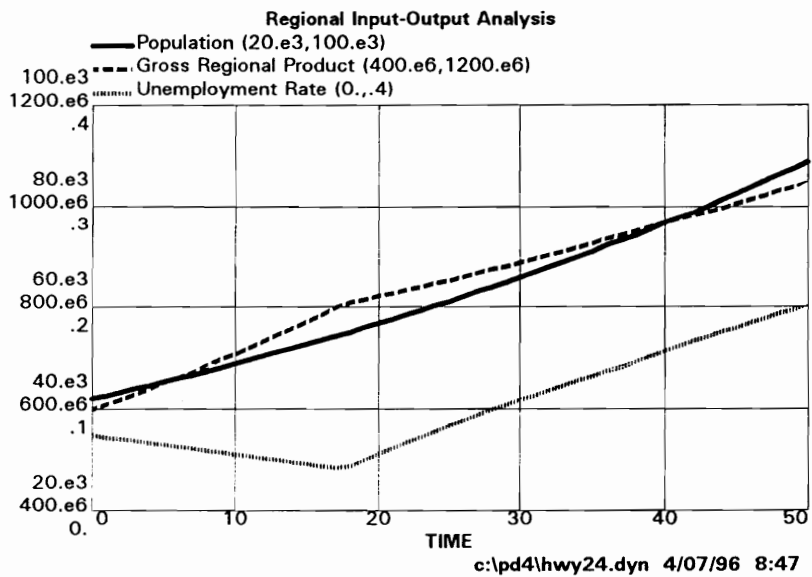


Fig. 3.8. Computer output of regional I-O analysis with constraints

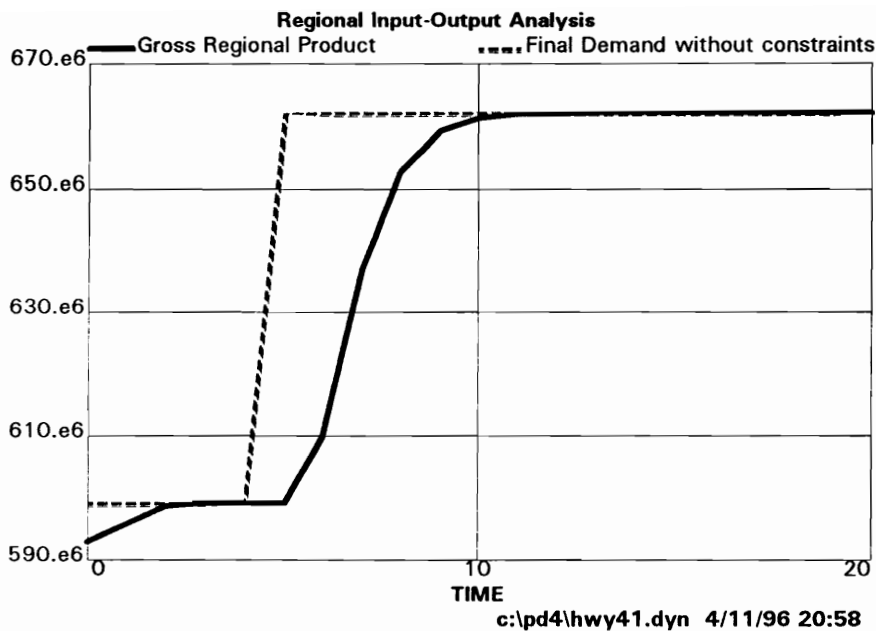


Fig. 3.9. Demand-oriented GRP forecasting

Constrained I-O analysis, or Linear Programming I-O analysis is introduced in Appendix C.2. In most cases of regional I-O analysis, additional input or a decrease in final demand is used to show the economic impacts on the region. In constrained I-O analysis, total economic activities need to be considered, as well as changes in final demand. In the example, two constraining factors are used: pollution and labor. In a static model, the assumptions in constrained I-O analysis are acceptable, but are not in a dynamic model. Sufficient jobs and low unemployment rates will generate immigration to the region. If pollution generation reaches the maximum in the region, each industry will spend more on reducing pollution, requiring more capital for the same amount of output.

A direct trade table in a hypothetical region is introduced and a three-sector dynamic input-output analysis is programmed based on Fig. 3.6., which is found in Appendix C.3. Using a direct coefficient matrix, a regional I-O analysis based on system dynamics approach is introduced, with and without constraints, in Appendix C.4 and C.5.

In order to simplify the problem, annual growths of population and industry are given as 0.015 and 0.017, respectively. Fig.3.7. shows the steady growth of industry and the steady decrease in the unemployment rate. In Fig. 3.8., constraints are given, where pollution generation affects the growth of GRP approximately 17 or 18 years later, which in turn increases the unemployment rate in the region. Fig. 3.9. shows demand-oriented GRP forecasting based on dynamic input-output analysis. However, the examples follow a rudimentary type of system dynamics model. In Chapter 5, more complicated but effective models will be introduced.

### 3.5.2. Interregional and Multiregional I-O Analysis

Johnson (1996) indicates two essential differences between the regional and interregional I-O models (IRIO); 1) the IRIO provides estimates of impacts not only in the region of primary interest, but in all other regions as well; 2) the IRIO includes estimates of interregional feedback caused by the endogenization of the extraregional final demand. The format of input-output tables is the same as that of a regional I-O model; therefore, an example of IRIO is not covered. Theoretical backgrounds were developed in the U.S., but IRIO has not been used in the U.S. in practice. Japan has used the IRIO, dividing the country into several regions.

The multiregional I-O model (MRIO) uses regional tables identical to that of the regional I-O model. The difference is formed in the use of trade tables. The interregional trade flow table in the MRIO only shows the flow of goods by the SIC industry, from origin to destination. IRIO is ideal for analysis, but even the interregional trade flow table for the MRIO requires major expenditures to collect data. An example of MRIO is found in Appendix D. Appendix D.1. shows programming in MATLAB, and D.2. shows DYNAMO programming for MRIO with constraints.

## 4.0. APPRAISAL OF TRANSPORTATION IMPACTS

The total benefits and impacts resulting from a transport improvement are never realized immediately (Drew et al., 1996). In other words, there is a stream of benefits flowing over time, and the economic effects are not fully felt in the region until any production-marketing economies and cost saving resulting from the improvement manifest themselves in the forms of freight rates, pricing structure, land values, production levels, etc. (Drew et al., 1996).

Transportation and planning models are basically used for prediction and forecasting. Sage (1977) indicates the importance of the value system, “Outcomes from a planning model must be evaluated in terms of the value system. From the specification of alternative policies in the system synthesis step, the planning model must not only predict the outcomes from implementing the alternative policies but also present these outcomes in terms of the value system in a form that is useful for ranking of alternatives, optimization and decision making.”

In the previous chapter, several planning or economic models were introduced for future policy and program implications. Another important issue has to do with the selection of the most appropriate method for ranking several scenarios, with cost-benefit analysis being the most frequently used. In the transportation field, this analysis is frequently employed for user impact analysis. Historically, the factor of cost was dealt with in a straightforward manner, usually taken to mean the amount of investment. In the concept of ‘sustainability’, the meaning of cost needs to be expanded. The value systems

of transportation impact analysis can be divided into two parts: cost-benefit analysis and non-user impact analysis. One may ask whether both can be integrated into one value system. However, user cost-benefit can be used to show for survivability of the program, indicating showing directly the user benefits, in addition to costs. Non-user impact analysis can be done when the policy or program is public oriented, or when it affects the overall society, including regional economies, environments, etc. Therefore, a model needs to provide sources for both user and non-user impact analysis

#### 4.1. User Impact Analysis

In the transportation field, cost-benefit analysis is noted for analyzing user impacts. Based on the idea of 'willingness-to-pay', the benefits will be considered for cost-benefit analysis. Transport benefits accruing to road users, in terms of time savings, cost savings and savings due to accident reduction, are the primary effects of transportation improvements (Drew et al., 1996). The transportation user benefits are the primary components of benefit-cost analysis, which provide a quantitative assessment of the relative benefits of different alternatives in terms of a common monetary measure (Drew et al., 1996).

##### 4.1.1. User Benefits

Road-user benefits are the sources for highway user benefits. The primary benefits of transportation improvements are time savings, cost savings, and savings due to accident reduction. Price-volume curves will be used as a conceptual framework for the process of pricing the benefits related to the following traffic components: 1) Benefits to existing traffic; 2) Benefits to generated traffic; 3) Benefits to diverted and transferred traffic;

4) Benefits to developed and normal growth traffic; and 5) Pricing benefits to community traffic.

In the simplest case from Fig. 4.1., the formula for consumers' surplus or net user benefit is:

$$UB = \frac{(P_0 - P_n)(V_0 + V_n)}{2} \quad (4.1)$$

where  $UB$  = user benefits,

$P_0$  = original price of travel,

$V_0$  = original travel demand (original annual volume),

$P_n$  = new price of travel, and

$V_n$  = new travel demand (new annual volume)

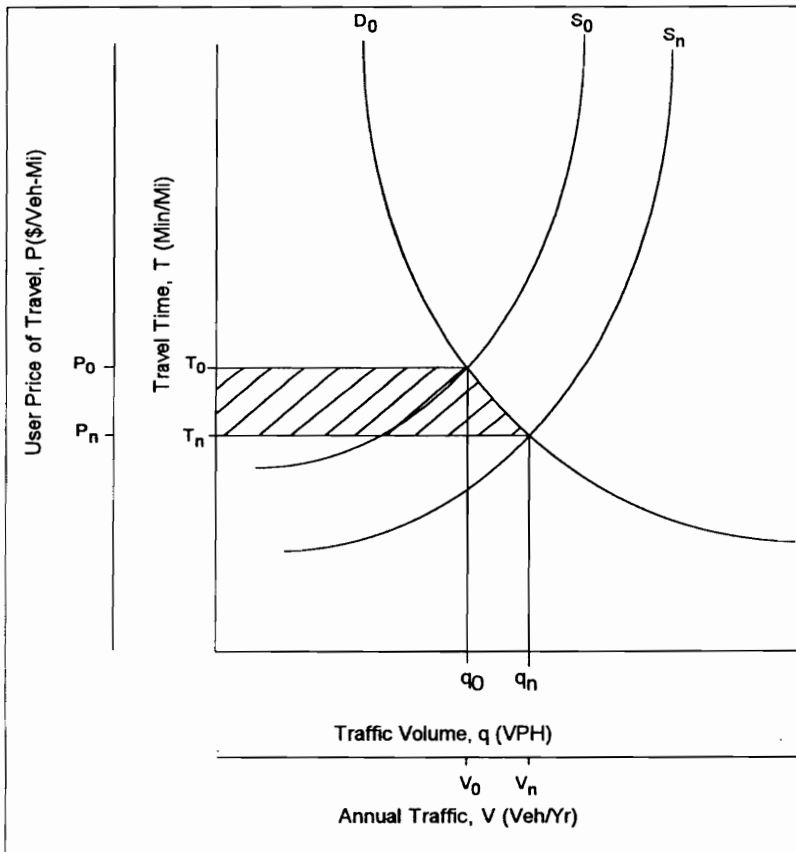


Fig. 4.1. Determination of user benefits in transportation improvement



However, improved transportation facilities may possibly change the demand curve, resulting in a shift to the right.

The user-price of travel can be computed by the following equation:

$$P = v \times T \quad (4.2)$$

where  $P$  = price of travel (\$/veh-mi)

$v$  = value of travel time

$T$  = travel time per unit length of road (min/mi)

In the case of a supply curve, it illustrates how the unit price or cost of travel will change as more trips are made and as the roadway system design and operation are changed.

Davidson's formula can be used for this relationship (see Fig. 4.2.):

$$T = T_f \frac{1 - (1 - j)q / Q}{1 - q / Q} \quad (4.3)$$

where  $T$  = total travel time per unit length of road (min/mi)

$T_f$  = free flow travel time (min/mi)

$q$  = traffic volume (vph)

$Q$  = capacity (vph)

$j$  = level of service factor ( $0 \leq j \leq 1$ )

#### 4.1.2. Costs

In most transportation projects, only construction costs and maintenance costs are used considering interest rates or discount rates. Generally, costs include the costs of advance planning, construction, maintenance, rights-of-way acquisition and preparation, preliminary engineering, and final design.

Strict environmental laws and regulations give not only constraints, but also pollution costs. Conn (1985) gives an example about total pollution cost by adding pollution damage and abatement cost. He also shows equity and efficiency based on the example. In transportation, air quality and noise are crucial factors for the survivability of

projects. The concepts of “sustainable development” will give more strict regulations, and environmental costs will greatly reduce feasibility of road projects.

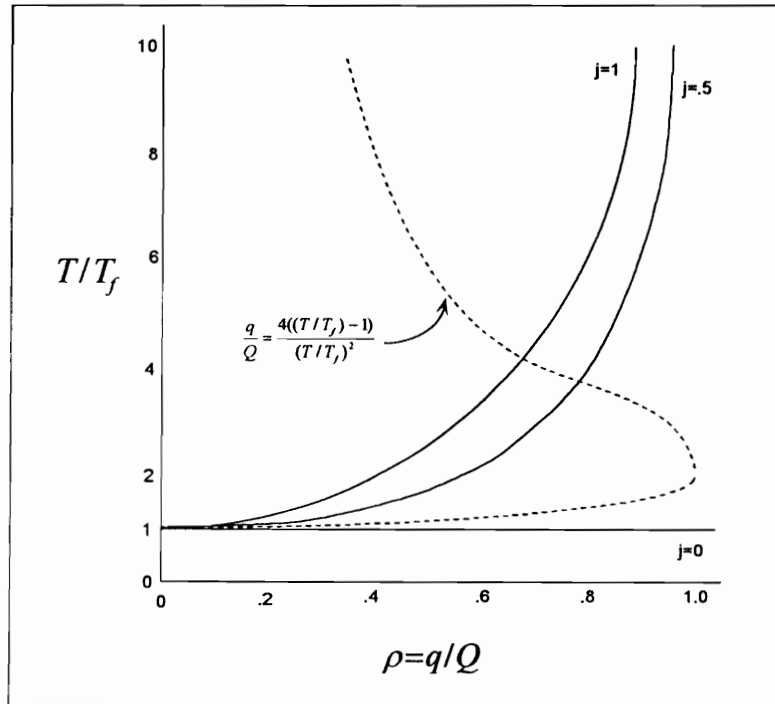


Fig. 4.2. Plot of  $T/T_f$  (Drew, 1993)

#### 4.1.3. Cost-Benefit Analysis

Cost-benefit analysis investigates the costs and benefits of each alternative, enabling the decision-maker to understand the consequences of a decision (McKenna, 1980). Similarly, Dickey and Miller (1984) define cost-benefit analysis as "the process of accumulating and comparing a project's benefits and costs so as to make some judgment on the advisability or inadvisability of the project or to compare the project to other projects." He refers to two basic types of determinations: determining costs and benefits accurately and expressing them in monetary terms.

Five elements are suggested for the process of cost-benefit analysis by McKenna (1980): (1) objectives, (2) alternatives, (3) benefits and costs, (4) a model, and (5) a criterion. Assumptions are made according to objectives. Technical assumptions should be made, such as the economic life of a project and the period of comparison. The economic life of a project is the period of time during which benefits can be expected, and is less than the physical life of the project. Comparisons are made based on all costs and benefits occurring during the period of comparison. Restrictions must be considered as part of the boundary of the decision making situation.

For the sake of simplicity, identifying costs and benefits are meaningful and necessary. Costs include initial and recurring costs, and benefits include tangible and intangible benefits. Private companies usually do not consider intangible benefits and spillover effects, which are rather subjective. Uncertainty is sometimes very crucial, and has three sources: uncertainty about cause-effect relationships, uncertainty about the future situation, and uncertainty related to chance effect (McKenna, 1980).

The time-value of money and the computing of present value are important parts of a cost-benefit analysis. The underlying time value of money is the basis for interest rates or discount rates. Computing present value is essential as a basis of comparison. The followings are terms for discovering present value: single payment present worth, uniform series present worth, and capitalized cost. The effects of inflation also can be factors, although they are not usually taken into account in B-C analysis.

Different comparison measures can be used for objectives and assumptions. Net present value simply shows the present value of total benefits minus total costs. Benefit-cost ratio, the so-called B/C ratio, is the present value of benefits divided by the present value of costs. Internal rate of return is a good measure of discount rates because a project is worthwhile when its internal rate of return exceeds the cost of the borrowing funds. The following equation is used for the computation of B/C ratio in infrastructure

developments, which is shown in a simple form:

$$BCR = \frac{R - E}{C \times r} (1 - e^{-n}) \quad (4.4)$$

where  $BCR$  = B/C ratio,

$R$  = annual revenues,

$E$  = annual expenses

$C$  = capital costs,

$r$  = annual interest rate, and

$t$  = life-span of the project.

## 4.2. Non-User Impact Analysis

### 4.2.1. Non-User Impacts

Nonuser benefits, also referred to as secondary or indirect benefits, are sometimes crucial for projects in infrastructure development of transportation. According to Dickey and Miller (1984), few long-term before and after studies of the non-user impacts of roads have been done, due to diverse impacts, change over time, and lack of funding. Several approaches were introduced in the previous chapter for non-user benefits. As for its characteristics, multi-criteria value comparison and sensitivity analysis for not-well defined values needs to be identified.

Harris Associates, Inc. (1974) refers to the benefits of highway systems: 1) construction expenditures; employment and income in other sectors of the economy, 2) reduction of the interregional transportation costs, an effect on the location of industries, 3) reduction of the amount of traffic congestion within a region, making it more attractive

as a location for industry and people. Perera (1989) classifies non-user consequences into the following economic categories:

1) Spending for highway construction

- Expenditure on labor and materials
- Secondary effects induced by direct expenditure

2) Land use and land values

- Loss of land due to Right-of-Way (R-O-W) acquisition
- Redistribution of jobs and services due to relocation attraction of people and business
- Land use changes
- Land value changes

3) Business activity

- Adjacent highway-oriented businesses
- Local general trade, and tourism and recreation

4) General industry

- Expansion of manufacturing, distributing, warehousing, and servicing types of industry, both light and heavy
- Attraction of basic, export industries classified as (1) fabricating or processing and (2) orientation to markets, resources or labor
- Business serving and household serving industrial induced growth

5) Agriculture

- Increase in productivity and profit
- Conversion of land to other uses

6) Mining and forestry

- Improved accessibility to markets

7) Energy

- Consumption associated with direct, indirect and induced effects.

#### 4.2.2. Measure of Effectiveness and Sensitivity Analysis

In cost-benefit analysis, benefits are identified in monetary terms. However, in non-user impact analysis, some values can hardly be quantified in monetary terms, such as convenience, quality of life, density, etc. Many methods have been developed to measure these kinds of values. However, they fail to include imported factors together. In this case, multi-criteria analysis can be adopted. Measures of effectiveness include not only the cost-benefit ratio or rate of return, but also many other types of criteria, such as GRP (Gross Regional Product), pollutants, quality of life, unemployment rate, and per capita income. Drew (1994a) indicates non-user benefits deriving from the decision variable 'number of lanes' to the measure of effectiveness 'unemployment rate' for transportation investments.

As another consideration, in any model, long-term or short-term, there is no guarantee that the future will follow the same trends as the past and present. In that case, uncertain values can be perceived in the range. According to the sensitivity analysis, some uncertain values can be dealt with. Sensitivity analysis can include factors such as industrial coefficients caused by technological change, financial change (budgeting), and changes in urban or regional structure owing to changed market strength. Change of travel costs can be regarded as endogenous, which will be covered in the next chapter.

#### 4.2.3. Environmental Impacts

Transport policy-makers have always appreciated that, in addition to economic benefits, transport imposes environmental costs. The concept of sustainability provides the sources of the negative impacts of development. Sustainable development is an attempt to balance environmental preservation and economic growth; it is development that meets the needs of present generations without compromising the ability of future generations to meet their own needs (Drew et al., 1996).

It is important to set up criteria for sustainable development with a focus on environmental factors. In other words, proper quantification needs to be carefully driven in this type of analysis. In highway construction and development, air quality and noise are crucial environmental factors in urban and metropolitan areas. Drew et al. (1996) show that environmental impacts can be considered separately from non-user benefits (Fig. 4.3).

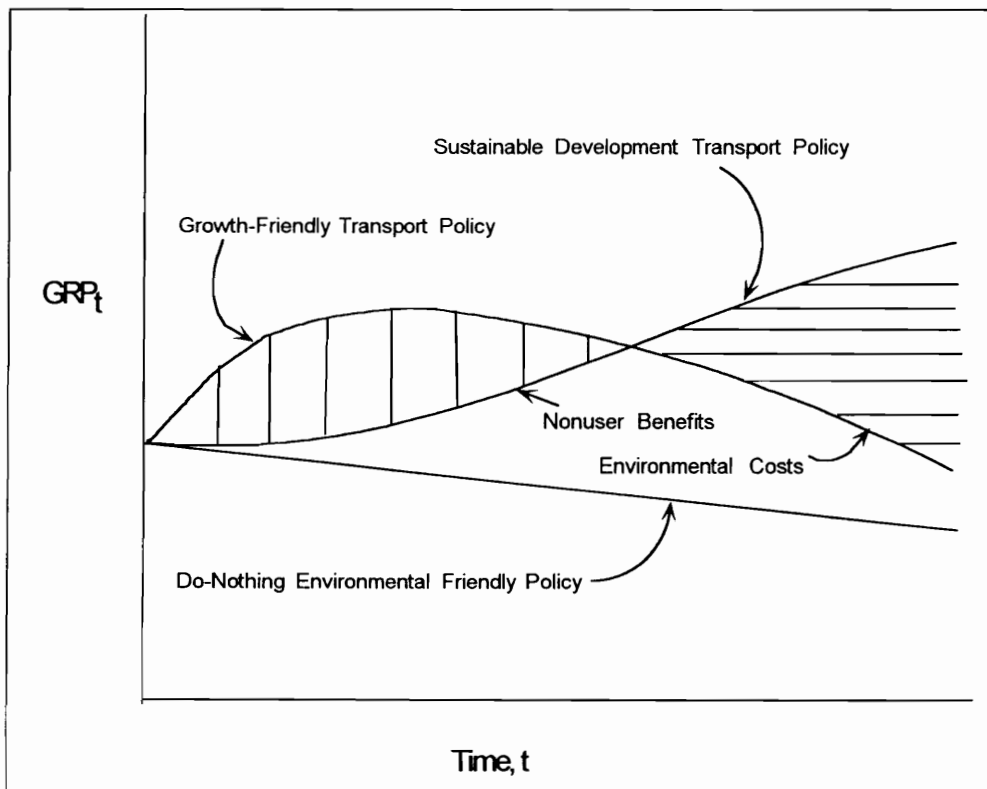


Fig. 4.3. Non-user benefits and environmental costs

## 5.0. TRANSPORTATION DEVELOPMENT METHODOLOGY (TDM)

Traditional models incorporate various aspects of the development process. Many of these models have been used to estimate the effects of transportation improvements; however, these models tend to emphasize and explain particular aspects, such as land use models, population models, location models, economic base models, or input-output models. Transportation planning is relatively long-term. A policy or improvement of transportation facilities can change the transportation/society structure. A better transportation facility induces more demands, ultimately resulting in more demand for a better facility. Thus, the black-hole theory of highway investment (Plane, 1986) indicates the endless need for transportation investments. The major drawback of the black-hole theory is in that it sees only a partial system of economy and transportation. In considering land use, housing, pollution, etc., a threshold or maximum tolerance state should be identified. Therefore, tools for estimating the transportation effects on regional economy need to be developed.

Where transportation, economy, and environments are concerned, it is necessary to have an accurate vision about their relationships in order to understand future implications. A lack of understanding of those relationships easily exacerbates the situation, in that proper investments in transportation facilities can maximize the utility or the profits in the regional economy, but on the other hand, the existence of an unsatisfied



demand for transportation will adversely effect the economy, and excessive pollution will require more capital to reduce pollutants, resulting in less productivity.

Drew (1994a) defines the requirements of a transportation/development methodology (TDM) as follows:

- Our first requirements for TDM is that it depict transportation initiatives and impact relationships in terms of variables so as to permit mathematical representation.
- Our second requirement for TDM is that it be applicable to the complete ranges of geographic scale (from interchange to corridor), mode (land, water and air transportation and their interfaces), and initiative (from project to program to policy).
- Our third requirement for TDM is that it be capable of developing theories so as to verify or refute conclusions regarding transportation and development interactions.
- Our fourth requirement is that TDM accommodate the three orientations -- user, provider and society -- and their values and goals so as to effectively trade off different policies.
- Since transportation development interactions are governed by feedback between supply and demand, analyzing supply and demand separately and in isolation will not even hint at overall behavior. Our fifth requirement is that TDM be comprehensive taking into consideration transportation investment to increase supply (capacity) and transportation management to smooth demand.
- A sixth requirement for TDM is that it makes use of the existing data bases generated in conjunction with the Urban Transportation Planning Process (UTPP) mandated during the period of Interstate Highway Planning.
- Requirement seven for TDM is that it be equally applicable to non-investment as well as investment initiatives. The advantage of incorporating the UTPP into TDM is that it provides a framework for defining a host of transportation initiatives including (1) communication substitution, (2) transit promotion, (3) increasing vehicle occupancy, (4) staggering work hours, etc.
- TDM should be a synthesizing device, accommodating the Development Process, the Urban Transportation Planning Process, User Benefits, Non-User Benefits, Investment Initiatives and Non-Investment (Management) Initiatives, and new transportation technologies such as ITS.

In TDM, several sectors need to be connected with feedback, including transportation, population, land use, industry (regional economy), and environments. Most of the current methodologies emphasize one or two, resulting in an imbalance. However, ideas and concepts can be adopted from current methodologies. For example, UTPP has strengths in estimating travel time and I-O model has merits in interindustry and multiregional flow. System dynamics can connect UTPP and I-O model on its system base, and migration, limited resources, and pollution can be added.

Based on the requirements of TDM, a proposed TDM process is described in Fig. 5.2. where Fig. 5.1. represents a simplified conventional transportation planning process. In TDM, various concepts of input-output analysis are adopted in the form of system dynamics modeling. Sectors, except for the demographic sector, rely on ratios and coefficients from input-output analysis. TDM incorporates concepts of UTPP, I-O analysis, land use models (the Lowry model), and System Dynamics model. Scenario analysis and sensitivity analysis can be done based on this framework.

### 5.1. Regional TDM

The major purpose in developing a transportation/development methodology (TDM) is not only to forecast the future, but also to influence and to help the decision-maker in deciding which of the candidate alternatives is preferable. A methodology for constructing regional transportation/development models would follow verbal descriptions, a causal diagram, and the mathematical model.

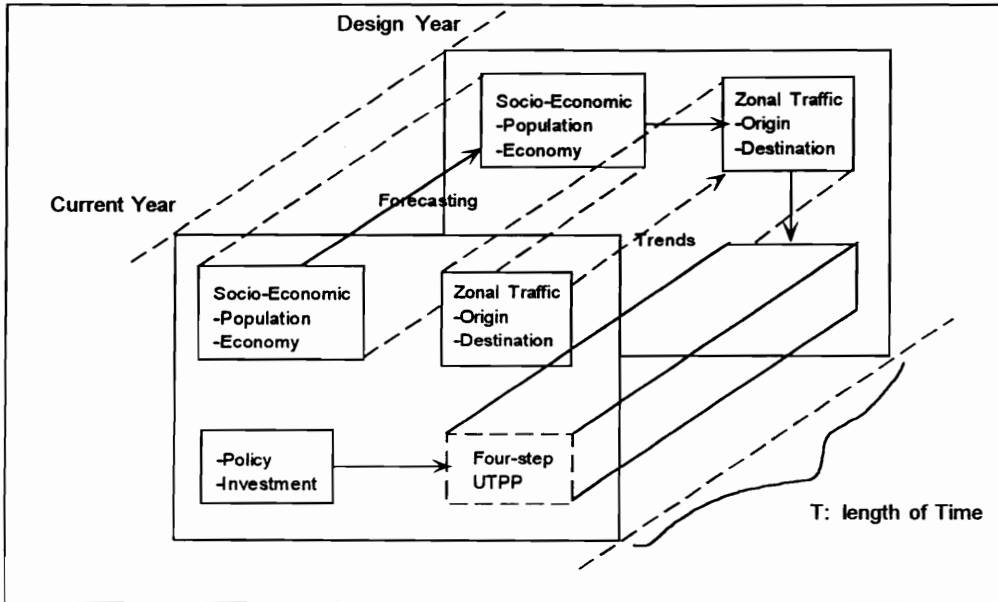


Fig 5.1. A simplified conventional transportation planning process

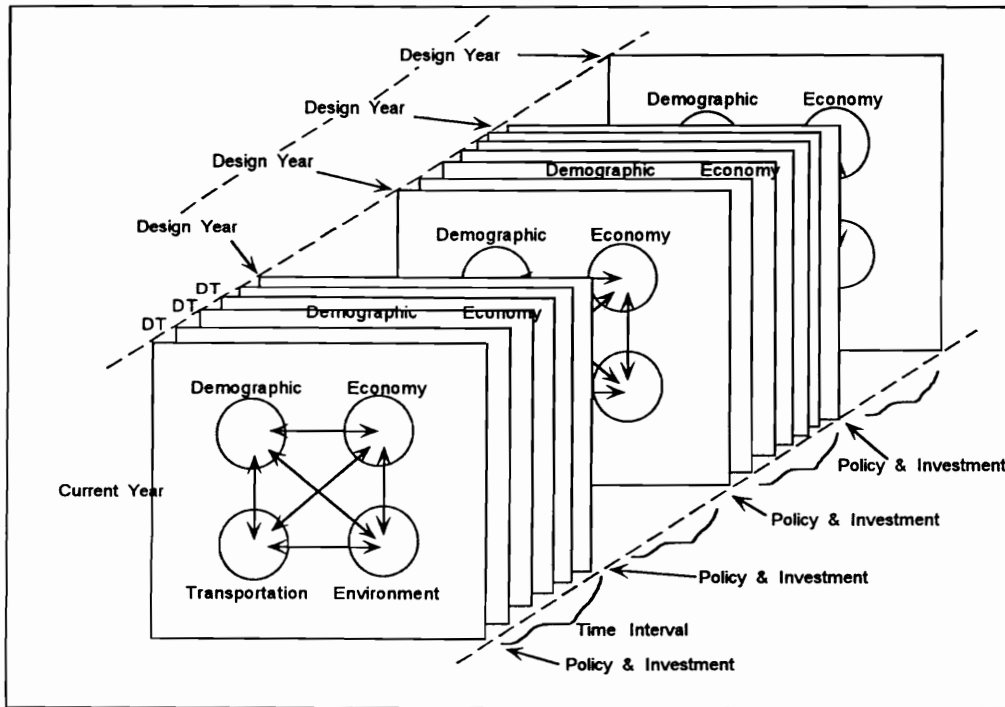


Fig. 5.2. A simplified version of a proposed transportation/development modeling process

A comprehensive model is essential for evaluation of projects and for making comparisons among alternative policies before execution. Subcategories or submodels should be carefully selected concerning input variables. Drew (1994a) categorized the urban systems into two: (1) those related to the urban socio-economic structure such as the population, industrial, and residential systems; and (2) those that serve the urban community, called the “urban technological systems,” such as water supply, energy, transportation and the environment. Therefore, a modeling of regional systems can be developed based on the following sectors as a minimum; 1) demographic sector; 2) regional economy sector (industry); 3) employment sector; 4) land use sector; 5) transportation sector; and 6) environment sector. This section concentrates on a prototype; the model can be explored more in detail with more data and information.

#### 5.1.1. Demographic Sector

In the demographic sector, the state or level variable is Population (P). It is affected by three rate variables: Net Population Growth (NPG), In-Migration (IM), and Out-Migration (OM). The first two serve to increase the state variable, and the third decreases it. The relationship can be expressed in the following integral equation:

$$P_t = P_{t-1} + \int_{t-1}^t (NPG_t + IM_t - OM_t) dt \quad (5.1)$$

Net population growth means births minus deaths in a given time. The number of births in a projection period is “multiplying the female population in the childbearing cohorts by the appropriate age-specific birth rates (Klosterman, 1990).”

$$NPG_t = P_t \times NGF \quad (5.2)$$

where *NGF* is a net growth factor (1/yr).

$$OM_t = P_t \times OMN \quad (5.3)$$

where *OMN* is an out-migration normal factor (1/yr).

$$IM_t = P_t \times IMN \times AM_t \quad (5.4)$$

where  $IMN$  is an in-migration normal factor and  $AM$  is an attractiveness multiplier.

$$AM_t = RLAM_t \times JAM_t \tag{5.5}$$

where  $RLAM$  is a residential land availability multiplier and  $JAM$  a job availability one.

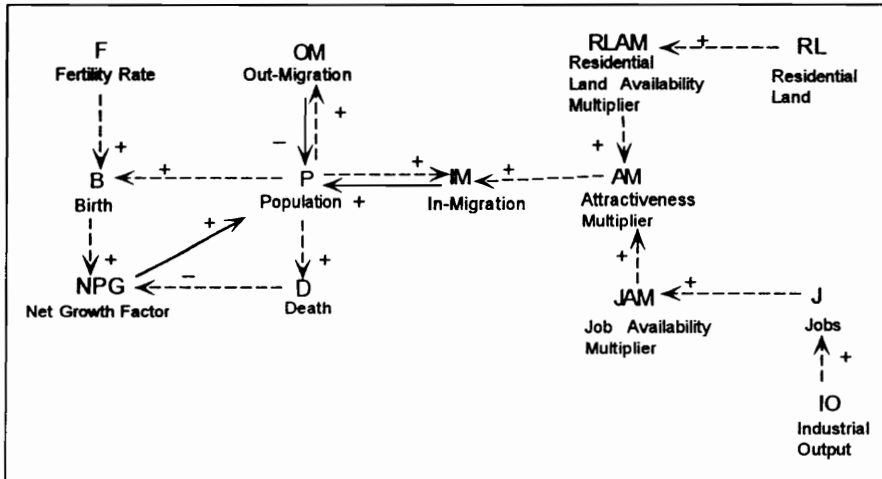


Fig. 5.3. Causal diagram of demographic sector

Demographic analysis can be made with several age groups or cohorts, and with several income groups. Fertility rates can be changed by factors such as those found in World Dynamics. Joint economic-population models with concentration of employment and a holding capacity approach such as land use capacity, density, saturation, or carrying capacity approach are considered as factors for immigration (Kaiser et al., 1995). Thus, residential land availability and job availability are the most crucial factors in migration.

### 5.1.2. Regional Economy Sector (Industry Sector)

Many of the sectors in the regional or national setting to be modeled can be considered as elements in a national account. The national accounts are concerned with the measure of aggregate output produced within the geographical boundary of a nation to gain a picture of the nation's economic performance. The most comprehensive measure of

national output is the gross national product (GNP). GNP is the value of all goods and services produced annually in a country. The “value-added” approach is used to avoid double-counting, i.e., to include only final goods and not the intermediate goods which are used to make the final goods (Drew et al., 1996).

Expenditure components of GNP, which means a final use of GNP, include private consumption, private investment, government consumption, and net export. Investment refers to that portion of the final output which takes the form of additions to or replacements of capital. Government purchases of goods and services are a second component of GNP. In addition, government makes other expenditures, “transfer payments,” which do not represent the purchase of output and are consequently excluded from GNP. Consumption refers to the portion of nation’s output devoted to meeting consumer wants. Net exports, exports minus imports of goods and service, are a final use of GNP and must be included in our total (Drew, 1989).

In the U.S. input-output accounts (BEA, 1991), GNP statistics are subdivided into nine major categories, which are mutually exclusive and collectively exhaustive, based on the Standard Industrial Classification (SIC). The description of the nine major categories (SIC 1 digit level) are in Table 5.1.

Table 5.1. Nine major categories in the U.S. input-output accounts: SIC 1-digit code (BEA, 1991)

SIC 1-digit code	Classification: Industries	Classification: Commodities
1	Agriculture	Agricultural Products
2	Mining	Minerals
3	Construction	Construction
4	Manufacturing	Manufactured products
5	Transportation	Transportation
6	Trade	Trade
7	Finance	Finance
8	Services	Services
9	Other	Other

Using these categories, the economic sector of the model can be disaggregated into virtually hundreds of subsectors, if desired, each with its own capital-output ratio, capital-labor ratio and pollutants per unit of output (Drew et al., 1996).

Input-output analysis uses a matrix showing interindustry relationships. Labor and capital requirements can be estimated as well as total output. A portion of Gross Regional Product (GRP) is used as investment and capital is depreciated with its lifetime. Dynamic input-output analysis can be used for investment of capital. In dynamic I-O analysis, capital can be a constraint for output because lack of enough capital cannot match the demand.

In I-O analysis, a partial change in final demand is usually considered; in fact, the whole structure of regional economy, i.e., the total final demand, should be considered because we need to take into account several scenarios with fixed budgets for public investment. In other words, we need to decide on the ranks of policies or investments. Concepts of supply-side input-output analysis are adopted. If not, we need to find the final demand exogenously for each time interval.

Aschauer's research found that total factor productivity has a significant positive statistical relationship with the net stock of government (non-military) capital stock (Apogee Research, Inc., 1989). Concepts of production function can be adopted for the change of final demand. A simple production function can be the following:

$$Q = AL^\alpha K^\beta \quad (5.6)$$

where  $Q$  = output, a measure of economic development

$A$  = efficiency parameters

$L$  = labor input

$K$  = capital input

$\alpha, \beta$  = labor and capital distribution parameters, respectively

Economic development occurs if, when holding  $\alpha$  and  $\beta$  constant, output ( $Q$ ) increases due to an increase in labor ( $L$ ), capital ( $K$ ) or both. Meanwhile, productivity increase

occurs if, when holding  $L$  and  $K$  constant, output  $Q$  increases. Gains in productivity could be included within a broad definition of economic development (Apogee Research, Inc., 1989). Production function has been used for transportation capital stock and investments. Similarly, Leontief (1986) described direct and indirect requirements of capital and labor per final output required for domestic production of each of the many types of commodities exported and imported by the U.S.

A change in transportation costs affects productivity by changing the fraction of industry output to input (FIOI). For example, increased transportation costs will reduce productivity, resulting in less output using the same capital of industry. However, great confidence is required for supply-side analysis. It is doubtful that capital can produce a fixed rate of output, because we need to have enough demand for more production. Market analysis should be preceded by supply-demand functions and projected final demand can be introduced with delay. Appendix E.1. shows an example of a demand-side dynamic I-O analysis, which does not consider inflation, price, and labor requirements.

The final demand of a region for future years can be obtained using regression analysis based on past trends with income change. Liew and Liew (1984) used the BEA Personal Income Projections for the base data for the industrial projection. Harris (1974) used personal income projections for econometrics and Johnson (1996) used time series data for dynamic input-output analysis.

In TDM, Gross Regional Product (GRP) is the following:

$$GRP_t = \sum FP_t(i) \quad (5.7)$$

where  $FP$  is final product of industry  $i$ .

A column vector, final product (FP), i.e.,  $Y$  can be obtained:

$$Y = (I - A) \times X \quad (5.8)$$

where  $A$  is a technical coefficient and  $X$  is a vector of total output ( $IO(i)$ ).

Industrial output (IO) is obtained:

$$IO_t(i) = IC_t(i) / COR_t \quad (5.9)$$



where  $IC$  is capital of industry  $i$  (\$),  $COR$  is capital-output ratio.

$$IC_t(i) = IC_{t-1}(i) + \int_{t-1}^t (CI_t(i) - CD_t(i))dt \quad (5.10)$$

where  $CI(i)$  is capital investment (\$/yr) and  $CD(i)$  is capital depreciation (\$/yr).

$$CD_t(i) = IC_t(i) / ALC(i) \quad (5.11)$$

where  $ALC(i)$  is average lifetime of capital, industry  $i$ .

$$CI_t(i) = GRP_t \times FGRPI_t(i) \quad \text{or} \quad CI_t(i) = VA_t(i) \times FVAI_t(i) \quad (5.12)$$

where  $GRP$  is gross regional product (\$/yr),

$FGRPI(i)$  is a fraction of  $GRP$  to investment to  $i$  industry,

$VA(i)$  is value-added to  $i$  industry (\$/yr), and

$FVAI(i)$  is a fraction of  $VA(i)$  to investment to  $i$  industry.

Per capita income (PCI) is:

$$PCI_t = GRP_t / P_t \quad (5.13)$$

Capital output ratio can be changed by pollution costs, technological change, etc. A row vector of transportation industry will be directly influenced by a change in travel costs (Liew and Liew, 1984). If GRP seems much higher than the projected final demand, an adjusted final demand can be used instead of final demand driven by a capital and technical coefficient matrix. A change in the technical coefficient matrix seems necessary for long-term forecasting, which should be done carefully and with reasonable assumptions.

### 5.1.3. Employment Sector

Labor force (LF) is a portion of the population. The ratio of labor force to population can change based on cohort analysis and participation of women over time. Obviously, the proportion of the labor force in rural areas is different from that in cities. In-migration and out-migration do not mean that all the family members move. Jobs

depend on the available labor force and quality of skills. Increased available jobs do not always mean an increase of jobs in the designated area.

$$LF_t = P_t \times LPF \quad (5.14)$$

where  $LPF$  is a labor participation fraction factor (persons/person)

Jobs are the sum of jobs in each SIC industry, and industry jobs can be acquired with output/job ratios or capital/job ratios through input-output analysis.

$$J_t = \sum_{i=1}^m J_t(i) \quad (5.15)$$

where  $J_t(i)$  is number of jobs in  $i$ th industry at time  $t$ .

$$AJ_t(i) = O_t(i) / OLR \quad \text{or} \quad AJ_t(i) = C_t(i) / CLR \quad (5.16)$$

where  $AJ(i)$  is available jobs of industry  $i$ ,

$O(i)$  is output of industry  $i$  and  $C(i)$  is capital of industry  $i$ , and

$OLR$  is output labor ratio and  $CLR$  is capital labor ratio.

$$UR_t = \frac{LF_t - J_t}{LF_t} \quad (5.17)$$

where  $UR$  is unemployment rate (DIM).

Industrial jobs cannot exceed the numbers in the labor force, but available industrial jobs can. As job availability increases the number of immigrants, the gap between available jobs and the labor force will be reduced over time by in-migration when there are enough jobs. Skill levels in the labor force can be also adopted in the analysis.

#### 5.1.4. Land Use Sector

Land availability can be a constraint in development. Commercial and industrial areas can be used as constraints in input-output analysis. Land occupancy can be the sum of required land in each SIC industry, and land for each industry can be determined by output/land ratios or capital/land ratios through input-output analysis.

$$L_t = \sum_{i=1}^m L_t(i) \quad (5.18)$$

Commercial and industrial land can be segregated based on the characteristics of the SIC industry. As in the employment sector, the priority of land for each industry can be decided with price and elasticity where there is not enough land left, but the maximum holding capacity will also continue to be a good indicator. Concerning household size and land per dwelling units and population, the holding capacity and the maximum residential area can be indicated. The following equations can be also adopted for residential land.

$$RLAM_t = 1 - RLFO_t \quad (5.19)$$

where  $RLFO_t$  is a residential land fraction occupied (DIM).

$$RLFO_t = P_t \times LPD / (PPD \times LZR_t) \quad (5.20)$$

where  $LPD$  is a land per dwelling factor (acres/unit),

$PPD$  is a persons per dwelling factor (persons/unit), and

$LZR_t$  is land zoned residential area (acres) as a function of commuting travel time.

The land use sector is especially important on the urban and metropolitan levels. In regional TDM the region is fairly spacious, therefore, tract or zone analysis is difficult to do on this level. More detailed information and data can be done for the urban level, integrating fully transportation and land use together. As shown in Ch. 3., the Lowry model or a gravity model can be incorporated into the regional TDM when needed.

#### 5.1.5. Transportation Sector

A model of the transport sector can be used in the determination of a transport policy where economic models have been and still are to be considered the most powerful tools for economists (Drew, 1994a). In TDM, the transport sector is introduced on a more aggregate level than the existing transport and traffic model.

Peak-hour traffic is decided by peak period commuter trips and peak period truck traffic. Peak period commuter trips can be obtained by number of jobs and trips per job. Detailed information, including origin and destination, can be used with careful adjustments for each highway. Peak-hour traffic demand is the sum of peak-hour car equivalents of highway truck traffic and highway commuter traffic. The demand-capacity ratio (DCR) is calculated by dividing demand by capacity, and DCR can show travel time and costs with the transportation mobility index.

Peak-hour traffic demand (PHTD, veh/hr) is the following:

$$PHTD_t = DPP \times PPHCT_t / AVO + PHCE_t \quad (5.21)$$

where  $DPP$  is duration of peak-period (hour/period),

$PPHCT$  is peak-period highway commuter trips (trips/period),

$AVO$  is average vehicle occupancy (persons/vehicle), and

$PHCE$  is peak-hour car equivalents of truck traffic (veh/hr).

$$PPHCT_t = PPCT_t \times HMS \quad (5.22)$$

where  $PPCT$  is peak-period commuter trips (trips/period),

$HMS$  is highway modal split (DIM).

$$PPCT_t = J_t \times TPJ \quad (5.23)$$

where  $J$  is jobs (person) and

$TPJ$  is trips per job (trips/person).

$$PHCE_t = PPTT_t \times PCE / DPP \quad (5.24)$$

where  $PPTT$  is peak-period truck traffic (trucks/period) and

$PCE$  is passenger car equivalents (veh/truck)

$$PPTT_t = \frac{\sum IO_t(i) \times TPIO(i)}{PPPY} \quad (5.25)$$

where  $IO(i)$  is industrial output of industry  $i$ ,

$TPIO(i)$  is trucks per industrial output (trucks/\$) and

$PPPY$  is peak-periods per year (periods/yr).

The fraction of industrial output to input (FIOI) can be the following:

$$FIOI_t = FIOIN \times DCR_t / DCRN \quad (5.26)$$

FIOI can be obtained by including more detailed equations. A row vector of the transportation industry is to be changed and coefficients of a row vector of transportation industry can be the following:

$$FIOI_t(i = transp, j) = \frac{TT_t(t = transp, j)}{TTN} \times FIOIN(i = transp, j) \quad (5.27)$$

where  $i, j$  are a row and column vector in the input-output coefficient matrix,

$TT$  is travel time, and  $TTN$  is initial travel time.

Equations for the transportation mobility index (TMI) can be:

$$TMI_t = TTN / TT_t = \frac{FFTTN \times (1 + DCRN)}{FFTT_t \times (1 + DCR_t)} \quad (5.28)$$

where  $FFTT$  is free-flow travel time,  $FFTTN$  is initial free-flow travel time,

$DCR$  is demand to capacity ratio, and  $DCRN$  is initial value of  $DCR$ .

$$DCR_t = PHTD_t / HC_t \quad (5.29)$$

where  $HC$  is highway capacity (veh/hr)

$$HC_t = NL_t \times LC_t \quad (5.30)$$

where  $NL$  is number of lanes (lanes) and

$LC$  is lane capacity (veh/hr-lane).

Truck costs include fuel consumption, engine oil consumption, tire wear, depreciation, interest, maintenance costs and time savings (improving vehicle turnaround and lowering driver costs). According to Harris associates, Inc. (1974), truck costs can be quantified in terms of speed relationships instead of travel times.

#### 5.1.6. Environment Sector

Forrester applied his system dynamics concepts to “the limits of growth” and developed a series of World Models. Since the late 1960’s environmental considerations, including limited resources, motivated growth management programs and many cities,

counties, and towns in the United States have instituted growth management programs (Levy, 1991).

The World Commission on Environment and Development published a book for “a global agenda for change”, called *Our Common Future* (World Commission on Environment and Development, 1987). Ecological concepts have been accepted in the term, “sustainable development.” Pearce and Warford (1989) referred to quality of life and equity, illustrating three ideas as paths of welfare over time: optimality, survivability, and sustainability. The concept of sustainability has been used in a more strict sense than the concepts of survivability or steady state that were generally accepted previously in planning.

It is important to set up criteria for sustainable development with a focus on the environmental factors such as natural resources, including wetlands, forests, and habitats, and pollution in land, air, and water. It is also necessary to adopt criteria based on future laws and regulations, as well as on the current ones. Pollution can be covered by TDM because it is more tangible than other important environmental factors such as forests, wetlands, habitats, etc. Pollution can simply be divided into three categories: land, water, and air pollution. In input-output analysis, generation of pollutants can be obtained by pollutant-output ratios. In highway construction and development, air quality and noise are crucial environmental factors, especially in urban and metropolitan areas. Pollutants generated by traffic can be obtained by vehicle fuel consumption as well as by industrial output.

The Intermodal Surface Transportation Efficiency Act of 1991 indicates the importance of ITS (Intelligent Transportation Systems), high-speed ground transportation systems, magnetic levitation technologies, and electric vehicles. Where pollution is concerned, complex trade-offs can arise in introducing those technologies; for example, electric vehicles are practically emissions-free, but the plants that produce electricity are not (Papacostas and Prevedouros, 1993). Thus the entire picture of pollution sources and consequences must be envisioned before decisions are made. Papacostas and Prevedouros

(1993) also indicated that relationships between speed and emissions are different for pollutants such as CO, HC and NO<sub>x</sub>.

Pollution or pollutant (POL(k)), expressed in P.U., pollution units, can be the following:

$$POL_t(k) = POL_{t-1}(k) + \int_{t-1}^t (PGR_t(k) - PAR_t(k))dt \quad (5.31)$$

where  $PGR(k)$  is pollution generation rate of  $k$  pollutant (P.U./yr) and

$PAR(k)$  is pollution absorption rate of  $k$  pollutant (P.U./yr).

Leontief (1986) provided direct 1967 air pollution output coefficients for particulate, SO<sub>x</sub>, HC, CO, and NO<sub>x</sub> (thousands of tons emitted into the atmosphere per million dollars of output, with the output of each industry measured in 1963 prices); Information of pollutant-output generation coefficients can be obtained easily to each SIC industry. Information about duration of air pollutants is also needed. Pollutants for land and water as well as air can be included for analysis.

$$PGR_t(k) = \sum_{i=1}^m IO_t(i) \times PPO(i, k) \quad (5.32)$$

where  $PPO(i, k)$  is  $k$  pollutant-generation ratio to  $i$ th SIC industrial output.

$$PAR_t(k) = POLAM_t(k) \times POL_t(k) / PAT_t(k) \quad (5.33)$$

where  $PAT(k)$  is pollution absorption time of  $k$  pollutant (yr) and

$POLAM(k)$  is pollution absorption multiplier (units/yr).

$$PAT_t(k) = PATN(k) \times POLA_t(k) \quad (5.34)$$

where  $POLA(k)$  is pollution absorption time multiplier and

$PATN$  is initial pollution absorption time.

POLA is a table function of POLR (pollution ratio), which can be obtained by experimental or empirical data. Environmental factors such as noise are caused only by generation for a certain time period without cumulation effects.

$$POLA_t(k) = f(POLR_t(k)) \quad (5.35)$$

where  $POLR(k)$  is pollution ratio (DIM).

$$POLR_t(k) = POL_t(k) / POLN \quad (5.36)$$

where  $POLN$  is initial pollution

Pollutants from traffic can be dealt separately from those by industrial outputs. Vehicle fuel consumption, affecting vehicle pollution generation rate (VPGR) with pollutants per gallon (PPG), is affected by fuel efficiency (FE) and vehicle-miles travel (VMT). Vehicle-miles travel (VMT) can be obtained from vehicle ownership (VO) and vehicle usage (VU) (See Fig. 5.6). Non-renewable resources and other natural resources can be obtained in a similar way to the above equations.

Capital inputs, such as pollution-abatement equipment and more efficient engines, can be used to reduce exhaust wastes, thereby reducing the consumption of clean air. Thus, capital essentially may be substituted for clean air in the production of transport services (Bureau of Transportation Statistics, 1995). The total output and traffic affect pollutants, reducing economic productivity by increasing COR (capital/output ratio).

#### 5.1.7. Prototype of Regional TDM

Major factors for transportation/development methodology are expressed in Fig. 5.4. Based on previous equations for each sector, graphical interpretations of User and Nonuser benefits for transportation initiatives can be driven (Fig. 5.5). TDM and the sustainable development paradigm employ the system dynamics modeling methodology for assessing socioeconomic benefits and environmental costs quantitatively, as in Figs 5.5, 5.6, and 4.3. One can easily prepare a policy summary that indicates which policy variables affect user benefits (the Demand-Capacity Ratio, DCR) and non-user benefits (the Gross Regional Product, GRP). Appendix E.2 gives an example of a prototype of regional TDM, which lacks the environment sector. Steady state analysis and transient analysis are also introduced. The measures of effectiveness,  $DCR_e$  and  $GRP_e$  are expressed by other values.



Based on TDM, scenario analysis can be done. In transportation, investment policy such as an increase in the number of lanes affects number of lanes (NL), ultimately increasing highway capacity (HC). Advanced technology can reduce the average headway between vehicles, affecting lane capacity (LC). Transportation Systems Management (TSM) can be equally effective by increasing Average Vehicle Occupancy (AVO), increasing the Duration of the Peak Period (DPP), etc. Chapter 6 covers several transportation policies for the Interstate 81 corridor. In order for the nonuser benefits to be pro-rated among different infrastructure initiatives, the breakdown of FIOI shown in Fig. 5.7 is required.

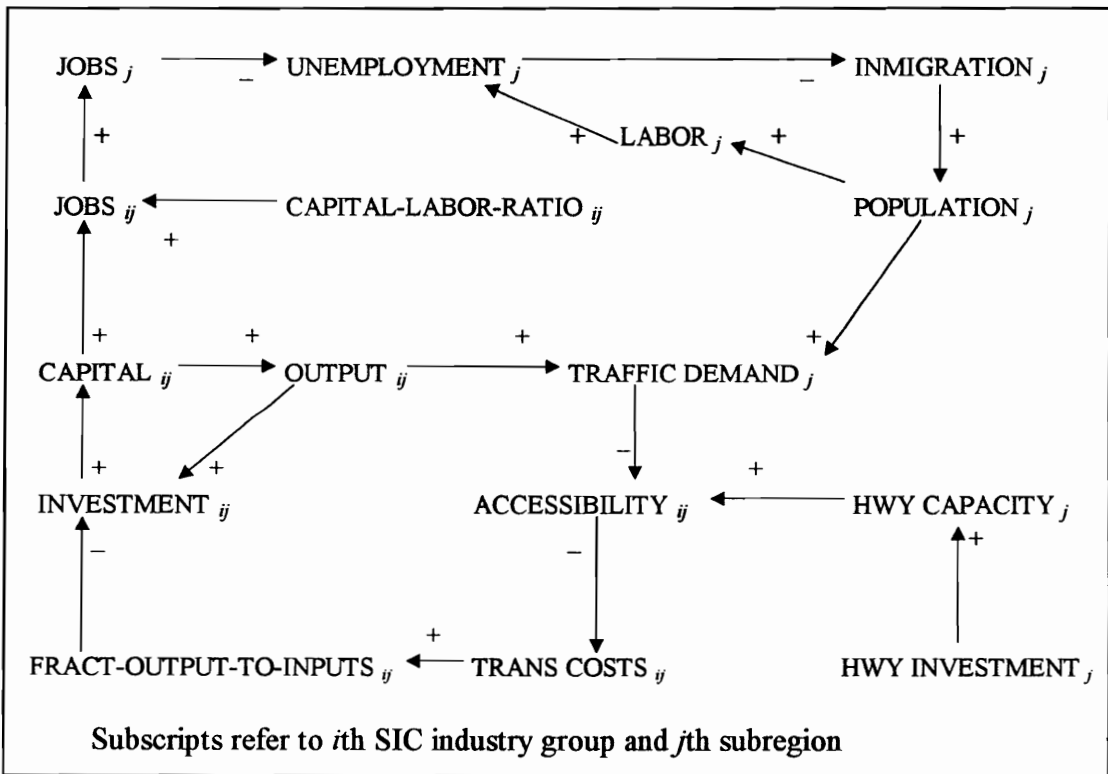


Fig. 5.4. Methodology for measuring regional transportation/development.

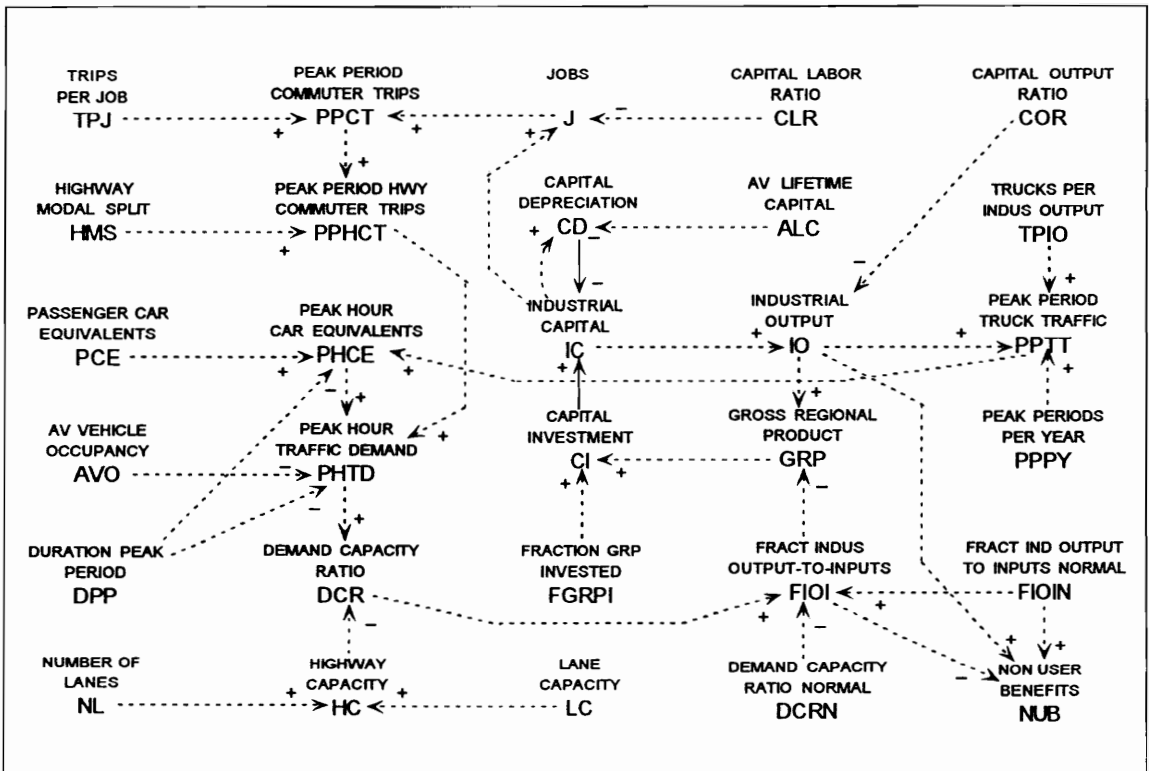


Fig. 5. 5. Transportation-economic development relationships

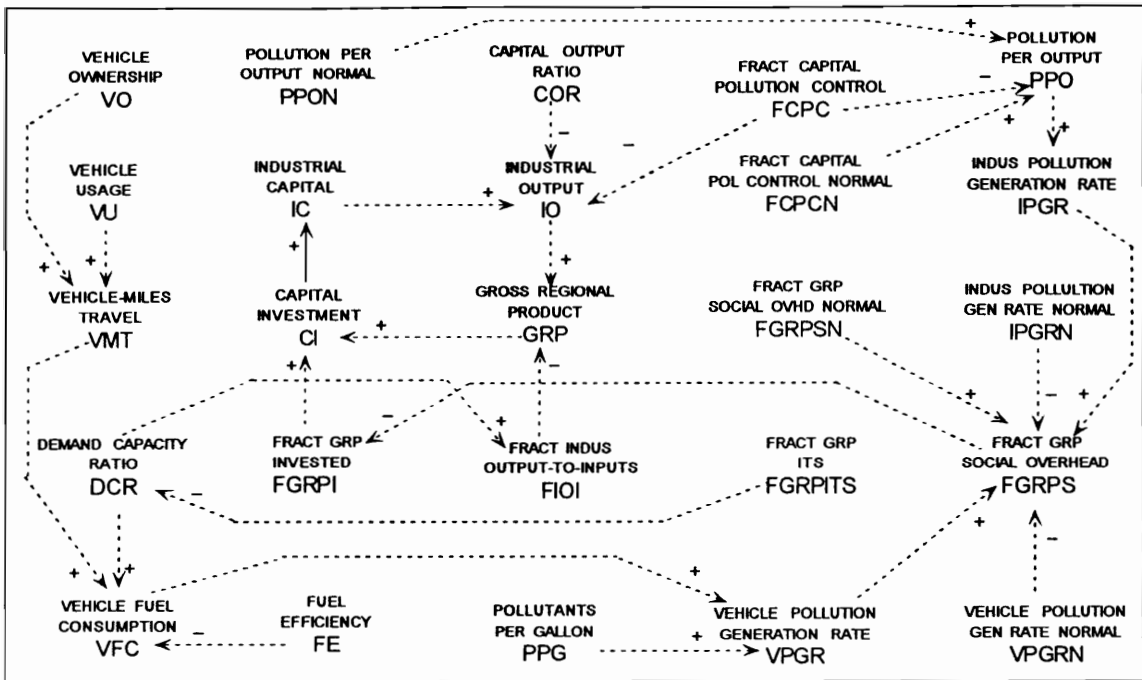


Fig. 5. 6. Environment-economic development relationships (Drew et al., 1996)

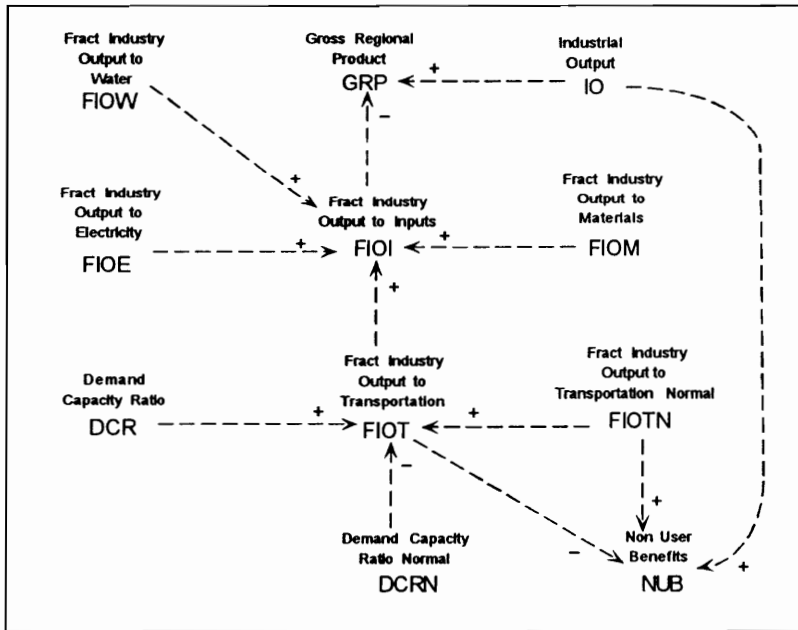


Fig. 5.7. Causal diagram of breakdown of FIOI (Drew, 1994a)

## 5.2. Multiregional Transportation Development Model (MTDM)

In the previous section, regional TDM was introduced. Although regional leakage in regional economies and net migration are considered, interregional relationships were not considered. Generally speaking, transportation impacts are not restricted to one region, but also affect adjacent areas; in fact, economic and environmental impacts induced by transportation will affect various scales of regions. When we consider the regional TDM as a prototype, each of the economic subregions in the highway corridor can be modeled separately, but in similar fashion.

Interregional effects can occur in the following areas: migration, capital flow, accessibility, interregional trade flow, and environmental effects, including pollution. The relationships and effects of the above factors among regions should be carefully examined before analysis. Migration and accessibility are covered in the previous section and environmental effects among regions are beyond the scope of this research. As Drew (1994a) indicates that multiregional input-output models provide a powerful tool for analyzing transport demands at the macroeconomic level, MRIO can provide interregional trade flow and the transport demands based on trade flow. Fig. 5.8. shows the major factors affecting multiregional TDM.

However, on the multiregional level, the substitution effects of market strength and price changes are crucial. For example, reduced travel costs of commuters and trucking generate more value-added for households, companies, and governments, ultimately increasing market strength. However, a better accessibility in rural areas can produce out-migration for outside regions and increase crime rates, affecting social overhead costs; therefore, factors affected by accessibility should be carefully dealt with.

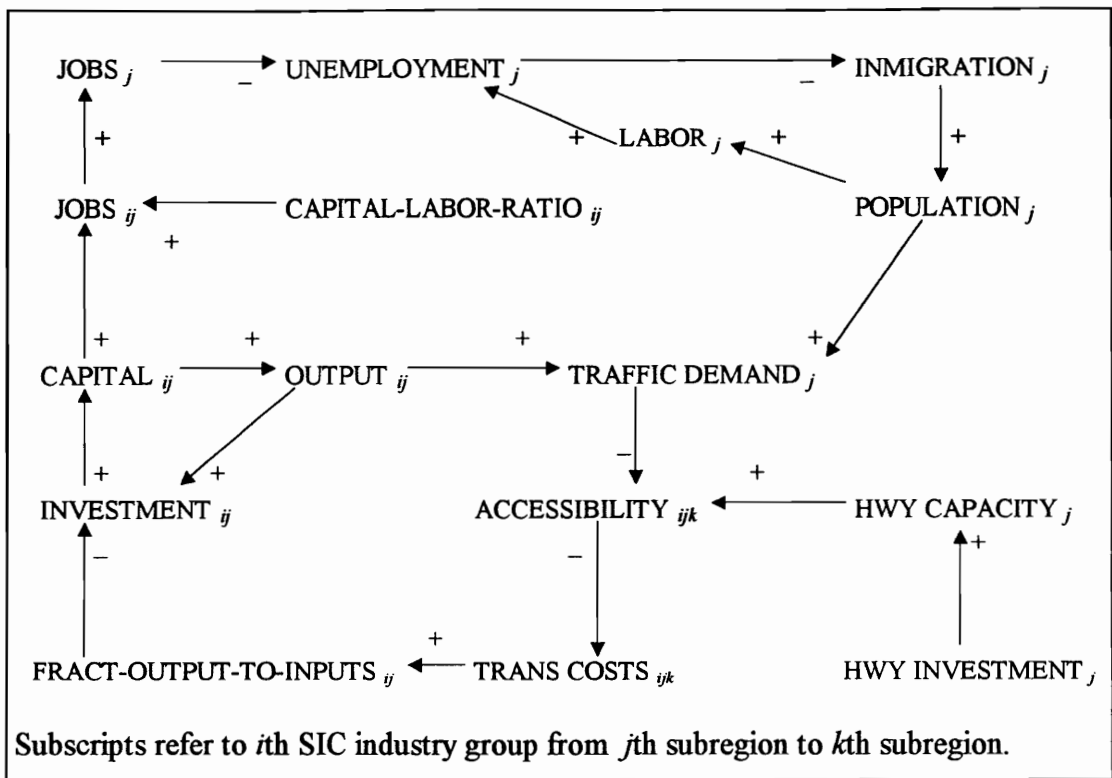


Fig. 5.8. Methodology for measuring multiregional transportation/development.

Interregional I-O analysis is ideal for many-region models. However, partial or non-survey methods are unavoidable in real world applications. The RAS-adjusted, gravity model (or balanced regional model), and a column-coefficient MRIO can be used for an interregional trade flow matrix. Interregional trade flows in a column-coefficient MRIO come from commodity flow data, which deals with state levels. Therefore, other methods such as RAS-adjusted and balanced regional models can be used for the local and county levels, as a trade-off for accuracy. As multiregional I-O analysis, especially a column-coefficient model, is very rudimentary in spatial orientation, Lowry-type models with land-use and transportation in small scale regions can be dealt with as needed. After forecasting population and regional economy, local economy and spatial relocation of industries and population, including employment, can be done with the Lowry-type

models. Based on origins and destinations, the UTPP can be used for mode choice and route selection in MTDM. Thus, I-O analysis, the Lowry model, and the UTPP can be incorporated fully in the MTDM for regional, metropolitan, and local areas, based on a system dynamics approach. Appendix E.3 presents an example of MTDM in a hypothetical area and Appendix B.3. can be incorporated with MTDM for local forecasting. For environmental effects, including pollution, a very large area such as a state level is not appropriate for investigation. It is more effective for a city or metropolitan area to be analyzed as one region.

## 6.0. INTERSTATE 81 CORRIDOR STUDY

Interstate Highway 81 goes through six states of the U.S., as a backbone of both passenger and freight transport. It connects Tennessee, Virginia, West Virginia, Maryland, Pennsylvania, and New York, between Knoxville, TN and Watertown, NY with a total length of about 850 miles. Geographically, it is a main connection between the southern economic hubs of Atlanta, New Orleans, Houston, and Dallas to the northeastern United States (Center for Transportation Research, 1996).

The Interstate 81 (I-81) highway has congestion problems in Virginia and the Commonwealth of Virginia is currently engaged in planning the future development of highway system and regional development along the I-81 corridor. Subjects for debate are: opposition by residents, environmental deterioration, and distributional effects and budget problems. In addition, Intelligent Transportation Systems (ITS) has been debated in the context of the corridor.

Development scenarios for improving regional economies, as well as for giving better service and reducing congestion, are to be analyzed in order to evaluate their effectiveness. Therefore, a simulation study using scenarios concerning transportation investment and programs is required. Scenarios for the I-81 corridor include the following: 1) no improvement, 2) additions of lanes, 3) exclusive truckway, 4) ATMS (Advanced Transportation Management Systems) applications, and 5) Hybrid Personal Maglev (HPM).

## 6.1. Study Area: Interstate 81 Corridor

The spread of the use of private transport has created its own type of low density residential area - a type that no other transport mode can efficiently serve - and also has created a host of service industries. By changing people's living patterns and lifestyles, the automobile has made itself economically indispensable and is an integral part of modern culture, but it has brought with it monumental problems of traffic congestion and atmospheric pollution (Drew et al, 1996).

Increasingly, just-in-time industry and distribution industry can introduce various income classes and may introduce more manufacturing industry in the future, which also relies on highways. The southwest part of Virginia, including Roanoke and Pulaski, is good for the distribution industry, which is based on the 'just-in-time' concept (Yancey, 1995), and requires reliable highway travel time. However, the I-81 highway has congestion problems (level of service C, D or E) during weekday peak hours in Virginia, especially near urban areas (VDOT, 1992). As we project from past trends, in a few years it will have serious congestion, mostly D, E, or F in these urban areas, affecting commuter traffic and truck travel time, ultimately reducing potentially productive hours and economic productivity.

Planning District Commissions 3 - 7 in Virginia created the I-81 Corridor Council in 1990 to strengthen relationships between corridor communities and to begin developing a regional strategic plan (Hensley, 1991). Subsequently Planning District Commissions 1 and 2 joined the Council. The Commonwealth of Virginia and the seven planning districts strive for the proper investments and programs to be done in a timely manner. They are also interested in ITS technologies, and are attempting to determine an appropriate



methodology that can show the relationships among transportation, economic productivity, and environments, in order to evaluate several scenarios, programs, and policies.

The total interstate highway length in Virginia is approximately 1,100 miles. The I-81 corridor is 325 miles long and provides “a strategically important transportation link to major economic production centers and major eastern United States markets (Hensley, 1991).” Three interstate highways (I-64, I-77, and I-66) connect the I-81 corridor to other areas in Virginia. I-81 serves a mostly rural region through predominantly rolling terrain blessed with many historical sites and natural attractions (Center for Transportation Research, 1996).

The highway cuts through seven planning districts constituting approximately 19% of Virginia’s population. The population of Planning District’s 1-7 increased only approximately 4 percent between 1980 and 1990, while the population of the state increased about 16 percent. The per-capita personal income in Planning District’s 1-7 is very low compared to that of the state. Five commercial airports are located within the corridor and there are eight major railroad companies operating in the corridor, with over 700 miles of track (Center for Transportation Research, 1996).

The Center for Transportation Research (1996) published a report, “The I-81 Corridor in Virginia: Transportation Issues and ITS Opportunities”, presenting the following general information:

According to past traffic count studies completed by VDOT, the Average Annual Daily Traffic (AADT) volumes on I-81 have increased from an average of 26,719 in 1991 to 30,705 vehicles in 1994, showing an increase of 15%. However, during that same period, the number of accidents increased 37% which indicates a deteriorating safety problem. Using VDOT’s accident database, it was determined what the major types of collisions and actions were for trucks, and compared these results to other vehicles traveling on I-81. According to a year-long vehicle classification study completed by VDOT in 1992, the number of trucks averaged approximately 8,150 AADT, or 25% of the total traffic stream. Overall, us-

ing VDOT's accident database, there were 5,591 reported accidents from 1991 to 1994. Of these accidents, 1,407 (or 25%) involved trucks; however, they were involved in 36% (37 out of 104) of the fatal accidents.....  
.....There are two weigh stations located on I-81 in Virginia. One is near Troutville and the other is near Stephen's City. Both operate using weight-in-motion (WIM) technology. The weigh stations determine if a particular truck needs to be weighed on a static scale because it might be in violation, or if it can be allowed to continue with minimal delay. The two stations operate on average 80% of the time and they processed 1,675,403 trucks (5/94 - 5/95) at Stephen's City and 2,218,725 trucks (1994) at Troutville using WIM technology. The estimated time saved using the new WIM technology is estimated at 2 to 5 minutes per truck. Using a time value cost of \$1.20 per minute (ATA), the total savings per year is approximately \$16.4 million using an average reduction in time of 3.5 minutes per truck. Currently VDOT is using over-head detectors, video cameras, variable message signs and document readers in conjunction with WIM technology to decrease the amount of delay per truck.

Appendix F gives the maps of the study area, including VDOT's (Virginia Department of Transportation) future investment plans. Appendix H provides the population and land area of each county and city in the I-81 corridor regions. IMPLAN by USDA Forest Service (1992) generates aggregate input-output regional coefficients. IMPLAN can be used to generate the regional direct coefficient, income, output, value-added, employment multipliers. Demand-side effects can be made through traditional I-O analysis using those coefficients. SIC 1 digit, SIC 2 digit and 3 digit levels are available in IMPLAN.

## 6.2. Intelligent Transportation Systems (ITS) Technologies

Looking toward the year 2020, Knox (1994) expresses his visions about the volatility of the urban system, as in the following:

In practice, the best-placed states and metropolitan areas will be those that are first to develop fiber-optic networks for use with "smart" telecommuni-

cations systems and to develop “smart” highways that will accommodate the next generation of trucks and automobiles. High-speed railway systems with trains that run at 300 mph or more will be crucial to the economic prospects of a few regions of high-density metropolitan development  
.....

The idea of Intelligent Transport Systems (ITS) has been initiated to meet the rapidly growing concerns of congestion and the environment. The Commonwealth of Virginia is considering ITS technologies for the I-81 corridor improvement plans. This section covers general ideas and information of ITS and the next section will provide scenarios based on ITS technologies.

With the decrease in the defense and aerospace industries, some state governments, as well as the federal government, have made efforts to introduce the advanced technologies to ground transportation operations and facilities, so-called Intelligent Vehicle-Highway Systems (IVHS). Lately, the name has been changed to Intelligent Transportation Systems (ITS, thereafter) to enlarge its application areas.

The passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), signed by President Bush in 1991, is intended to develop a National Intermodal Transportation System that is economically efficient and environmentally sound, and to provide a foundation for the Nation to use in competing in the global economy by moving people and goods in an energy-efficient manner. ITS, high-speed ground transportation systems, magnetic levitation technologies, and electric vehicles are considered for future transportation alternatives by ISTEA.

Euler (1990) defines the purpose of ITS as “to make significant improvements in mobility, highway safety, and productivity by building transportation systems that draw upon advanced electronic technologies and control software.” Papacostas and Prevorous (1993) characterize IVHS as a management system formed by “the integration of navigation, real-time route guidance, and continuous highway and signal network surveillance.” Similarly, Intelligent Transportation Systems (ITS) has been defined as,

“the application of electronic, computer, and communications technology to add efficiently to motor vehicle use and capacity to existing roadways (IVHS America, 1992).”

Papacostas and Prevorous (1993) indicate the objectives of advanced urban transportation technologies as fivefold: systems efficiency improvements through information (informatics), safety, pricing, capacity enhancements, and pollution reduction. ITS takes advantages of these technologies: 1) to inform the traveler by better and more timely information; 2) to improve the vehicle by better equipment such as early warning systems, route navigation devices and improved communication; 3) to improve the infrastructure by better traffic flow monitoring, roadside communication, and devices (IVHS America, 1992).

All of the proposed user services will be available in the 20-year time-frame, according to IVHS America (1992). The deployment vision beyond the 20-year time-frame involves the evolution of transportation data collection, dissemination, and traffic management. Appendix G summarizes three phases and technologies for ITS and shows three tables, and information that comes from “the Strategic Plan for IVHS, 1992”: 1) characteristics of six categories, 2) plan elements of ITS (operational testing and deployment) for near term, middle term, and longer term, and 3) requirements and required techniques and models for a full-fledged stage of ITS. The major change during the time-frame between stage II and III is the deployment of Automated Highway System (AHS). Data collection, sharing, and dissemination systems and enhanced vehicle control systems are the basic elements of AHS (Hughes Aircraft Co., 1994).

There are six components in the ITS:

- ATMS (Advanced Traffic Management Systems)
- ATIS (Advanced Traveler Information Systems)
- AVCS (Advanced Vehicle Control Systems)
- CVO (Commercial Vehicle Operations)
- APTS (Advanced Public Transportation Systems)
- ARTS (Advanced Rural Transportation Systems)

The term Advanced Traffic Management Systems (ATMS) refers to systems in which these advances are applied to current Traffic Management Systems. According to Euler (1990), ATMS have six primary characteristics: 1) real-time traffic data, 2) response to changes in traffic flow with timely traffic management strategies, 3) area-wide surveillance and detection systems, 4) integration of the management of various functions, including travel demand management, freeway ramp metering, electronic toll collection, and arterial signal control, 5) collaborative action on the part of transportation management agencies and jurisdictions so that the user perceives a seamless transportation system, and 6) rapid response incident management strategies.

Advanced Traveler Information Systems (ATIS) are used “to acquire, analyze, communicate, and present information to assist surface transportation travelers in moving from a starting location (origin) to their desired destination (IVHS America, 1990)”, evolving in three stages; an Information Stage, an Advisory Stage and a Coordination Stage.

Advanced Vehicle Control Systems (AVCS) incorporate sensors, computers and control systems in vehicles and on the roadway to enhance drivers' control of vehicles, to intervene in the driving tasks, or ultimately to relieve the drivers of most driving tasks for greater safety and capacity (IVHS America, 1992). Texas Transportation Institute (1990) distinguishes three stages of AVCS in “mobility 2000”: 1) AVCS-I: Individual Vehicle Control, 2) AVCS-II: Cooperative Driver-Vehicle-Highway Systems, and 3) AVCS-III: Automated Vehicle-Highway Systems.

Commercial Vehicle Operations (CVO) systems employ various ITS technologies to enhance the safety and productivity of commercial vehicle and fleet operations, including large trucks, delivery vans, buses, taxis and emergency vehicles. Technologies in CVO include automated vehicle identification, automated vehicle location, weigh-in-motion, dynamic network routing and scheduling, and automated toll collection (Euler, 1990 and IVHS America, 1992).

Advanced Public Transportation Systems (APTS) is the application of constituent technologies of these ITS elements to high occupancy and shared-ride vehicles, including conventional buses, rail vehicles, and the entire range of para-transit vehicles (IVHS America, 1992). Advanced Rural Transportation Systems (ARTS) is application of ITS to rural transportation systems, to improve safety, increase the efficiency of maintaining and operating them, and provide recreational travelers with improved navigational aids (IVHS America, 1992).

There has been a debate about a full-fledged ITS, concerning how to perform the final stage, in other words, should it be centralized or decentralized, and whether to automate highway systems, or vehicle systems? In addition, major non-technological barriers to the deployment of the technologies need to be overcome, including social, safety, legal, political, and environmental considerations (Papacostas and Prevedouros, 1993). Social issues are those such as privacy and equity (Waller, 1994). Some requirements of a full-fledged ITS, such as automated vehicle identification and automated vehicle operations and highway systems, will be difficult to implement and operate because the ability to monitor citizens' activities (the Big Brother syndrome) raises controversial issues, including that of whether they are constitutionally acceptable.

### 6.3. Scenarios

Solution strategies for alleviating urban transportation problems may be classified in three categories: pricing, policy and management, and technology-based (Papacostas and Prevorous, 1993). Among those categories, policy and management, and technology-based programs can be alternatives for the I-81 corridor; however, pricing can be dealt

with in TDM. Some alternatives are being considered, including widening the lanes, exclusive truckways, and ATMS applications.

According to Bureau of Transportation Statistics (1995), the estimates of output elasticity of highway infrastructure in the U.S. are in the range of 0.03 to 0.06, meaning that a 1 percent increase in highway infrastructure would cause the U.S. Gross Domestic Product (GDP) to rise by 0.03 to 0.06 percent. It also indicates a cost elasticity of -0.07, stating that a 1-percent increase in highway infrastructure stock would reduce highway freight costs by 0.07 percent. However, the relationship between highway stock and GDP cannot be linear. In other words, after a certain level investment in transportation will not give the same effect as before that level, and too much investment would have a negative impact on the GDP, by reducing the amount of investments to other SIC industries.

According to the Virginia Department of Transportation (VDOT, 1993), heavy trucks will make up 22 percent of the traffic using I-81 through the Roanoke Valley in 2025. VDOT (1993) also projects that traffic on I-81 near Roanoke will increase by 65 percent in 2015. In the near future, if there is no improvement, the I-81 will confront serious congestion and safety problems, especially during weekday peak hours, according to the data from VDOT. Five scenarios are considered for the I-81 corridor in this research: 1) No improvement, 2) Additions of lanes, 3) Exclusive truckway, 4) ATMS applications, and 5) Hybrid Personal Maglev (HPM).

- **No improvement**

Without scenario analysis, we know that there will be serious congestion on I-81 during the weekday peak hours, considering the natural increase in traffic. However, this scenario is necessary and meaningful because it gives the base for user benefits and changes in economic productivity for other scenarios. This scenario can be the “do-nothing” negative public response to highway development proposals typified by the growing vocabulary of terms such as NIMBY (not in my back yard).

- **Additions of lanes**

Historically, this scenario is conventional. For example, there will be expansion of lanes if there is a need for more lanes. Increasingly, less available land, increased R-O-W (right-of-way), pollution generation and environmental deterioration are barriers to this scenario. It has a function in shifting the supply function to the right in the supply-demand curve with travel times and traffic volume as in Fig. 4.1.

- **Exclusive truckway**

As the I-81 is in the category of rolling terrain and there is much truck traffic, an exclusive truckway is considered as a scenario in that it can reduce accidents, incidents, and passenger-car-equivalents. Thus, separation of commuter and truck traffic needs to be considered for maintenance, incidents, accidents, and safety. However, an exclusive truckway requires more R-O-W (Right-Of-Way) and construction costs.

- **ATMS applications**

For the ATMS alternative, it is assumed that there is no change in supply (capacity) and that congestion reduction is achieved by demand management through better signalization and ramp metering, use of HOV lanes to increase average vehicle occupancy (AVO), improved public transit so as to reduce highway modal split (HMS), telecommunications to reduce trips per job (TPJ), and real time system status information to defer some trips to a later time, which has the effect of increasing the duration of the peak period (DPP). The policy variables, AVO, HMS, TPH and DPP, increase economic growth as shown by the causal chains in Fig. 5.5. Expansion of lanes are also added to ATMS applications. Fig. 6.1. shows the effects of ATMS applications without expansions.

- **Hybrid Personal Maglev (HPM)**



For the AVCS alternative selected to illustrate the modeling paradigm, we assume a highly sophisticated hybrid personal transport system capable of operating on existing streets using electrical energy and on specially constructed Automated Highway Systems (AHS) using magnetic levitation. This “Hybrid Personal Maglev” (HPM) system has been the subject of considerable research under Drew and Trani in Virginia Tech.

Among three types of sections in the AVCS guideway, the RCS design speed  $V(RCS)$  determines the practical capacity of the guideway  $Q$  with the average length of vehicle  $L$  and the intervehicular spacing  $\varepsilon$  which can be achieved by the AVCS technology (Drew et al., 1994).

$$Q = V(RCS) \times 5280 / S_L \quad (6.1)$$

where  $S_L = L + \varepsilon$ .

The HPM vehicle will be able to reach a top speed of 300 mph. Fig. 6.1. shows the effects of AHS applications.

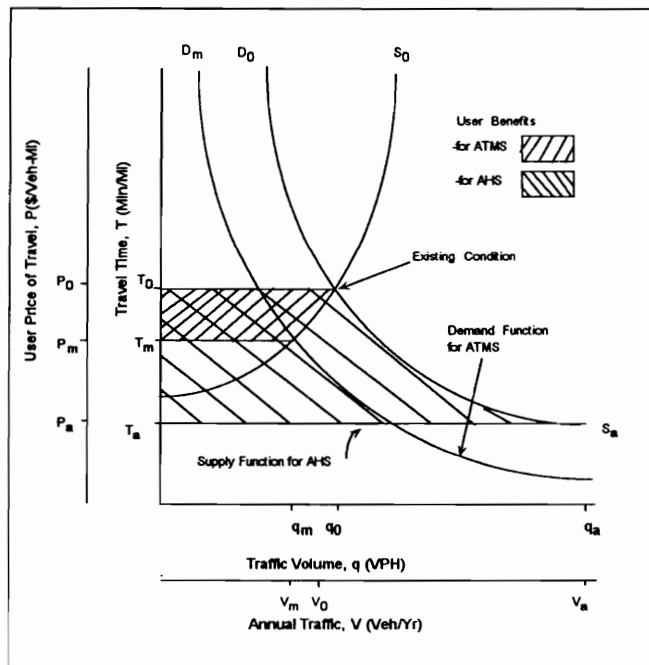


Fig. 6.1. Determination of user benefits for ITS

Besides scenarios, information and data about the I-81 for TDM analysis were collected. Traffic data were acquired from VDOT, and input-output coefficients and final demands, investments, population, final outputs, and others were calculated in IMPLAN, which are in Appendix H. The numbers in Appendix H are directly used in the TDM, which can be found in Appendix I. A causal diagram for the study area can be found in Fig. 5.3 and Fig. 5.5. Equations used for the study area are well described in the TDM, Ch. 5. Some assumptions were necessary and some parts, such as pollution, were not considered because of unavailable data for these analyses. Therefore, further study is strongly recommended, with partial survey methods and more data from reliable sources for ITS information, pollutants, and the I-81 study area.

#### 6.4. Simulation Results

Current capital, capital investment, and capital-output ratios are important inputs for the system. We may follow the trends of the past, or national or state trends when information about previous trends are unavailable. Approximation of costs and benefits from technologies are also necessary. As an example of ATMS applications, SCANDI from Michigan covers Detroit freeways, initially totaling 32 miles, and could be increased to more than 350, with a proposed \$75-million (French, 1990). On Long Island, travel time decreased from 13 to 20 % from ATMS applications (Mobility 2000, 1990). Costs for HPM are approximately 16 million \$/mile (Lee, 1994) and addition of two lanes for both directions costs approximately 3 million \$/mile (VDOT, 1992). Appendix J and Table 6.1 give procedures and results of user cost-benefit analysis.

The nonuser benefits for the two ITS alternatives are calculated by finding the changes in the Gross Regional Product (GRP) due to reductions in the demand capacity ratio (DCR). In the case of the ATMS alternative, the reduction in DCR is accomplished

by reducing demand; in the case of the AVCS alternative, it is brought about by the increase in capacity. Following the causal chain in Fig. 5.5, a decrease in DCR decreases industrial transport costs, which decrease the fraction of industrial output to inputs (FIOI), and increases the GRP (Drew et al., 1996).

In Scenario 1, there is no improvement, due to the natural growth of passenger and freight traffic, and severe traffic jams are expected to occur within five to ten years. Table 6.2. shows the results of this scenario. Consideration of alternate routes and modal split will postpone this trend; however, it will affect only a few years, resulting in congestion in other modes and routes. It is clear that a better facility or program is required.

Table 6.1. Summary of the inputs and cost/benefit ratio

Scenario	Configuration	Cost	B/C Ratio
Do Nothing	N/A	N/A	N/A
Two More Lanes	2 more lanes in each direction	3 million \$/mile Maintenance costs: 5% of construction costs	2.20
Exclusive Truckways	2 truckway in each direction with CVO	3.5 million \$/mile & M.C.: 5% of C.C.	1.81
ATMS Applications	Traffic control center, freeway control with two more lanes	150 million \$ for the whole section & Construction costs & M.C.: 5% of C.C.	4.01
HPM	1 Maglev lane in each direction	16 million \$/mile & M.C.: 5% of C.C.	2.99

Table 6.2. Summary of non-user impacts: No improvements

Year	Design Year	Year 3	Year 5	Year 8
GRP (billion \$)	34.92	35.42	35.67	35.3
TT(Travel Time, Min)	363.16	432.05	528.59	1141.3
PCI (Per Capita Income)	29,240	29,020	28,810	27,930
POP (population, persons)	1,194,000	1,221,000	1,238,000	1,264,000
IC (Ind'l Capita, \$ billion)	26.33	27.19	27.74	28.82
UR (Unemployment rate, %)	5.254	6.531	7.254	8.23

In Scenario 2, by adding two more lanes in each direction in three years, travel times will be reduced greatly in the near future. Table 6.3. shows the results of this scenario. Approximately 25 years later, improvements of highways would be required. According to Fig. 6.5. and 6.6., increased travel time affects GRP negatively.

**Table 6.3. Summary of non-user impacts: Additions of lanes**

Year	Year 5	Year 10	Year 20	Year 30
GRP (\$ billion)	36.05	37.09	39.19	40.47
TT(Travel Time)	285.28	300.33	365.37	874.46
PCI (Per Capita Income)	29,190	28,930	28,540	27,530
POP (population, persons)	1,238,000	1,282,000	1,373,000	1,470,000
IC (Ind'l Capital, \$ billion)	27.76	29.15	31.78	34.21
UR (Unemployment Rate, %)	7.218	8.491	9.563	9.398

In Scenario 3, two exclusive truckways in each direction are constructed in three years, the output in this area is expected to be increased by reducing truck travel time leading to the reduction of transportation cost. Table 6.4. shows the results of this scenario. As truck travel time is very stable in the long term, reduction of industrial travel costs increase economic productivity, which results in a lower unemployment rate and a better per capita income than scenario 2. However, traffic congestion in conventional highways for passenger cars is expected sooner than Scenario 2. Other ITS technologies such as ATMS and ATIS can postpone the congestion by several years.

In Scenario 4, ITS technologies have been considered in addition to expansion of lanes. Advanced Traffic Management System (ATMS), including highway traffic surveillance, control, and operation by sending information through a traffic control center has been applied. Table 6.5. shows the results of this scenario. PCI and GRP are slightly worse than Scenario 3. Compared to Scenario 2, traffic congestion is expected five to ten years later.

**Table 6.4. Summary of non-user impacts: Exclusive truckway**

Year	Year 5	Year 10	Year 20	Year 25
GRP (\$ billion)	36.05	37.1	39.28	40.18
TT(Travel Time, Minutes)	286.42	295.44	320.17	337.77
PCI (Per Capita Income)	27,110	28,930	28,600	28,440
POP (population, persons)	1,238,000	1,282,000	1,373,000	1,421,000
IC (Ind'l Capital, \$ billion)	27.76	29.15	31.79	32.81
UR (Unemployment Rate, %)	7.219	8.491	9.537	9.488
TF (Freeway Travel Time, Min)	278.82	295.38	398.95	825.88

**Table 6.5. Summary of non-user impacts: ATMS applications**

Year	Year 5	Year 10	Year 20	Year 30
GRP (\$ billion)	36.06	37.11	39.25	41.22
TT(Travel Time)	279.67	271.41	335.83	510.47
PCI (Per Capita Income)	29,120	28,940	28,580	28,040
POP (population, persons)	1,238,000	1,282,000	1,373,000	1,470,000
IC (Ind'l Capital, \$ billion)	27.76	29.15	31.79	34.28
UR (Unemployment Rate, %)	7.217	8.486	9.537	9.23

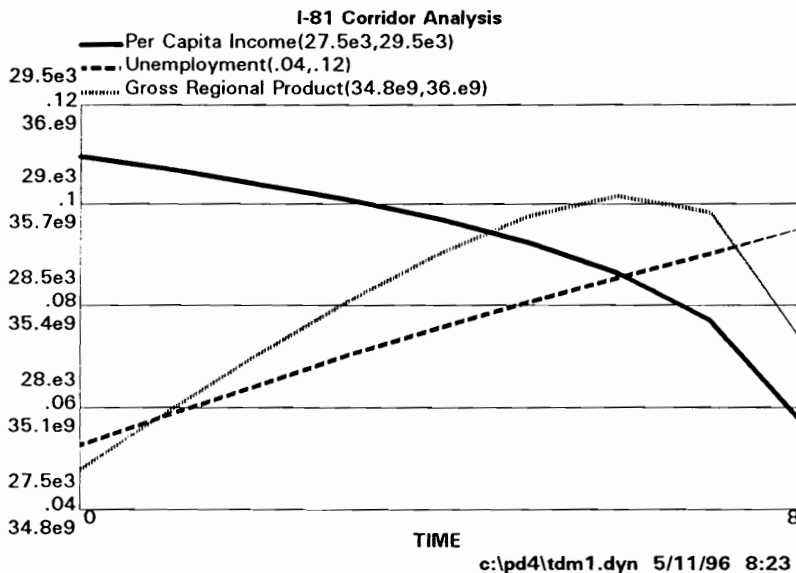
In Scenario 5, HPM, the commuter travel time will be reduced greatly after five years with the completion of the personal maglev project. As HPM only carries passengers, there is not a great impact on the travel time for truck traffic in the near future. In the long run, truck travel time will be reduced by shifting more passenger traffic from the highway to a maglev system. PCI stays steady around 25 years later and after 20 years the GRP increases exponentially based on Fig. 6.14. Within 50 years, most passenger vehicles will use the HPM system. Truck travel time is expected to decrease after 23 years. In this scenario, within 50 years or more, there would be no need for improvements. This scenario has the best economic productivity and user benefits are tremendous. However, a change in allocation of budgets and investments for the future

should be considered in the analysis, concerning investments to other SIC industries, which is not covered in this analysis for the sake of simplicity. The result can be similar to those found in Fig. 4.3. This scenario reduces pollution greatly, also not covered in the simulation.

**Table 6.5. Summary of non-user impacts: HPM applications**

Year	Year 5	Year 10	Year 20	Year 30
GRP (\$ billion)	35.82	36.68	38.06	40.15
TT(Travel Time, Minutes)	424.53	523.68	855.11	736.83
PCI (Per Capita Income)	28,930	28,600	27,730	27,360
POP (population, persons)	1,238,000	1,282,000	1,373,000	1,468,000
IC (Ind'l Capital, \$ billion)	27.74	29.08	31.51	33.71
UR (Unemployment Rate, %)	7.264	8.644	11.016	10.43
TM (Maglev Travel Time, Min)	78	78	78	78

- **Base Run: No Improvement**



**Fig. 6.2. Simulation Result 1: Base Run**

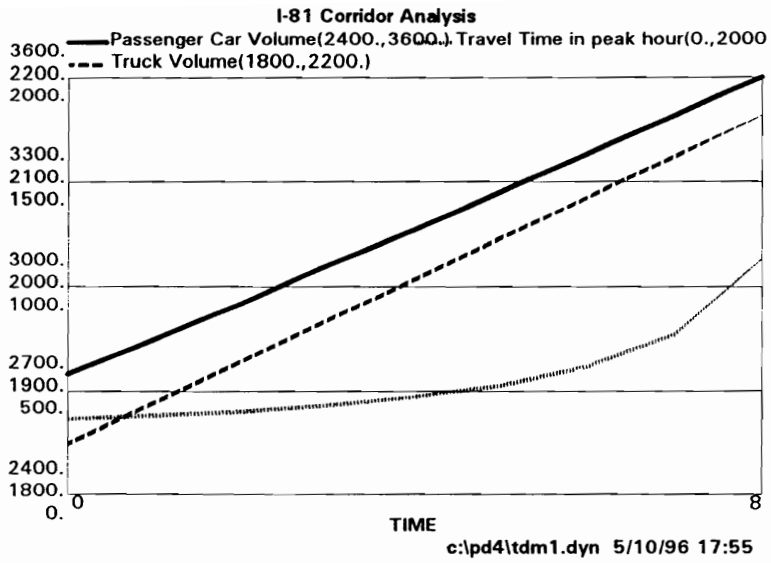


Fig. 6.3. Simulation Result 2: Base Run

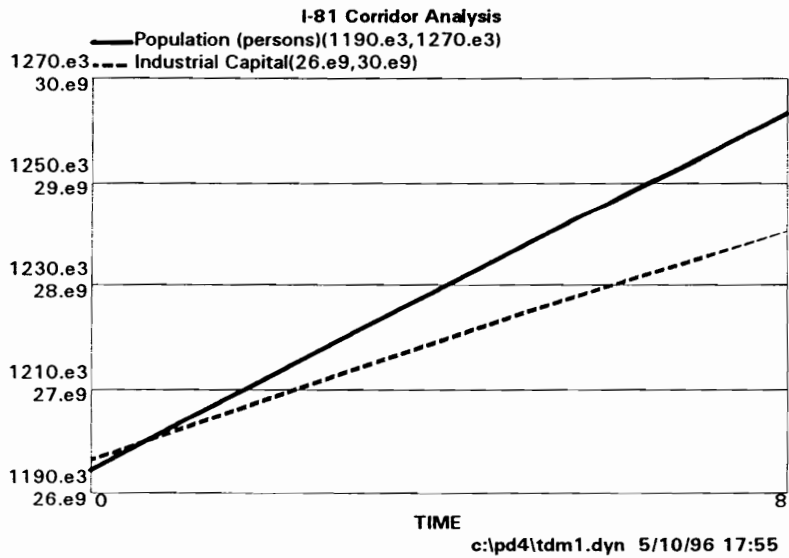


Fig. 6.4. Simulation Result 3: Base Run

- Scenario 2: Additions of lanes

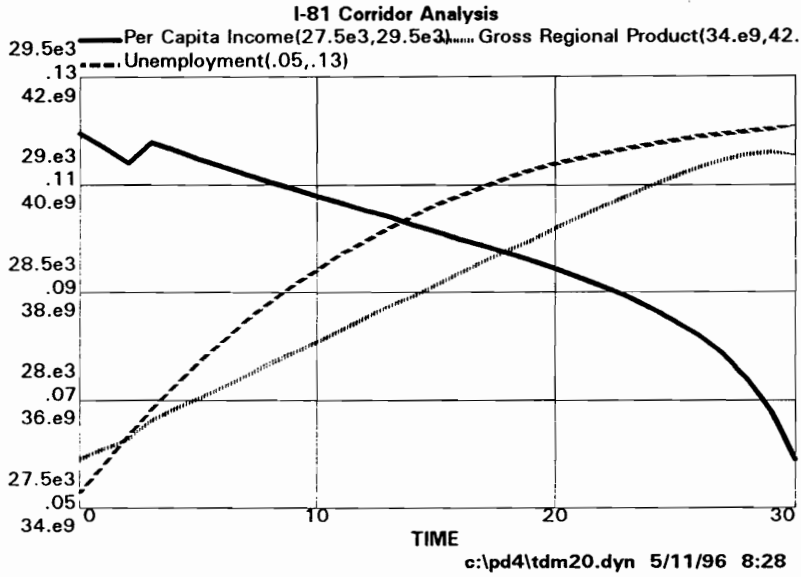


Fig. 6.5. Simulation Result 1: Scenario 2

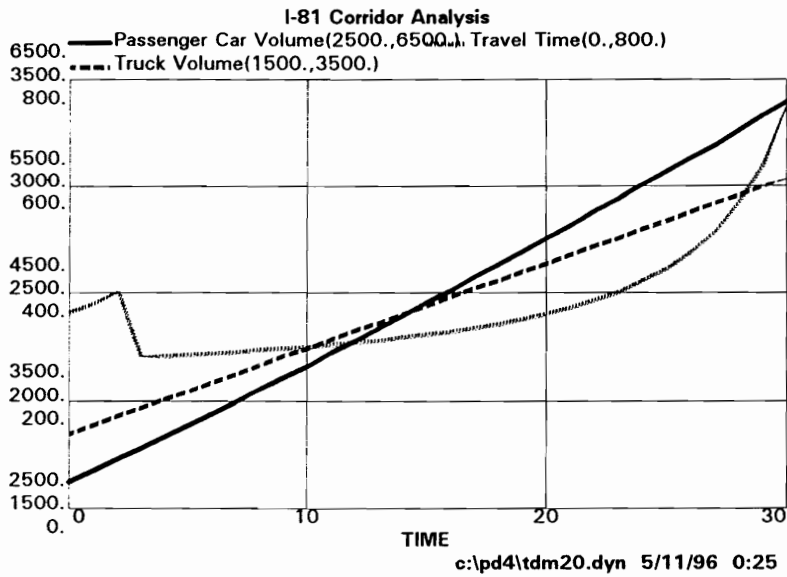


Fig. 6.6. Simulation Result 2: Scenario 2



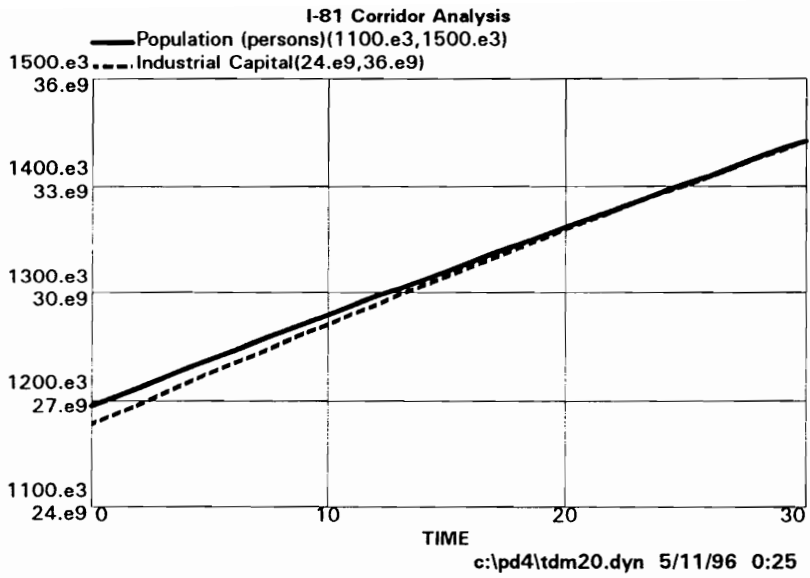


Fig. 6.7. Simulation Result 3: Scenario 2

- Scenario 3: Exclusive truckway

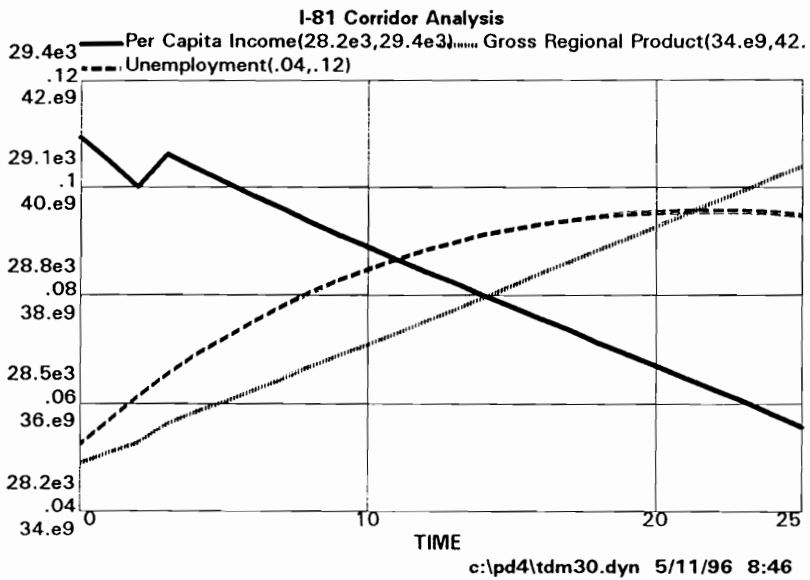


Fig. 6.8. Simulation Result 1: Scenario 3

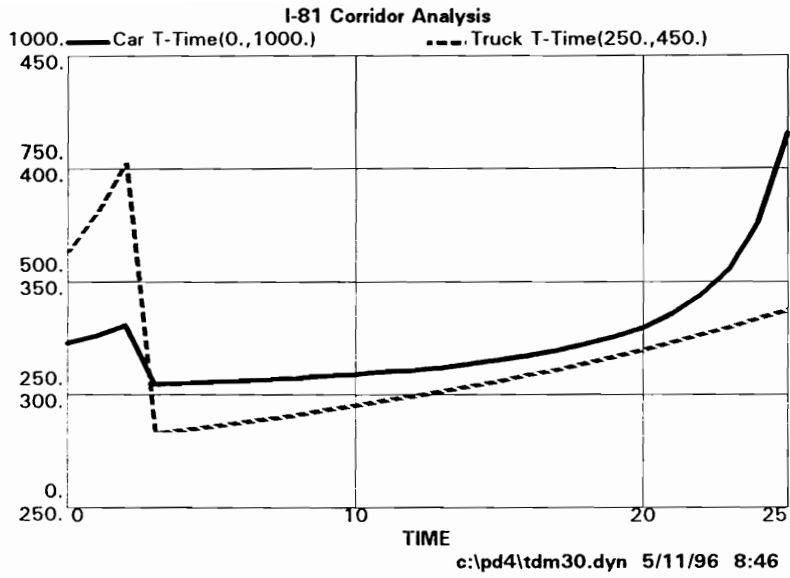


Fig. 6.9. Simulation Result 2: Scenario 3

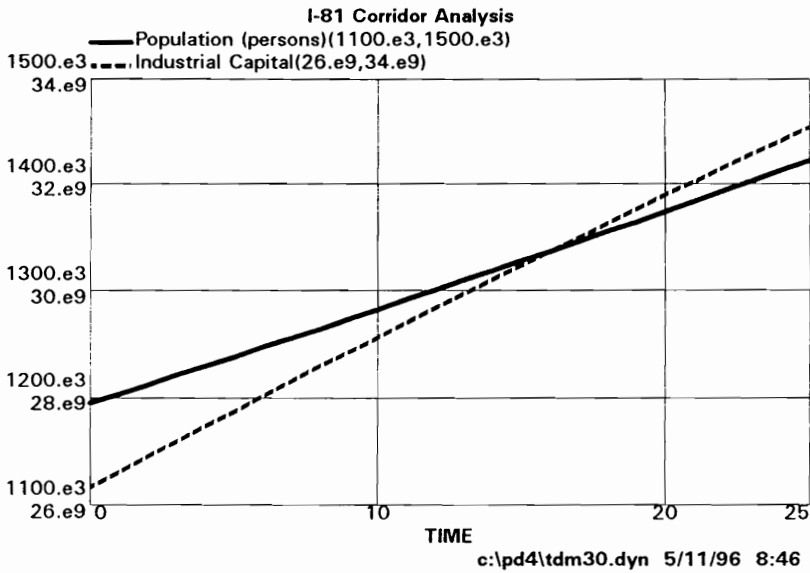


Fig. 6.10. Simulation Result 3: Scenario 3

- Scenario 4: ATMS applications

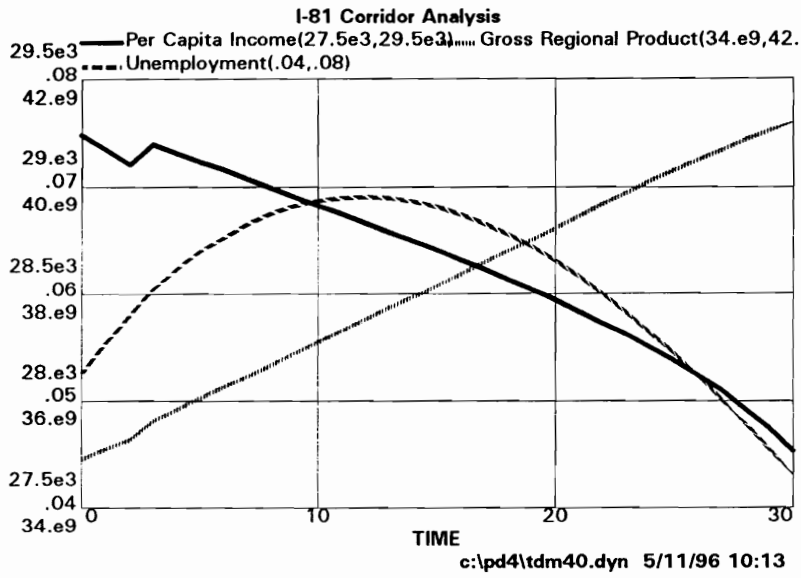


Fig. 6.11. Simulation Result 1: Scenario 4

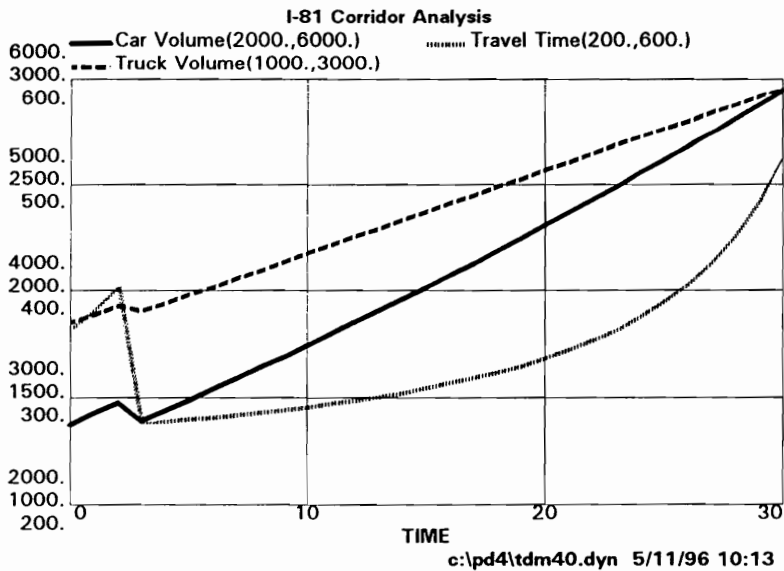


Fig. 6.12. Simulation Result 2: Scenario 4

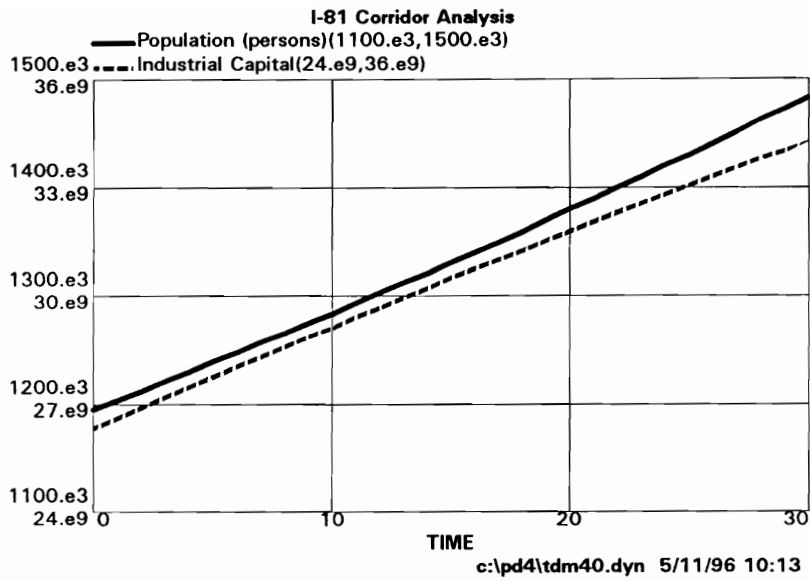


Fig. 6.13. Simulation Result 3: Scenario 4

- Scenario 5: HPM

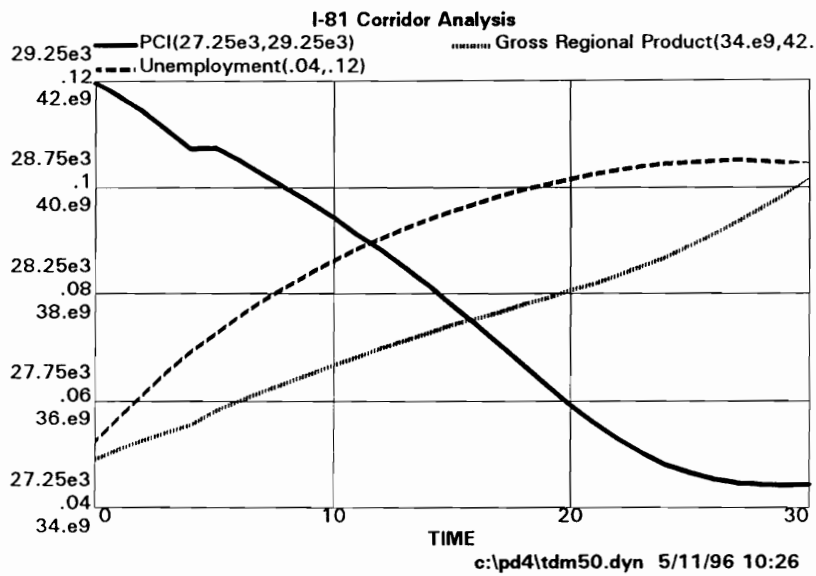


Fig. 6.14. Simulation Result 1: Scenario 5

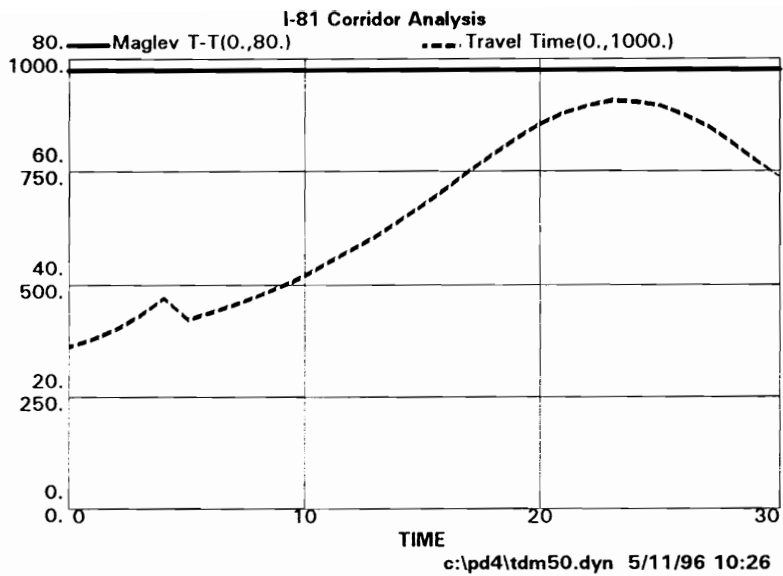


Fig. 6.15. Simulation Result 2: Scenario 5

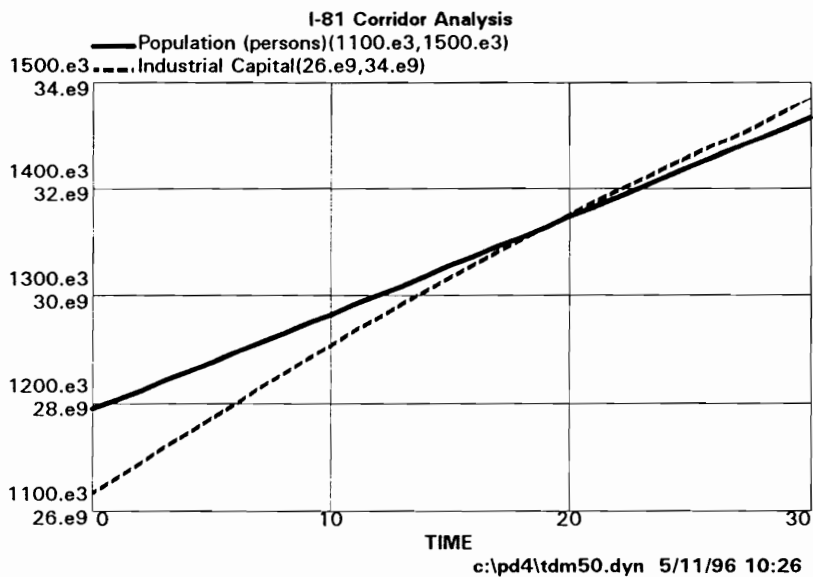


Fig. 6.16. Simulation Result 3: Scenario 5

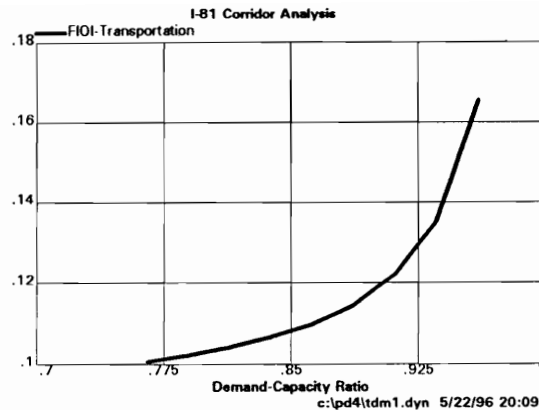


Fig. 6.17. Relationship between DCR and FIOI: Base Run

In conclusion, ATMS technologies only affect a few years, and additions of lanes in a conventional way will require more improvements in 20 to 50 years. Although a huge investment is required, a significant increase in highway capacity such as HPM can solve traffic problems for the long term. As exclusive truckways can be a good alternative for safety, benefits from reducing accidents and incidents need to be included. For better and more reliable results, the capital-output ratio for the I-81 region, and market strength, commodity flow data, etc. need to be acquired and verified.

In the scenario analysis, capital inputs for pollution-abatement equipment can be considered in further research. Results from the base run seem exaggerated, primarily because of facts that are not considered in the analysis, which include alternative routes, and competition among modes such as air-cargoes and railroads. Estimation of travel times in the scenario analysis needs improvement with respect to non-peak hour travel demands, and Queuing theory can be introduced to give better results in estimating travel times and delays, rather than using Davidson’s formula.

## 7.0. DISCUSSION

This chapter presents a discussion of four areas of the research. First, it presents a summary of this research on Transportation/Development Methodology (TDM), value systems, and the I-81 corridor study. Second, validation and verification problems are discussed for the proposed methodology, TDM, with regard to other methodologies. The third section provides conclusions with respect to methodologies and scenarios. Finally, further research is recommended, for both TDM and the I-81 corridor.

### 7.1. Summary

In the United States, the nation's infrastructure has become a steady theme for national debate. On the one hand, infrastructure is seen as an instrument of community and national development, a source for new jobs in a slow-growth economy, or an ingredient in restoring America's global competitive strength. On the other hand, infrastructure, in general, and transport, in particular, is perceived as a major intruder in the environment (Drew et al., 1996).

However, in estimating impacts induced by transportation investments and policies, both transportation processes and development management processes lack feedback effects among sectors, resulting in nearly total isolation from ongoing planning

activities. This research is a step towards clarifying the relationships between transportation investment and economic productivity, and further, is a step toward building a methodology for evaluating transportation policies and projects concerning regional economies and environments. As a scientific process, TDM was developed for regional and multiregional analyses. TDM conceptualizes the role of transportation in a broad socioeconomic and environmental context. As the demand for and the supply of transportation cannot be determined within the transportation system, identifying the relationships among several sectors is necessary. TDM adopts several sectors as a minimum for the analysis: 1) demographic sector, 2) regional economy sector, 3) employment sector, 4) land use sector, 5) transportation sector, and 6) environment sector.

Application of TDM in the I-81 corridor scenarios allowed us to draw important conclusions that otherwise would not have been possible using conventional methodologies, regarding peak-hour demands. To implement new technologies, such as Maglev and ITS, for transportation in a region, impact analyses are necessary. In this research, scenario analyses of transportation investments and programs, including ITS technologies, are introduced for the Interstate-81 (I-81) corridor. To evaluate rankings among scenarios induced by transportation investments and programs, user, non-user, and environmental impacts are considered based on user cost-benefit analysis and multicriteria analysis.

## 7.2. Validation and Verification Problems

The simulation models concerning long-term human behavior have strengths in that they can incorporate expert opinions, and the models could serve as a focus for multidisciplinary research (Mitchiner et al., 1977). However, these models are almost



impossible to validate and verify. Validation and verification problems fall into two categories using a system dynamics approach: 1) relationships among variables and 2) the behavior of the model as a whole. For TDM, a proposed methodology in this research, a “goodness of fit” criterion, i.e., a least squares fit of the “fitted sequence” is required for parameter identification. According to Erickson (1996), the behavior of the model as a whole system should not display any implausible ideas, and should also display behavior similar to typical real world systems. Sensitivity and steady state analysis can support validation and verification of the entire system of the model.

For TDM, the justification of most elements is found in the previous works from which they are drawn. Validation and verification problems can occur in two ways in TDM. First, as concepts are adopted from several methodologies, problems inherent in those methodologies are carried forward and evidenced in TDM. In dynamic, regional and multiregional I-O analysis, input-output coefficients and capital coefficients need to be verified with historic data. Change of the industrial structure for input-output coefficients and capital coefficients, private and governmental expenditures with investments, capital formation and depreciation, lags or delays, price change, income change, and competition among regions are concerns for validation and verification. Lowry (1964) indicated that the process of fitting the model involved a great deal of trial and error. For verification, extensive work was done in estimating proper equations for work-trips and non-work trips in the Lowry model. Identifying attractiveness is a major difficulty in using the Lowry model. In the UTPP, many models have been used for each step of the four step process, and each model requires validation and verification. For example, parameters in logit or probit models for modal split need validation, and each traffic assignment technique produces some errors.

Second, TDM and value systems for appraisal also require validation and verification. For example, in value systems, time values and benefits from reduction of traffic accident and incidents can be controversial. The entire system of TDM and its parameters can really only be verified and identified in the future, after the fact.

### 7.3. Conclusions

Current methodologies concerning transportation, regional economic development, and land use have weaknesses in showing the feedback effects among demographic, land use, regional economy, transportation, and the environment. Urban Transportation Planning Process (UTPP), the Lowry model, and Input-Output analysis are specific problem oriented methodologies, whereas system dynamics is a general problem-oriented methodology. In other words, the first three methodologies do not show a complex socio-economic system well, simply because they do not include some important sectors, i.e., by making the sectors exogenous. Transportation demand and supply need to be identified outside transportation systems, and an integrated comprehensive model can provide an appropriate way to show the relationships among sectors, and further, can test scenarios concerning transportation and non-transportation policies and programs. Thus, the proposed methodology has strengths by integrating partial models, incorporated into a system dynamics approach with temporal aspects. Specifically, system dynamics plays a key role as a general problem-oriented methodologies, by incorporating a specific problem-oriented methodology such as the I-O, the Lowry model, or the UTPP. By interconnecting the influential factors, it is possible to show the sustainable future in regard to transportation and environmental factors in a given region, or given regions.

Multiregional TDM (MTDM) uses trucking or modal splits based on interregional trade flow. As an approximation of commuter traffic in highways is necessary in regional TDM, information and data for local commuter traffic can give more reliable numbers for highway commuter traffic. This can be done by incorporating the Lowry model in MTDM.

In TDM, original concepts and ideas are combined with concepts from current methodologies. Travel costs are dealt with in the technical coefficients using fraction of industrial outputs to inputs (FIOI), affecting economic productivity. Pollution is also dealt with in a capital-output ratio, affecting total industrial output. For the traffic demand for interregional commodity flow, trucks per industrial output from origin to destination is used. Mode choice is considered as a fixed ratio and can be explored for modal competition using concepts from the UTPP. Data for interregional trade flow, capital-output ratio, modal split, route selection, and trucks per SIC industrial output, are required for the scenario analysis to be valid.

As a “real-life” problem, the I-81 corridor is considered and studied using TDM. The I-81 corridor is subjected to five scenarios, which assume that funds are generated from state and federal governments. The first scenario, “no improvement”, shows that severe traffic jams are expected within ten years, considering the natural growth of passenger and freight traffic. Based on the value systems concerning user and non-user impacts, covered in Chapter 4, ATMS applications and HPM show the best simulation results. Scenario 3, an exclusive truckway, can reduce highway accidents and incidents significantly for both passenger vehicles and trucks; however, this scenario is not so cost-effective compared to ATMS applications and HPM. Scenario 4, ATMS applications, shows the best result in user cost-benefit analysis, and Scenario 5, HPM, show the best in non-user impact analysis. ATMS applications reduce peak-hour demands along with additions of lanes, whereas HPM (Hybrid Personal Maglev) increases highway capacity and decreases pollution significantly. As shown in Fig. 4.3., HPM technologies can be regarded as a sustainable development transport policy, and the other scenarios, except “do-nothing”, can be categorized as growth-friendly transport policies. In other words, Scenario 5, HPM applications, is the optimum scenario for the long-term sustainable future.

As another suggestion, since the I-81 region does not show a strong economy with high investments, other programs for industrial locations should be followed. Trucking on the I-81 is primarily thru-traffic, and budgets should be externally generated, from state, and federal governments, for example.

#### 7.4. Recommendations for Further Research

This research can be expanded in various ways and at various levels. First of all, it can be expanded to address a sustainable development model. Data about pollution generation from industry and transportation can be more detailed, and other environmental factors can be included.

Second, multiregional TDM (MTDM) can be extended to metropolitan and local levels. For the local case, a gravity-oriented MRIO with RAS-adjusted methods and Lowry-type models can be used in dealing with competition among regions. Thus, an integration of the three models, based on a system dynamics approach is required for a full scale MTDM. Interregional commodity flow data for the United States are being published this year, updating a 1977 publication. Towards the end of this year, data for most states will be available. Each mode will be well described for commodity flow among regions, and the amounts given for each state of origin and destination. A column-coefficient MRIO can be developed with these commodity flow data from the BEA (Bureau of Economic Analysis), as a basis for TDM. Analysis can be extended to infrastructure, housing, quality of life, etc., using more localized information. On the metropolitan and local levels, passenger travel demand based on land use patterns, including industrial, commercial, and residential areas, can be included in the analysis. In fact, allocation of residence is critical for analyzing commuter travel time, and also highway peak hour travel.

Third, while this research only considers highways for analysis, multimodal analysis would be the preferred approach. Modal competition and route selection will give better travel time estimations and travel costs. For this reason, intermodal analysis is strongly recommended.

Fourth, changes in urban structure, as well as changes in interregional trade and technical coefficients, are critical for future land use and urban patterns. It is recommended that these be given careful consideration. Infrastructure, such as water and energy, can be connected in a similar pattern to transportation. “Just-in-time” industries, which are highly dependent on truck travel time on highways, will change technical and interregional trade matrices, and can be tested by TDM. Relocation of industries, market strength, substitution effects, and price effects are further areas that could be fruitfully addressed using TDM. In addition, ITS technologies, Maglev, telecommunication industry, and the automotive industry will change the technical coefficients.

As an example of change in urban structure, a hexagonal arrangement can be adopted for urban areas based on HPM technologies and a modular structure is proposed in which self-contained urban units could be combined and added-to over time. The new cities, accommodating populations of from 50,000 to 500,000 persons, would consist of various modules combined according to topographic and demographic conditions, and would be located at guideway interchanges (Drew et al., 1996). Fig. F.4. gives an example of an urban pattern based on HPM.

Fifth, several things are recommended for more accurate results. Data concerning benefits from accident reduction, and construction and maintenance costs for exclusive truckway can generate more accurate cost-benefit ratios. Non-peak hour travel demands can be also considered, as well as peak-hour demands. Allocation of budgeting with regard to expenditures for each scenario is recommended, although for the purposes of this study, it was assumed that funding was exogenous.

Finally, in this dissertation, only the I-81 corridor region in Virginia is considered, and the research does not cover the interregional effects extensively. For more reliable

data on trucking, MTDM is recommended, including commodity flow data among regions. In a future study, the six related states, New York, Pennsylvania, West Virginia, Maryland, Virginia, and Tennessee can be included to cover the whole Interstate 81 highway. For more localized analysis, the I-81 corridor in Virginia can be divided into several regions according to planning districts, counties, or by interchanges.

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## Appendices

- A. Programming: UTPP
- B. Programming: Lowry Model
- C. Programming: Regional I-O Model
- D. Programming: Multiregional I-O Model
- E. Programming and Analysis: TDM
- F. Study Area: I-81 Corridor
- G. ITS Technologies
- H. IMPLAN Results: I-81 Corridor
- I. Programming: I-81 Corridor study
- J. User Cost-Benefit Analysis

## A. Programming: UTPP

NOTE \*\*\*\*\* UTPP (Urban Transportation Planning Process) \*\*\*\*\*

NOTE \*\*\*\*\* Allocation of Residential Activity using the accessibility model \*\*\*\*\*

Note There are three residential and two industrial areas.

NOTE TIJ: PEAK-HR TRAVEL TIME (MIN)

NOTE WTIJ: WEIGHT TRAVEL TIME (MIN)

A  $TAC21.K = CLIP(ATAC21, T21.K, 0, T21.K)$

L  $T21.K = T21.J + (DT/ST)(WT21.J - T21.J)$

N  $T21 = T21N$

C  $T21N = 0$

C  $ATAC21 = 18$

A  $TAC31.K = CLIP(ATAC31, T31.K, 0, T31.K)$

L  $T31.K = T31.J + (DT/ST)(WT31.J - T31.J)$

N  $T31 = T31N$

C  $T31N = 0$

C  $ATAC31 = 19$

A  $TAC41.K = CLIP(ATAC41, T41.K, 0, T41.K)$

L  $T41.K = T41.J + (DT/ST)(WT41.J - T41.J)$

N  $T41 = T41N$

C  $T41N = 0$

C  $ATAC41 = 30$

A  $TAC22.K = CLIP(ATAC22, T22.K, 0, T22.K)$

L  $T22.K = T22.J + (DT/ST)(WT22.J - T22.J)$

N  $T22 = T22N$

C  $T22N = 0$

C  $ATAC22 = 13$

A  $TAC32.K = CLIP(ATAC32, T32.K, 0, T32.K)$

L  $T32.K = T32.J + (DT/ST)(WT32.J - T32.J)$

N  $T32 = T32N$

C  $T32N = 0$

C  $ATAC32 = 14$

A  $TAC42.K = CLIP(ATAC42, T42.K, 0, T42.K)$

L  $T42.K = T42.J + (DT/ST)(WT42.J - T42.J)$

N  $T42 = T42N$

C  $T42N = 0$

C  $ATAC42 = 25$

N  $ST = DT$

NOTE X: A MEASURE OF THE IMPORTANCE OF PROXIMITY

NOTE AI: ACCESSIBILITY TO EMPLOYMENT OPPORTUNITIES AFFORDED BY RESIDENTIAL ZONE i

NOTE HI: HOLDING CAPACITY OF ZONE i

NOTE JJ: JOBS IN INDUSTRIAL j

NOTE LPF: LABOR PARTICIPATION FRACTION

NOTE PI: POPULATION IN ZONE i

C  $J1 = 40000$

C  $J2 = 40000$

A  $A2.K = (J1/TAC21.K) + (J2/TAC22.K)$   
 A  $A3.K = (J1/TAC31.K) + (J2/TAC32.K)$   
 A  $A4.K = (J1/TAC41.K) + (J2/TAC42.K)$   
 A  $L2.K = ((A2.K * H2) / (A2.K * H2 + A3.K * H3 + A4.K * H4)) * (J1 + J2)$   
 A  $L3.K = ((A3.K * H3) / (A2.K * H2 + A3.K * H3 + A4.K * H4)) * (J1 + J2)$   
 A  $L4.K = ((A4.K * H4) / (A2.K * H2 + A3.K * H3 + A4.K * H4)) * (J1 + J2)$   
 P  $H2 = 125000, H3 = 38000, H4 = 225000$   
 A  $P2.K = L2.K / LPF$   
 A  $P3.K = L3.K / LPF$   
 A  $P4.K = L4.K / LPF$   
 C  $LPF = 0.4$

NOTE \*\*TRIP GENERATION USING GRAVITY MODEL \*\*

NOTE OI: ORIGINS IN ZONE i

NOTE DJ: DESTINATIONS IN ZONE j

A  $O2.K = ALPHA * L2.K$

A  $O3.K = ALPHA * L3.K$

A  $O4.K = ALPHA * L4.K$

A  $D1.K = BETA * J1$

A  $D2.K = BETA * J2$

C  $ALPHA = 1.0$

C  $BETA = 1.0$

NOTE \*\*\* TRIP DISTRIBUTION \*\*\*

NOTE GAI AND GBI: CONSTRAINTS OF THE GRAVITY MODEL

NOTE GVIJ: NUMBER OF TRIPS FROM ZONE i TO ZONE j

NOTE GA21: FIRST ITERATION FOR A CONSTRAINT A AT i=2

NOTE GB11: FIRST ITERATION FOR A CONSTRAINT B AT j=1

NOTE GA22, GB12: SECOND ITERATION FOR CONSTRAINTS A AND B

A  $GA21.K = 1 / ((GB11 * D1.K / TAC21.K) + (GB21 * D2.K / TAC22.K))$

A  $GA22.K = 1 / ((GB12.K * D1.K / TAC21.K) + (GB22.K * D2.K / TAC22.K))$

A  $GA23.K = 1 / ((GB13.K * D1.K / TAC21.K) + (GB23.K * D2.K / TAC22.K))$

A  $GA31.K = 1 / ((GB11 * D1.K / TAC31.K) + (GB21 * D2.K / TAC32.K))$

A  $GA32.K = 1 / ((GB12.K * D1.K / TAC31.K) + (GB22.K * D2.K / TAC32.K))$

A  $GA33.K = 1 / ((GB13.K * D1.K / TAC31.K) + (GB23.K * D2.K / TAC32.K))$

A  $GA41.K = 1 / ((GB11 * D1.K / TAC41.K) + (GB21 * D2.K / TAC42.K))$

A  $GA42.K = 1 / ((GB12.K * D1.K / TAC41.K) + (GB22.K * D2.K / TAC42.K))$

A  $GA43.K = 1 / ((GB13.K * D1.K / TAC41.K) + (GB23.K * D2.K / TAC42.K))$

A  $IGA21.K = 1 / GA21.K$

A  $IGA22.K = 1 / GA22.K$

A  $IGA23.K = 1 / GA23.K$

A  $IGA31.K = 1 / GA31.K$

A  $IGA32.K = 1 / GA32.K$

A  $IGA33.K = 1 / GA33.K$

A  $IGA41.K = 1 / GA41.K$

A  $IGA42.K = 1 / GA42.K$

A  $IGA43.K = 1 / GA43.K$

C  $GB11 = 1.0$

C  $GB21 = 1.0$

A  $GB12.K = 1 / ((GA21.K * O2.K / TAC21.K) + (GA31.K * O3.K / TAC31.K) + (GA41.K * O4.K / TAC41.K))$



A GB13.K=1/((GA22.K\*O2.K/TAC21.K)+(GA32.K\*O3.K/TAC31.K)+(GA42.K\*O4.K/TAC41.K))  
 A GB22.K=1/((GA21.K\*O2.K/TAC22.K)+(GA31.K\*O3.K/TAC32.K)+(GA41.K\*O4.K/TAC42.K))  
 A GB23.K=1/((GA22.K\*O2.K/TAC22.K)+(GA32.K\*O3.K/TAC32.K)+(GA42.K\*O4.K/TAC42.K))  
 A V21.K=GA23.K\*GB13.K\*O2.K\*D1.K/TAC21.K  
 A V22.K=GA23.K\*GB23.K\*O2.K\*D2.K/TAC22.K  
 A V31.K=GA33.K\*GB13.K\*O3.K\*D1.K/TAC31.K  
 A V32.K=GA33.K\*GB23.K\*O3.K\*D2.K/TAC32.K  
 A V41.K=GA43.K\*GB13.K\*O4.K\*D1.K/TAC41.K  
 A V42.K=GA43.K\*GB23.K\*O4.K\*D2.K/TAC42.K

NOTE \*\*\*\*\* TRIP END MODEL SPLIT \*\*\*\*\*

NOTE PICH: PERCENTAGE OF CHOICE RIDERS IN ZONE i  
 NOTE PICA: PERCENTAGE OF CAPTIVE RIDERS IN ZONE j  
 NOTE VIJCH: NUMBER OF TRIPS BY CHOICE RIDERS FROM ZONE i TO j  
 NOTE VIJCA: NUMBER OF TRIPS BY CAPTIVE RIDERS FROM ZONE i TO j  
 NOTE COI: CAR OWNERSHIP IN ZONE i  
 A P2CH.K=CLIP(1.0,CO2/O2.K,CO2/O2.K,1.0)  
 A P3CH.K=CLIP(1.0,CO3/O3.K,CO3/O3.K,1.0)  
 A P4CH.K=CLIP(1.0,CO4/O4.K,CO4/O4.K,1.0)  
 C CO2=20000  
 C CO3=10000  
 C CO4=35000

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=V21.K-V21CH.K  
 A V22CA.K=V22.K-V22CH.K  
 A V31CA.K=V31.K-V31CH.K  
 A V32CA.K=V32.K-V32CH.K  
 A V41CA.K=V41.K-V41CH.K  
 A V42CA.K=V42.K-V42CH.K

NOTE \*\*\*\*\* DETERMINATION OF TRIP INTERCHANGE MODAL SPLIT VALUE OF TIME \*\*\*\*\*

NOTE TIJC: TIME SPENT USING MODE CAR FROM i TO j (MIN)  
 NOTE TIJB: TIME SPENT USING MODE BUS FROM i TO j (MIN)  
 NOTE CIJC: MONEY SPENT USING MODE CAR FROM i TO j (\$)  
 NOTE CIJB: MONEY SPENT USING MODE BUS FROM i TO j (\$)  
 NOTE ZIJC: TRIP DISUTILITY (GENERALIZED COST) USING MODE CAR FROM i TO j (\$)  
 NOTE ZIJB: TRIP DISUTILITY USING MODE BUS FROM i TO j (\$)  
 NOTE PIJC: FRACTION OF TRIPS FROM i TO j USING CAR  
 NOTE PIJB: FRACTION OF TRIPS FROM i TO j USING BUS

L T21C.K=T21C.J+(DT/ST)(TT21CF.J-T21C.J)  
 N T21C=T21CN  
 L T22C.K=T22C.J+(DT/ST)(TT22CF.J-T22C.J)  
 N T22C=T22CN  
 L T31C.K=T31C.J+(DT/ST)(TT31CF.J-T31C.J)

N T31C=T31CN  
 L T32C.K=T32C.J+(DT/ST)(TT32CF.J-T32C.J)  
 N T32C=T32CN  
 L T41C.K=T41C.J+(DT/ST)(TT41CF.J-T41C.J)  
 N T41C=T41CN  
 L T42C.K=T42C.J+(DT/ST)(TT42CF.J-T42C.J)  
 N T42C=T42CN  
 L T21B.K=T21B.J+(DT/ST)(TT21BA.J-T21B.J)  
 N T21B=T21BN  
 L T22B.K=T22B.J+(DT/ST)(TT22BA.J-T22B.J)  
 N T22B=T22BN  
 L T31B.K=T31B.J+(DT/ST)(TT31BA.J-T31B.J)  
 N T31B=T31BN  
 L T32B.K=T32B.J+(DT/ST)(TT32BA.J-T32B.J)  
 N T32B=T32BN  
 L T41B.K=T41B.J+(DT/ST)(TT41BA.J-T41B.J)  
 N T41B=T41BN  
 L T42B.K=T42B.J+(DT/ST)(TT42BA.J-T42B.J)  
 N T42B=T42BN

P T21BN=37, T21CN=18, T22BN=27, T22CN=13, T31BN=44, T31CN=19  
 P T32BN=36, T32CN=14, T41BN=66, T41CN=30, T42BN=58, T42CN=25  
 A Z21C.K=C21C+VT\*T21C.K  
 A Z22C.K=C22C+VT\*T22C.K  
 A Z31C.K=C31C+VT\*T31C.K  
 A Z32C.K=C32C+VT\*T32C.K  
 A Z41C.K=C41C+VT\*T41C.K  
 A Z42C.K=C42C+VT\*T42C.K  
 P C21C=0.73, C22C=0.23, C31C=1.02, C32C=0.75, C41C=1.73, C42C=1.45  
 C VT=0.1

A Z21B.K=C21B+VT\*T21B.K  
 A Z22B.K=C22B+VT\*T22B.K  
 A Z31B.K=C31B+VT\*T31B.K  
 A Z32B.K=C32B+VT\*T32B.K  
 A Z41B.K=C41B+VT\*T41B.K  
 A Z42B.K=C42B+VT\*T42B.K  
 P C21B=0.5, C22B=0.25, C31B=0.5, C32B=0.5, C41B=0.5, C42B=0.5

NOTE DZIJ.K: □Z, THE DIFFERENCE BETWEEN ZIJB AND ZIJC

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))  
 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  $P42B.K=1-P42C.K$   
 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  $V21B.K=(1-P21C.K)*V21CH.K+V21CA.K$   
 A  $V22B.K=(1-P22C.K)*V22CH.K+V22CA.K$   
 A  $V31B.K=(1-P31C.K)*V31CH.K+V31CA.K$   
 A  $V32B.K=(1-P32C.K)*V32CH.K+V32CA.K$   
 A  $V41B.K=(1-P41C.K)*V41CH.K+V41CA.K$   
 A  $V42B.K=(1-P42C.K)*V42CH.K+V42CA.K$

NOTE \*\*\*\*\* NETWORK ASSIGNMENT ANALYSIS \*\*\*\*\*

NOTE QIJ: NO. OF PEAK HOUR VEH-TRIPS ON LING ij

NOTE QIJC, QIJB: QIJ USING CAR OR BUS

NOTE FDTPH: FRACTION OF DAILY TRIPS DURING PEAK HOUR

NOTE AMO: AVERAGE VEHICLE OCCUPANCY OF MODE M

A  $Q21C.K=(V21C.K+V31C.K+V41C.K)*FDTPH/ACO$

A  $Q21B.K=(V21B.K+V31B.K+V41B.K)*FDTPH/ABO$

A  $Q32C.K=(V31C.K+V32C.K+V41C.K+V42C.K)*FDTPH/ACO$

A  $Q32B.K=(V31B.K+V32B.K+V41B.K+V42B.K)*FDTPH/ABO$

A  $Q43C.K=(V41C.K+V42C.K)*FDTPH/ACO$

A  $Q43B.K=(V41B.K+V42B.K)*FDTPH/ABO$

C  $ACO=2$

C  $ABO=40$

C  $FDTPH=0.4$

NOTE NIJF: NUMBER OF LANES ON FREEWAY

NOTE NIJA: NUMBER OF LANES 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 BEF: BUS EQUIVALENCY FACTOR (CARS/BUS)

NOTE XIJF: LENGTH OF FREEWAY FROM i TO j (MILE)

NOTE XIJA: LENGTH OF ARTERIAL FROM i TO j (MILE)

P  $N21F=4, N32F=5, N43F=4, N21A=2, N32A=2, N43A=2$

P  $QF=2000, QA=1500$

P  $FSF=80, FSA=60$

C  $BEF=3$

P  $X21F=5, X32F=5, X43F=7, X21A=5, X32A=5, X43A=7$

C  $Y=50$

NOTE \*\*\* NETWORK ASSIGNMENT ANALYSIS \*\*\*\*\*

L  $Q43CA.K=Q43CA.J+(DT/ST)(FAD43.J)$   
 N  $Q43CA=Q43CAN$   
 C  $Q43CAN=0$   
 A  $FAD43.K=CLIP(X43.K,0,T43CF.K,T43CA.K)$   
 A  $X43.K=CLIP(0,(T43CF.K-T43CA.K)*Y,EQ43CA,QA*N43A)$   
 N  $EQ43CA=Q43B*BEF$   
 A  $SR43A.K=.5+(.5)(SQRT(1.0-(Q43CA.K+EQ43CA)/(QA*N43A)))$   
 A  $V43CTA.K=SR43A.K*FSA$   
 A  $T43CA.K=(X43A/V43CTA.K)*60$   
 A  $Q43CF.K=Q43C.K-Q43CA.K$   
 A  $SR43F.K=.5+(.5)(SQRT(1.0-(Q43CF.K)/(QF*N43F)))$   
 A  $V43CTF.K=SR43F.K*FSF$   
 A  $T43CF.K=(X43F/V43CTF.K)*60$   
 A  $T43BA.K=T43CA.K$   
 L  $Q32CA.K=Q32CA.J+(DT/ST)(FAD32.J)$   
 N  $Q32CA=Q32CAN$   
 C  $Q32CAN=0$   
 A  $FAD32.K=CLIP(X32.K,0,T32CF.K,T32CA.K)$   
 A  $X32.K=CLIP(0,(T32CF.K-T32CA.K)*Y,EQ32CA,QA*N32A)$   
 N  $EQ32CA=Q32B*BEF$   
 A  $SR32A.K=.5+(.5)(SQRT(1.0-(Q32CA.K+EQ43CA)/(QA*N32A)))$   
 A  $V32CTA.K=SR32A.K*FSA$   
 A  $T32CA.K=(X32A/V32CTA.K)*60$   
 A  $Q32CF.K=Q32C.K-Q32CA.K$   
 A  $SR32F.K=.5+(.5)(SQRT(1.0-(Q32CF.K)/(QF*N32F)))$   
 A  $V32CTF.K=SR32F.K*FSF$   
 A  $T32CF.K=(X32F/V32CTF.K)*60$   
 A  $T32BA.K=T32CA.K$   
 L  $Q21CA.K=Q21CA.J+(DT/ST)(FAD21.J)$   
 N  $Q21CA=Q21CAN$   
 C  $Q21CAN=0$   
 A  $FAD21.K=CLIP(X21.K,0,T21CF.K,T21CA.K)$   
 A  $X21.K=CLIP(0,(T21CF.K-T21CA.K)*Y,EQ21CA,QA*N21A)$   
 N  $EQ21CA=Q21B*BEF$   
 A  $SR21A.K=.5+(.5)(SQRT(1.0-(Q21CA.K+EQ43CA)/(QA*N21A)))$   
 A  $V21CTA.K=SR21A.K*FSA$   
 A  $T21CA.K=(X21A/V21CTA.K)*60$   
 A  $Q21CF.K=Q21C.K-Q21CA.K$   
 A  $SR21F.K=.5+(.5)(SQRT(1.0-(Q21CF.K)/(QF*N21F)))$   
 A  $V21CTF.K=SR21F.K*FSF$   
 A  $T21CF.K=(X21F/V21CTF.K)*60$   
 A  $T21BA.K=T21CA.K$

NOTE \*\*\*\*\* EQUILIBRIUM CHECK OF HORIZON YEAR DEMAND FUNCTION \*\*\*\*\*

A  $WT21.K=((TT21CF.K*V21C.K)+(TT21BA.K*V21B.K))/V21.K$   
 A  $WT22.K=((TT22CF.K*V22C.K)+(TT22BA.K*V22B.K))/V22.K$   
 A  $WT31.K=((TT31CF.K*V31C.K)+(TT31BA.K*V31B.K))/V31.K$   
 A  $WT32.K=((TT32CF.K*V32C.K)+(TT32BA.K*V32B.K))/V32.K$   
 A  $WT41.K=((TT41CF.K*V41C.K)+(TT41BA.K*V41B.K))/V41.K$   
 A  $WT42.K=((TT42CF.K*V42C.K)+(TT42BA.K*V42B.K))/V42.K$   
 A  $TT21CF.K=T21CF.K+CDT21C$

A TT32CF.K=T32CF.K+CDT32C  
 A TT21BA.K=T21BA.K+CDT21B  
 A TT32BA.K=T32BA.K+CDT32B  
 A TT31CF.K=T32CF.K+T21CF.K+CDT31C  
 A TT42CF.K=T43CF.K+T32CF.K+CDT42C  
 A TT31BA.K=T32BA.K+T21BA.K+CDT31B  
 A TT42BA.K=T43BA.K+T32BA.K+CDT42B  
 A TT41CF.K=T43CF.K+T32CF.K+T21CF.K+CDT41C  
 A TT41BA.K=T43BA.K+T32BA.K+T21BA.K+CDT41B  
 A TT22CF.K=CDT22C  
 A TT22BA.K=CDT22B  
 P CDT21C=13,CDT22C=13,CDT31C=9,CDT32C=9,CDT41C=13,CDT42C=13  
 P CDT21B=32,CDT22B=27,CDT31B=34,CDT32B=31,CDT41B=49,CDT42B=46

NOTE \*\*\*\* CONTROL STATEMENTS \*\*\*\*

SPEC DT=1/LENGTH=200/SAVPER=1/PLTPER=1/PRTPER=.25  
 SAVE T21,T31,T41,T22,T32,T42  
 SAVE A2,A3,A4  
 SAVE L2,L3,L4,P2,P3,P4  
 SAVE IGA21,IGA22,IGA23,IGA31,IGA32,IGA33,IGA41,IGA42,IGA43,GB12,GB13,GB22,GB23  
 SAVE V21,V31,V41,V22,V32,V42  
 SAVE D1,D2,O2,O3,O4  
 SAVE V21B,V31B,V41B,V22B,V32B,V42B  
 SAVE V21C,V31C,V41C,V22C,V32C,V42C  
 SAVE Q21C,Q21B,Q32C,Q32B,Q43C,Q43B  
 SAVE Q21CF,Q21CA,Q32CF,Q32CA,Q43CF,Q43CA  
 SAVE TT21CF,TT31CF,TT41CF,TT22CF,TT32CF,TT42CF  
 SAVE TT21BA,TT31BA,TT41BA,TT22BA,TT32BA,TT42BA  
 SAVE T21CF,T32CF,T43CF,T21CA,T32CA,T43CA  
 SAVE T21BA,T32BA,T43BA  
 SAVE WT21,WT31,WT41,WT22,WT32,WT42

□

## B. Programming: Lowry Model

### 1. Dynamo Solution: prototype

\*\*\*\*\* LOWRY MODEL \*\*\*\*\*

- \* The following is a prototype of lowry model programming. As it focuses
- \* on the procedure, it needs developing with more dynamic behaviors for
- \* a systems approach. However, it can be directly used in a converted form,
- \* such as FORTRAN, C, BASIC, etc.

```
L  LF.K(I)=LF.J(I)+(DT/AT)*CLF.JK(I)
NOTE LF - LABOR FORCE
N  LF(I)=ILF(I)
R  CLF.KL(I)=HSL.K(I)-LF.K(I)
A  HSL.K(I)=ARHJ.K(I)*ZR(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,N)
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,N)
A  TS8.K(I,J)=LF.K(J)/T(I,J)
T  ZHS=////////-----
N  AT=DT
C  P=
NOTE P - HOUSEHOLD JOBS PER PERSON
C  F=
NOTE F - LABOR PARTICIPATION FRACTION
N  TBJ=SUM(BJ)
NOTE TBJ - TOTAL NUMBER OF BUSINESS JOBS
T  BJ=////////-----
NOTE BJ - BUSINESS JOBS IN ZONE I
I  N=
FOR I=1,N/J=1,N
N  ASI(I)=SUMV(TS1(I,*),1,N)
N  TSI(I,J)=BJ(J)/T(I,J)
N  BSJ(I)=ASI(I)*ZSI(I)*ZSI(I)*TBSJ/SUM(TS2)
N  TS2(I)=ASI(I)*ZSI(I)
T  ZSI=////////-----
T  T(*,1)=////---
T  T(*,2)=////---
-----
T  T(*,N)=////-----
N  TBSJ=TBJ*S
C  S=
NOTE S - SERVICE INDUSTRY MULTIPLIER
N  IJ(I)=BJ(I)+BSJ(I)
NOTE IJ-INDUSTRIAL JOBS (BASIC &BUSINESS SERVICE)
N  TIJ=TBJ+TBSJ
N  ILF(I)=ARIJ(I)*ZR(I)*TKJ/SUM(TS3)
```

N  $TS3(I)=ARKJ(I)*ZR(I)$   
 N  $ARIJ(I)=SUMV(TS4(I,*),I,N)$   
 N  $TS4(I,J)=IJ(J)/T(I,J)$   
 T  $ZR=////---$   
 NOTE ZR - RESIDENTIAL ZONE AREA  
 NOTE TS-TRANSIENT SOLUTION

SPEC  $DT=1/LENGTH=10/PRTPRE=1/PLTPER=1/SAVPER=1$   
 SAVE BSJ, LF, HSJ

□

## 2. DYNAMO solution to the Lowry Model: Case 1

\*TWO REGIONS (URBAN AND SUBURBAN) ARE TESTED FOR THE LOWRY MODEL. THE LOWRY MODEL CAN SHOW DISTRIBUTION OF HOUSEHOLD POPULATION BASED ON NUMBERS OF JOBS IN REGIONS AND TRAVEL TIME BETWEEN REGIONS. THIS MODIFIED VERSION TO SYSTEM DYNAMICS CAN SHOW THE TRENDS OF MIGRATION OVER TIME.

L  $BS.K=BS.J+(DT)(BGS.JK)$   
 NOTE BS: BASIC SUBURBAN URBAN  
 N  $BS=BSN$   
 C  $BSN=2800$   
 R  $BGS.KL=(PBS-BS.K)/BAT.K$   
 NOTE BGS: BASIC GROWTH SUBURBAN  
 C  $PBS=19000$   
 NOTE PBS: PROJECTED BASIC SUBURBAN  
 L  $RS.K=RS.J+(DT)(RGS.JK)$   
 NOTE RS: RESIDENTS SUBURBAN URBAN  
 N  $RS=RSN$   
 C  $RSN=4000$   
 R  $RGS.KL=(PRS.K-RS.K)/RAT.K$   
 NOTE RGS: RESIDENTIAL GROWTH SUBURBAN  
 A  $PRS.K=(BU.K+SU.K)*WURS.K+(BS.K+SS.K)*WSRS.K$   
 NOTE PRS: PROJECTED RESIDENTIAL SUBURBAN  
 L  $SS.K=SS.J+(DT)(SGS.JK)$   
 NOTE SS: SERVICE SUBURBAN URBAN  
 N  $SS=SSN$   
 C  $SSN=800$   
 R  $SGS.KL=(BETA*PGU.KL*PUSS.K+BETA*PGS.KL*PSSS.K)/AT$   
 NOTE SGS: SERVICE GROWTH SUBURBAN  
 C  $BETA=0.2$   
 L  $PS.K=PS.J+(DT)(PGS.JK)$   
 NOTE PS: POPULATION SUBURBAN URBAN  
 N  $PS=PSN$   
 C  $PSN=10000$   
 R  $PGS.KL=ALPHA*RGS.KL$   
 NOTE PGS: POPULATION GROWTH SUBURBAN  
 C  $ALPHA=2.5$   
 L  $BU.K=BU.J+(DT)(BGU.JK)$

NOTE BU: BASIC URBAN JOBS  
 N BU=BUN  
 C BUN=14000  
 R  $BGU.KL=(PBU-BU.K)/BAT.K$   
 NOTE BGU: BASIC GROWTH URBAN  
 C PBU=90000  
 NOTE PBU: POPULATION BASIC URBAN  
 A  $BAT.K=TABLE(BATT,(BS.K+BU.K)/(PBU+PBS),0,1,0.2)$   
 T  $BATT=10/9/8/7/6/5$   
 NOTE BAT: BASIC ADJUSTED TIME  
 L  $RU.K=RU.J+(DT)(RGU.JK)$   
 NOTE RU: RESIDENTIAL URBAN  
 N RU=RUN  
 C RUN=20000  
 R  $RGU.KL=(PRU.K-RU.K)/RAT.K$   
 NOTE RGU: RESIDENTIAL GROWTH URBAN  
 A  $PRU.K=(BU.K+SU.K)*WURU.K+(BS.K+SS.K)*WSRU.K$   
 NOTE PRU: PROJECTED RESIDENTIAL URBAN  
 A  $RAT.K=TABLE(RATT,(RUN+RSN)/(RU.K+RS.K),0,1,2,0.2)$   
 T  $RATT=6/5/4/3/2/2/2$   
 L  $SU.K=SU.J+(DT)(SGU.JK)$   
 NOTE SU: SERVICE URBAN  
 N SU=SUN  
 C SUN=4000  
 R  $SGU.KL=(BETA*PGU.KL*PUSU.K+BETA*PGS.KL*PSSU.K)/AT$   
 NOTE SGU: SERVICE GROWTH URBAN  
 C AT=3  
 NOTE AT: ADJUSTED TIME  
 L  $PU.K=PU.J+(DT)(PGU.JK)$   
 NOTE PU: POPULATION URBAN  
 N PU=PUN  
 C PUN=50000  
 R  $PGU.KL=ALPHA*(RGU.KL)$   
 A  $UTTM.K=TABLE(TTMT,(BUN+SUN+PUN)/(BU.K+SU.K+PU.K),0,2,0.2)$   
 NOTE UTTM: TABLE URBAN TRAVEL TIME MULTIPLIER  
 A  $USTTM.K=TABLE(TTMT,(BUN+SUN+BSN+SSN)/(BU.K+SU.K+BS.K+SS.K),0,2,0.2)$   
 NOTE USTTM: TABLE URBAN-SUBURBAN TRAVEL TIME MULTIPLIER  
 A  $STTM.K=TABLE(TTMT,(BSN+SSN+PSN)/(BS.K+SS.K+PS.K),0,2,0.2)$   
 NOTE STTM: TABLE SUBURBAN TRAVEL TIME MULTIPLIER  
 T  $TTMT=1.9/1.7/1.45/1.4/1.4/1.3/1.25/1.2/1.1/1.05/1$   
 A  $WURS.K=(SAREA/USTT.K)/((URA/UUTT.K)+(SAREA/USTT.K))$   
 NOTE WURS: WORK URBAN RESIDENTIAL SUBURBAN  
 A  $WSRU.K=(URA/SUTT.K)/((URA/SUTT.K)+(SAREA/SSTT.K))$   
 NOTE WSRU: WORK SUBURBAN RESIDENTIAL URBAN  
 A  $WURU.K=(URA/UUTT.K)/((URA/UUTT.K)+(SAREA/USTT.K))$   
 NOTE WURU: WORK URBAN RESIDENTIAL URBAN  
 A  $WSRS.K=(SAREA/SSTT.K)/((URA/SUTT.K)+(SAREA/SSTT.K))$   
 NOTE WSRS: WORK SUBURBAN RESIDENTIAL SUBURBAN  
 C SAREA=10000  
 NOTE SAREA: SUBURBAN AREA  
 C URA=9000



NOTE URA: URBAN RESIDENTIAL AREA  
 C UBA=1000  
 NOTE UBA: URBAN BASIC AREA  
 A UUTT.K=30\*UTTM.K  
 NOTE UUTT: URBAN TO URBAN TRAVEL TIME  
 A USTT.K=20\*USTTM.K  
 NOTE USTT: URBAN TO SUBURBAN TRAVEL TIME  
 A SSTT.K=10\*STTM.K  
 NOTE SSTT: SUBURBAN TO SUBURBAN TRAVEL TIME  
 A SUTT.K=20\*USTTM.K  
 NOTE SUTT: SUBURBAN TO URBAN TRAVEL TIME  
 A PUSU.K=(UBA/UUTT.K)/((UBA/UUTT.K)+(SAREA/USTT.K))  
 NOTE PUSU: POPULATION URBAN SERVING URBAN  
 A PUSS.K=(SAREA/USTT.K)/((UBA/UUTT.K)+(SAREA/USTT.K))  
 NOTE PUSS: POPULATION URBAN SERVING SUBURBAN  
 A PSSU.K=(UBA/SUTT.K)/((UBA/SUTT.K)+(SAREA/SSTT.K))  
 NOTE PSSU: POPULATION SUBURBAN SERVING URBAN  
 A PSSS.K=(SAREA/SSTT.K)/((UBA/SUTT.K)+(SAREA/SSTT.K))  
 NOTE PUSU: POPULATION URBAN SERVING URBAN

SAVE BU,RU,BS,RS,SU,PU,SS,PS  
 SPEC DT=.25/LENGTH=60/SAVPER=1

### 3. DYNAMO solution to the Lowry Model: Case 2

The hypothetical area is divided into two parts: urban and suburban areas. Urban population (UPOP) plus suburban population (SPOP) are POP (population of the hypothetical area). The basic industries are located, or will be located in the urban area. A three lane road is upgraded to a four lane road between urban and suburban areas in year 3. The collection-distribution time at both ends of the link is 10 minutes. Inter-zonal travel time will be stable at 30 minutes in the urban area and 15 minutes in the suburban area. Basic industrial capital (BIC) produces basic industrial output (BIO) and basic industrial product (BIP). Basic industrial product (BIP) is affected by BIO, FIOIN (fraction of industrial output to inputs normal), and travel costs in the road. Service jobs and household jobs are allocated to each region according to the concepts of the Lowry model. BIC is a level variable, affected by capital investments (BICI) and capital depreciation (BICD).

NOTE \*\*\*\*\* SYSTEM DYNAMICS APPROACH TO THE LOWRY MODEL \*\*\*\*\*  
 NOTE  
 NOTE \*\*\*\*\* POPULATION SECTOR \*\*\*\*\*  
 L POP.K=POP.J+(DT)(NPG.JK)  
 N POP=POP  
 NOTE POP-POPULATION (PERSONS)  
 C POPN=60000  
 NOTE POPN-POPULATION AT TIME O (PERSONS)  
 R NPG.KL=POP.K\*NGF  
 NOTE NPG-NET POPULATION GROWTH (PERSONS/YR)  
 C NGF=.01  
 NOTE NGF-NET GROWHT FACTOR (1/YR)  
 NOTE  
 NOTE \*\*\*\*\* ECONOMIC SECTOR \*\*\*\*\*

NOTE

L  $BIC.K = BIC.J + (DT)(BICI.JK - BICD.JK)$

NOTE BIC-BASIC INDUS CAPITAL (\$)

N  $BIC = BICN$

NOTE BICN-BASIC INDUS CAPITAL AT TIME 0 (\$)

C  $BICN = 2.5E9$

NOTE BICI-BASIC INDUS CAPITAL INVESTMENT (\$/YR)

R  $BICI.KL = BIP.K * FIPI$

C  $FIPI = .17$

NOTE FIPI-FRACT INDUS PRODUCT INVESTED (DIM)

A  $BIP.K = BIO.K * (1 - FIOI.K)$

NOTE BIP-BASIC INDUS PRODUCT (\$/YR)

A  $FIOI.K = FIOIN * (1 - FHWY) + FIOIN * FHWY * (T21.K / T21N)$

C  $FHWY = 0.1$

NOTE FIOI-FRACT INDUS OUTPUT TO INPUTS NORM (DIM)

C  $FIOIN = .7$

NOTE FIOIN-FRACT INDUS OUTPUT TO INPUTS NORM (DIM)

A  $BIO.K = BIC.K / COR$

NOTE BIO-BASIC INDUS OUTPUT (\$/YR)

C  $COR = 1.2$

NOTE COR-CAPITAL OUTPUT RATIO (YR))

R  $BICD.KL = BIC.K / ALC$

NOTE BICD-BASIC INDUS CAPITAL DEPRECIATION (\$/YR)

C  $ALC = 30$

NOTE ALC-AVERAGE LIFETIME CAPITAL (YR)

NOTE

NOTE \*\*\*\*\* TRANSPORTAION SECTOR \*\*\*\*\*

L  $T21.K = T21.J + (DT/ST)(CT21.JK)$

N  $T21 = T21N$

C  $T21N = 48.774$

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  $DCR.K = Q21.K / CA.K$

NOTE DCR: DEMAND CAPACITY RATIO (DIM)

A  $CA.K = LC * NL.K * DPP$

NOTE CA: CAPACITY (VEH/HR)

C  $LC = 1800$

NOTE LC: LANE CAPACITY (VEH/HR)

A  $NL.K = CLIP(4, 3, TIME.K, 3)$

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: TRAFFIC DEMAND FROM SUBURB TO CENTRAL CITY (VEH/PERIOD)

C ACO=1

NOTE C ACO=1.5

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 PARAMETER (DIM)

C T11=30

A T12.K=T21.K

C T22=15

NOTE TIJ: ZONAL TRAVEL TIME (MIN)

A O1.K=UO1.K

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

A O2.K=TJ.K-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=UD1.K

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

A D2.K=TJ.K-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.K+BSJ1.K+THSJ1.K

NOTE UD1: UPDATED D1 (TRIPS/PERIOD)

NOTE

NOTE \*\*\*\*\* EMPLOYMENT SECTOR \*\*\*\*\*

NOTE

A BJ1.K=BIC.K/CLR

C CLR=250000

NOTE C BJ1=10000

NOTE BJ1: BASIC JOBS IN CENTRAL CITY (JOBS)

NOTE CLR-CAPITAL LABOR RATIO (\$/PERSON)

A  $BSJ1.K = TBSJ.K * ASI1.K * ZSI1 / (ASI1.K * ZSI1 + ASI2.K * ZSI2)$

A  $BSJ2.K = TBSJ.K - BSJ1.K$

NOTE A BSJ1.K=TBSJ\*ASI1.K\*ZSI1/(ASI1.K\*ZSI1+ASI2.K\*ZSI2)

NOTE A BSJ2.K=TBSJ-BSJ1.K

NOTE BSJ1: ZONE I BUSINESS SERVICE JOBS (JOBS)

A TBSJ.K=BJ1.K\*S

NOTE 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 CAPACITY OF SERVICE INDUSTRY (THOUSAND JOBS)  
 A ASI1.K=BJ1.K/T11  
 A ASI2.K=BJ1.K/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 INDUSTRIAL LABOR FORCE (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.K+BSJ1.K)/T11)+(BSJ2.K/T12.K)  
 A ARIJ2.K=((BJ1.K+BSJ1.K)/T21.K)+(BSJ2.K/T22)  
 NOTE ARIJ: ACCESSIBILITY OF RESIDENTIAL ZONE I TO INDUS JOBS  
 A THSJ1.K=THSJ.K\*AHP1.K\*ZHS1/(AHP1.K\*ZHS1+AHP2.K\*ZHS2)  
 A THSJ2.K=THSJ.K-THSJ1.K  
 NOTE THSJI: ZONE I TOTAL HOUSEHOLD SERVICE JOB (JOBS)  
 A THSJ.K=POP.K\*JCPP  
 NOTE THSJ: TOTAL HOUSEHOLD SERVICE JOBS (JOBS)  
 C JCPP=.05  
 NOTE JCPP: JOBS CREATED PER PERSON (DIM)  
 A TJ.K=BJ1.K+TBSJ.K+THSJ.K  
 NOTE THSJ=TJ-BJ1.K-TBSJ  
 NOTE C TJ=36000  
 NOTE TJ: TOTAL JOBS OF THE METROPOLITAN AREA (JOBS)  
 C ZHS1=20  
 C ZHS2=20  
 NOTE ZHSI: ZONE I HOLDING CAPACITY OF H'HOLD INDUSRY (THOUSAND PEOPLE)  
 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'HOLD TO POPULATION  
 A THSL1.K=THSJ.K\*ARHJ1.K\*ZR1/(ARHJ1.K\*ZR1+ARHJ2.K\*ZR2)  
 NOTE THSLI: ZONE I TOTAL H'HOLD 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'HOLD JOBS  
 A SPOP.K=O2.K/LPF  
 NOTE SPOP-SUBURBAN POPULATION (PERSONS)  
 A UPOP.K=POP.K-SPOP.K  
 NOTE UPOP-URBAN POPULATION (PERSONS)  
 C LPF=0.4  
 NOTE LPF-LABOR PARTICIPATION FACTOR (DIM)  
 A LF.K=POP.K\*LPF  
 A UR.K=MAX((LF.K-TJ.K)/LF.K,0)  
 NOTE  
 SPEC DT=0.25/LENGTH=20/PRTPER=1/PLTPER=1/SAVPER=1  
 SAVE T21,Q21,O1,O2,D1,D2,BSJ1,THSJ1,AHP1,AHP2,POP,UPOP,SPOP,BJ1,BIC  
 SAVE TJ,THSJ1,THSJ2,TBSJ,THSJ,ILF1,ILF2,UR,BIP,BIO,UT21,CT21,CA,DCR,Q21

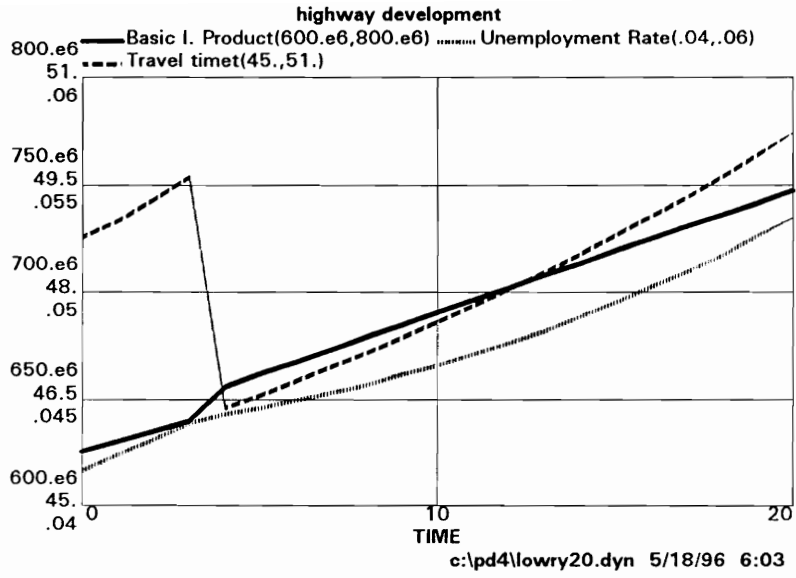


Fig. B.1. Simulation Result 1: The Lowry model

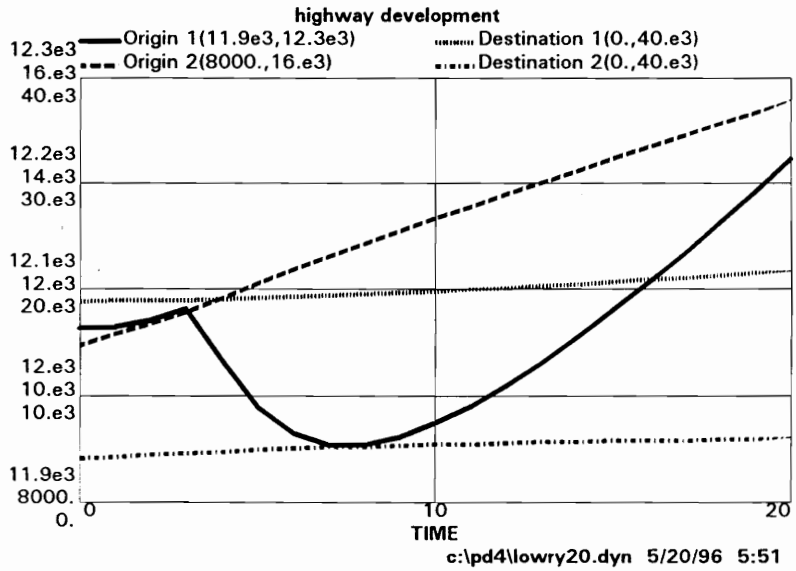


Fig. B.2. Simulation Result 2: The Lowry model

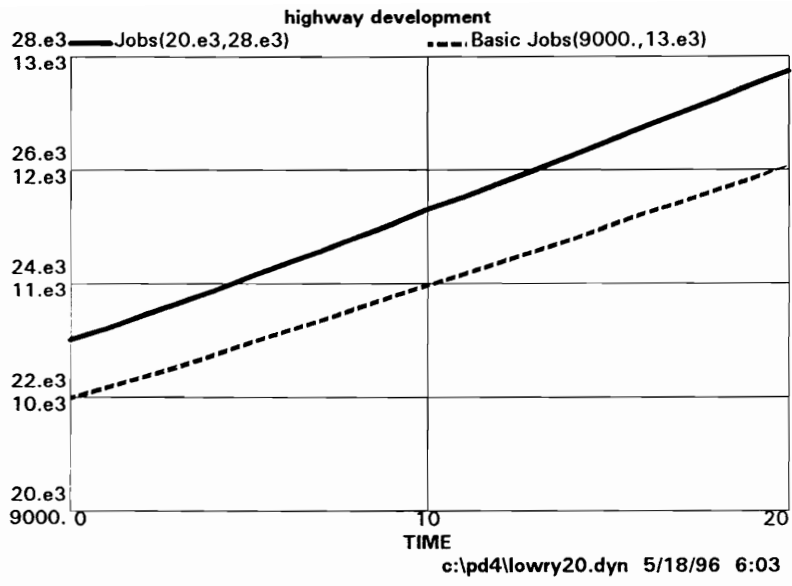


Fig. B.3. Simulation Result 3: The Lowry model

## Appendix C. Programming: Regional I-O Model

### 1. Technical coefficient matrix and regional I-O analysis for a hypothetical region.

A regional planner needs to evaluate the impacts of construction activities. A hypothetical input-output model transactions matrix is introduced in the following. There are three sectors: the processing sector, the payment sector, and the final demand sector. Final demand sectors are the ultimate consumers of output, but provide no inputs to the processing sectors. Four items are selected in the processing sector: agriculture and manufacturing, transportation, wholesale & retail and services, and households. To make the problem simple, household sector will be excluded.

Table 1. The hypothetical I-O Model Transactions Matrix (\$1,000)

Output-> Input	Agri & Manuf	Transp.	Whole & Services	Househ.	Final Demand	Total Sales
Agri & M	1483	5	201	614	12478	14781
Transp.	310	54	105	22	119	610
Whole	1010	71	877	2558	2381	6897
Househ.	3450	252	2697	869	1447	8715
Payment	8528	228	3017	4652		
Total S.	14781	610	6897	8715		

- The direct requirements matrix needs to be found. This case excludes the household sector in the processing sector.

### Program in MATLAB

```
x11=1483, x12=5, x13=201, x14=614
x21=310, x22=54, x23=105, x24=22
x31=1010, x32=71, x33=877, x34=2558
x41=3450, x42=252, x43=2697, x44=869
```

```
x1=14781, x2=610, x3=6897, x4=8715
```

```
X = [ x1; x2; x3 ]
```

```
I = [ 1 0 0 ; 0 1 0 ; 0 0 1 ]
```

```
Y = [ x1-x11-x12-x13-x14; x2-x21-x22-x23-x24;
      x3-x31-x32-x33-x34; x4-x41-x42-x43-x44 ]
```

```
A = [ x11/x1 x12/x2 x13/x3 ; x21/x1 x22/x2 x23/x3;
      x31/x1 x32/x2 x33/x3 ]
```

```
B = inv(I-A)
```

```
Y1 = [ 0; 0; 100000 ]
```

```
X1 = B*Y1
```

**Results**

**Table 2. The I-O Model Direct Requirements Matrix: A**

<i>Output-&gt; Input</i>	<i>Agri &amp; Manuf</i>	<i>Transp.</i>	<i>Whole &amp; Services</i>
<i>Agri &amp; M</i>	.1003	.0082	.0291
<i>Transp.</i>	.0210	.0885	.0152
<i>Whole</i>	.0683	.1164	.1272
<i>Househ.</i>	.2334	.4131	.3910
<i>Payment</i>	.5770	.3738	.4374
<i>Total S.</i>	1.0000	1.0000	1.0000

**Table 3. The Interdependency Coefficient Matrix:  $(I - A)^{-1}$**

<i>Output-&gt; Input</i>	<i>Agri &amp; Manuf</i>	<i>Transp.</i>	<i>Whole &amp; Services</i>
<i>Agri &amp; M</i>	1.1147	.0148	.0374
<i>Transp.</i>	.0272	1.0999	.0201
<i>Whole</i>	.0909	.1478	1.1513
<i>Total S.</i>	1.2328	1.2625	1.2088

- There is a new demand for construction activities for \$100,000 dollars. What is the total economic activity generated? Find out the input-output model output multipliers of each in the processing sector.

**Results**

1.2088 \* 100,000 = 120,880  
 Agriculture & Manufacturing: 1.2328  
 Transportation: 1.2625  
 Wholesale & Retail and Services: 1.2088

- Find out the I-O model employment multipliers of each sector. Suppose \$1,000 output of each sector.

**Table 4. The Input-Output Model Labor/Output Ratios**

<i>Processing Sector</i>	<i>Labor/Output Ratio (man yrs. of labor/\$1000 Output)</i>
<i>Agri &amp; Manufacturing</i>	0.05
<i>Transp.</i>	0.04
<i>Whole Sale &amp; Services</i>	0.07

For example, a \$1,000 increase in final demand sales by Agriculture requires 0.05735 man years of Agriculture labor (1.1147 \* 1,000 \* 0.05/1,000).



Table 5. Employment Multiplier

<i>Processing Sector</i>	<i>Agri &amp; Manuf</i>	<i>Transp.</i>	<i>Whole &amp; Services</i>	<i>Total Labor Requirements</i>	<i>Employment Multiplier</i>
<i>Agri &amp; M</i>	.05735	.00136	.00455	.06326	1.2652
<i>Transp.</i>	.00059	.04400	.00591	.05050	1.2626
<i>Whole &amp; Ser.</i>	.00262	.00141	.08059	.08462	1.2089

## 2. Linear Programming Approach to I-O Approach

Total economic activities need to be considered instead of additional economic activities. The objective function can be maximization or minimization. The maximization function is generally used for I-O analysis. A linear programming approach to regional I-O analysis is introduced in MATLAB in the following. Labor and pollution are used for constraining factors. There are many software packages for linear programming. Professor Henry Wolkowicz programmed the simplex method and Big-M method in MATLAB. He gave his programming as public domain in Internet. Although there are modifications, I used his programming for linear programming in MATLAB.

Data input by user or calling routine: a, b, c, bas  
 where minmax = 1, if minimizing problem  
                   0, if maximizing problem  
 a - m by (m+n) matrix (containing identity)  
 b - m-column vector assumed  $\geq 0$   
 c - m+n-row vector of costs which is placed left hand side (LHS)  
 bas - m-row vector with column indices corresponding to the identity matrix in a, i.e., a(bas,:)=  
 identity.

In the following, programming in MATLAB is introduced for a linear programming approach to regional input-output analysis.

### Programming in MATLAB

minmax=0; % maximizing problem

a = [ a1 a2; a3 a4]

a1 = B

B = (I-A)

$$I = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A = \begin{bmatrix} .1003 & .0082 & .0291 & .0704 \\ .0210 & .0885 & .0152 & .0025 \\ .0683 & .1164 & .1272 & .2935 \\ .2334 & .4131 & .3910 & .0997 \end{bmatrix}$$

```
a2 = [ -1 0 0 0 1 0 0 0 0 0 0 0 0 0
        0 -1 0 0 0 1 0 0 0 0 0 0 0 0
        0 0 -1 0 0 0 1 0 0 0 0 0 0 0
        0 0 0 -1 0 0 0 1 0 0 0 0 0 0]
```

```
a3 = [  0  0  0  0
        0  0  0  0
        0  0  0  0
        0  0  0  0
        0.05 0.04 0.07  0
        0.02 0.08 0.03 0.01]
```

```
a4 = [ 1 0 0 0 0 0 0 0 1 0 0 0 0 0
        0 1 0 0 0 0 0 0 0 1 0 0 0 0
        0 0 1 0 0 0 0 0 0 0 1 0 0 0
        0 0 0 1 0 0 0 0 0 0 0 1 0 0
        0 0 0 0 0 0 0 0 0 0 0 0 1 0
        0 0 0 0 0 0 0 0 0 0 0 0 0 1]
```

```
b = [ 0 0 0 0 14781 610 6897 8715 1200 700]'
```

```
c = [ -1 -1 -1 -1 0 0 0 0 0 0]
```

```
bas = [ 9 10 11 12 13 14 15 16 17 18 ]
```

- Regional Input-Output Programming in DYNAMO

### 3. Three Sectors Regional Dynamic Input-Output Analysis -- Case 1

NOTE

NOTE A SIMPLE THREE SECTOR REGIONAL DYNAMIC INPUT-OUTPUT ANALYSIS IS

NOTE CONSIDERED.

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 FORM AGRICULTURE (\$)

NOTE FAA-FRACTION OF AGRICULTURE INPUT FROM AGRICULTURE

NOTE FAI-FRACTION OF INDUSTRY INPUT FROM AGRICULTURE

NOTE FAS-FRACTION OF SERVICE 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 \*\*\*\*\* 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 SERVICE 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 SERVICE 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  $FAAN=.1425$   
 A  $FIA.K=FIAN+FIAM.K$   
 A  $FIAM.K=1.0$   
 C  $FIAN=.3020$   
 A  $FSA.K=FSAN*FSAM.K$   
 A  $FSAM.K=1.0$   
 C  $FSAN=.1214$   
 A  $FAI.K=FAIN*FAIM.K$   
 A  $FAIM.K=1.0$   
 C  $FAIN=.0147$   
 A  $FII.K=FIIN*FIIM.K$   
 A  $FIIM.K=1.0$   
 C  $FIIN=.3688$   
 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  $FASN=.0008$   
 A  $FIS.K=FISN*FISM.K$   
 A  $FISM.K=1.0$   
 C  $FISN=.1032$   
 A  $FSS.K=FSSN*FSSM.K$   
 A  $FSSM.K=1.0$   
 C  $FSSN=.0861$

NOTE

NOTE\*\*\*\*\*CAPITAL INFORMATION\*\*\*\*\*

NOTE AC: AGRICULTURE CAPITAL (\$)

NOTE ACI: AGRICULTURE CAPITAL INVESTMENT (\$/YR)

NOTE ACD: AGRICULTURE CAPITAL DEPRECIATION (\$/YR)

NOTE AP: AGRICULTURE PRODUCT (\$/YR)  
 NOTE AP: AGRICULTURE PRODUCT (\$/YR)  
 NOTE FAPC: FRACTION OF AGRICULTURE PRODUCT TO CAPITAL  
 NOTE ALAC: AVERAGE LIFETIME OF AGRICULTURE CAPITAL (YR)  
 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 IC: INDUSTRY CAPITAL (\$)  
 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)  
 L  $IC.K=IC.J+(DT)(ICI.JK-ICD.JK)$   
 N  $IC=ICN$   
 C  $ICN=5.44E10$   
 R  $ICI.KL=IP.K * FIPC$   
 C  $FIPC=.2708$   
 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  $FSPC=.0318$   
 R  $SCD.KL=SC.K/ALSC$   
 C  $ALSC=20$   
 NOTE  
 SPEC  $DT=1/LENGTH=30/PRTPER=10/PLTPER=1/SAVPER=1$   
 SAVE AC,AP,AO,IC,IP,IO,SC,SP,SO

#### 4. Regional Input-Output Analysis without Constraints -- Case 2

NOTE SYSTEMS APPROACH TO REGIONAL INPUT-OUTPUT MODELING: CASE 2  
 NOTE \*\*\*\*\*  
 NOTE IN THIS EXAMPLE, THE DIRECT AND INVERSE LEONTIEF COEFFICIENTS ARE  
 NOTE ALREADY CALCULATED AND USED AS EXOGENOUS. FINAL DEMAND HAS  
 NOTE AVERAGE ANNUAL GROWTH FROM REGRESSION OR TIME-SERIES ANALYSIS.

NOTE THERE IS NO CONSTRAINT HERE.

NOTE \*\*\*\*\*

NOTE

NOTE DEMOGRAPHIC SECTOR

NOTE

L  $POP.K=POP.J+(DT)(NPG.JK)$

N  $POP=POPN$

C  $POPN=42000$

NOTE POP-POPULATION (PERSONS)

R  $NPG.KL=POP.K*NGF$

NOTE NPG-NET POPULATION GROWTH (PERSON/YR)

C  $NGF=0.024$

NOTE NGF-NET GROWTH FACTOR (1/YR)

NOTE

NOTE ECONOMIC SECTOR

NOTE

A  $FD.K=FD1.K+FD2.K+FD3.K$

L  $FD1.K=FD1.J+(DT)(NFD1.JK)$

L  $FD2.K=FD2.J+(DT)(NFD2.JK)$

L  $FD3.K=FD3.J+(DT)(NFD3.JK)$

NOTE FD-FINAL DEMAND(\$) 1,2,3 - AGRICULTURE, MANUFACTURING, SERVICES

R  $NFD1.KL=FD1.K*IGF1$

R  $NFD2.KL=FD2.K*IGF2$

R  $NFD3.KL=FD3.K*IGF3$

NOTE NFD-NET GROWTH IN FINAL DEMAND (\$/YR)

N  $FD1=FD1N$

N  $FD2=FD2N$

N  $FD3=FD3N$

C  $FD1N=12E6$

C  $FD2N=393E6$

C  $FD3N=194E6$

P  $IGF1=.025/IGF2=.025/IGF3=.025$

NOTE IGF-INDUSTRIAL GROWTH FACTOR

A  $O.K=O1.K+O2.K+O3.K$

A  $O1.K=FO11*FD1.K+FO12*FD2.K+FO13*FD3.K$

A  $O2.K=FO21*FD1.K+FO22*FD2.K+FO23*FD3.K$

A  $O3.K=FO31*FD1.K+FO32*FD2.K+FO33*FD3.K$

NOTE O-OUTPUT

P  $FO11=1.1110/FO12=0.0856/FO13=0.0260$

P  $FO21=0.0269/FO22=1.0999/FO23=0.0331$

P  $FO31=0.1253/FO32=0.1187/FO33=1.1538$

NOTE FO-FINAL DEMAND-TO-OUTPUT COEFFICIENT

NOTE

NOTE EMPLOYMENT SECTOR

NOTE

A  $L.K=POP.K*FLR$

NOTE L-LABORFORCE (PERSONS)

C  $FLR=.55$

NOTE FLR=FRACTION OF LABOR TO POPULATION

A  $J.K=J1.K+J2.K+J3.K$

NOTE J-JOBS

A  $J1.K = O1.K * LOR1$   
 A  $J2.K = O2.K * LOR2$   
 A  $J3.K = O3.K * LOR3$   
 P  $LOR1 = 60E-6 / LOR2 = 23E-6 / LOR3 = 30E-6$   
 NOTE LOR-LABOR OUTPUT RATIO  
 A  $UR.K = MAX(((L.K - J.K) / L.K), 0)$   
 NOTE UR-UNEMPLOYMENT RATE  
 A  $GRP.K = FD1.K + FD2.K + FD3.K$   
  
 SPEC  $DT = .125 / LENGTH = 25 / SAVPER = 1 / PLTPER = 1 / PRTPER = .25$   
 SAVE POP, GRP, FD, O, UR, J, L

5. Regional Input-Output Analysis with constraints -- Case 3

NOTE SYSTEMS APPROACH TO REGIONAL INPUT-OUTPUT MODELING: CASE 3  
 NOTE \*\*\*\*\*  
 NOTE IN THIS EXAMPLE, THE DIRECT AND INVERSE LEONTIEF COEFFICIENTS ARE  
 NOTE ALREADY CALCULATED AND USED AS EXOGENOUS. FINAL DEMAND HAS  
 NOTE AVERAGE ANNUAL GROWTH FROM REGRESSION OR TIME-SERIES ANALYSIS.  
 NOTE THERE ARE CONSTRAINTS HERE: LABOR AND POLLUTION  
 NOTE \*\*\*\*\*  
 NOTE  
 NOTE DEMOGRAPHIC SECTOR  
 NOTE  
 NOTE SAME AS CASE 2  
 NOTE  
 NOTE ECONOMIC SECTOR  
 NOTE  
 A  $FD.K = FD1.K + FD2.K + FD3.K$   
 L  $FD1.K = FD1.J + (DT)(NFD1.JK)$   
 L  $FD2.K = FD2.J + (DT)(NFD2.JK)$   
 L  $FD3.K = FD3.J + (DT)(NFD3.JK)$   
 NOTE FD-FINAL DEMAND(\$)  
 R  $NFD1.KL = FD1.K * IGF1$   
 R  $NFD2.KL = FD2.K * IGF2$   
 R  $NFD3.KL = FD3.K * IGF3$   
 NOTE NFD-NET GROWTH IN FINAL DEMAND (\$/YR)  
 N  $FD1 = FD1N$   
 N  $FD2 = FD2N$   
 N  $FD3 = FD3N$   
 C  $FD1N = 12E6$   
 C  $FD2N = 393E6$   
 C  $FD3N = 194E6$   
 P  $IGF1 = .025 / IGF2 = .025 / IGF3 = .025$   
 NOTE IGF-INDUSTRIAL GROWTH FACTOR  
 A  $O.K = O1.K + O2.K + O3.K$   
 A  $O1.K = FO11 * FD1.K + FO12 * FD2.K + FO13 * FD3.K$   
 A  $O2.K = FO21 * FD1.K + FO22 * FD2.K + FO23 * FD3.K$   
 A  $O3.K = FO31 * FD1.K + FO32 * FD2.K + FO33 * FD3.K$   
 NOTE O-OUTPUT  
 P  $FO11 = 1.1110 / FO12 = 0.0856 / FO13 = 0.0260$

P FO21=0.0269/FO22=1.0999/FO23=0.0331  
 P FO31=0.1253/FO32=0.1187/FO33=1.1538  
 NOTE FO-FINAL DEMAND-TO-OUTPUT COEFFICIENT  
 A AO1.K=MIN(O1.K,MO1.K)  
 A MO1.K=MIN(LO1.K,PO1.K)  
 A AO2.K=MIN(O2.K,MO2.K)  
 A MO2.K=MIN(LO2.K,PO2.K)  
 A AO3.K=MIN(O3.K,MO3.K)  
 A MO3.K=MIN(LO3.K,PO3.K)  
 NOTE AO-ACTUAL OUTPUT  
 A LO1.K=L1.K/LOR1  
 A LO2.K=L2.K/LOR2  
 A LO3.K=L3.K/LOR3  
 NOTE LO-MAXIMUM OUTPUT BY LABORFORCE  
 A L1.K=L.K\*0.14  
 A L2.K=L.K\*0.48  
 A L3.K=L.K\*0.38  
 NOTE L1,L2,L3-ALLOCATION OF LABORFORCE TO INDUSTRY  
 A PO1.K=MPOL1/POLOR1  
 A PO2.K=MPOL2/POLOR2  
 A PO3.K=MPOL3/POLOR3  
 P MPOL1=150/MPOL2=650/MPOL3=200  
 P POLOR1=0.4E-6/POLOR2=1.1E-6/POLOR3=0.3E-6  
 A AFD.K=AFD1.K+AFD2.K+AFD3.K  
 A AFD1.K=AO1.K\*OF11+AO2.K\*OF12+AO3.K\*OF13  
 A AFD2.K=AO1.K\*OF21+AO2.K\*OF22+AO3.K\*OF23  
 A AFD3.K=AO1.K\*OF31+AO2.K\*OF32+AO3.K\*OF33  
 NOTE AFD-ACTUAL FINAL DEMAND  
 P OF11=0.9038/OF12=-0.0683/OF13=-0.0184  
 P OF21=-0.0192/OF22=0.9134/OF23=-0.0257  
 P OF31=-0.0962/OF32=-0.0866/OF33=0.8713  
 NOTE OF-OUTPUT-TO-FINAL DEMAND COEFFICIENT  
 NOTE  
 NOTE EMPLOYMENT SECTOR  
 NOTE  
 NOTE SAME AS CASE 2  
 NOTE  
  
 SPEC DT=.125/LENGTH=80/SAVPER=1/PLTPER=1/PRTPER=.25  
 SAVE POP,GRP,FD,AFD,O,UR,AO1,AO2,AO3,LO1,LO2,LO3,PO1,PO2,PO3,J,L

6. Programming: system dynamics approach to demand-oriented GRP forecasting

NOTE SYSTEMS APPROACH TO REGIONAL INPUT-OUTPUT MODELING:  
 NOTE \*\*\*\*\*  
 NOTE IN THIS EXAMPLE, THE DIRECT AND INVERSE LEONTIEF COEFFICIENTS ARE  
 NOTE ALREADY CALCULATED AND USED AS EXOGENOUS. THE FINAL DEMAND HAS  
 NOTE AVERAGE ANNUAL GROWTH FROM REGRESSION OR TIME-SERIES ANALYSIS.  
 NOTE THERE ARE CONSTRAINTS HERE.  
 NOTE \*\*\*\*\*



NOTE

NOTE DEMOGRAPHIC SECTOR

NOTE

L  $POP.K = POP.J + (DT)(NPG.JK)$

N  $POP = POPN$

C  $POPN = 42000$

NOTE POP-POPULATION (PERSONS)

R  $NPG.KL = POP.K * NGF$

NOTE NPG-NET POPULATION GROWTH (PERSON/YR)

C  $NGF = 0.020$

NOTE NGF-NET GROWTH FACTOR (1/YR)

NOTE

NOTE ECONOMIC SECTOR

NOTE

A  $FD.K = FD1.K + FD2.K + FD3.K$

A  $FD1.K = CLIP(FD1B, FD1N, TIME.K, 5)$

A  $FD2.K = CLIP(FD2B, FD2N, TIME.K, 5)$

A  $FD3.K = CLIP(FD3B, FD3N, TIME.K, 5)$

NOTE FD-FINAL DEMAND(\$)<sup>1,2,3</sup> - AGRICULTURE, MANUFACTURING, SERVICES

C  $FD1N = 12E6$

C  $FD2N = 393E6$

C  $FD3N = 194E6$

C  $FD1B = 12E6$

C  $FD2B = 450E6$

C  $FD3B = 200E6$

A  $O.K = O1.K + O2.K + O3.K$

A  $O1.K = DELAY3(FO11 * FD1.K + FO12 * FD2.K + FO13 * FD3.K, 2)$

A  $O2.K = DELAY3(FO21 * FD1.K + FO22 * FD2.K + FO23 * FD3.K, 2)$

A  $O3.K = DELAY3(FO31 * FD1.K + FO32 * FD2.K + FO33 * FD3.K, 2)$

NOTE O-OUTPUT

P  $FO11 = 1.1110 / FO12 = 0.0856 / FO13 = 0.0260$

P  $FO21 = 0.0269 / FO22 = 1.0999 / FO23 = 0.0331$

P  $FO31 = 0.1253 / FO32 = 0.1187 / FO33 = 1.1538$

NOTE FO-FINAL DEMAND-TO-OUTPUT COEFFICIENT

A  $AO1.K = MIN(O1.K, CO1.K)$

A  $AO2.K = MIN(O2.K, CO2.K)$

A  $AO3.K = MIN(O3.K, CO3.K)$

NOTE AO-ACTUAL OUTPUT

A  $LO1.K = L1.K / LOR1$

A  $LO2.K = L2.K / LOR2$

A  $LO3.K = L3.K / LOR3$

NOTE LO-MAXIMUM OUTPUT BY LABORFORCE

A  $L1.K = L.K * 0.14$

A  $L2.K = L.K * 0.48$

A  $L3.K = L.K * 0.38$

NOTE L1,L2,L3-ALLOCATION OF LABORFORCE TO INDUSTRY

A  $CO1.K = C1.K / COR1$

A  $CO2.K = C2.K / COR2$

A  $CO3.K = C3.K / COR3$

P  $COR1 = 1.5 / COR2 = 1.9 / COR3 = 1.7$

NOTE CO-MAXIMUM OUTPUT BY CAPITAL AVAILABILITY

A  $AFD.K=AFD1.K+AFD2.K+AFD3.K$   
 A  $AFD1.K=AO1.K*OF11+AO2.K*OF12+AO3.K*OF13$   
 A  $AFD2.K=AO1.K*OF21+AO2.K*OF22+AO3.K*OF23$   
 A  $AFD3.K=AO1.K*OF31+AO2.K*OF32+AO3.K*OF33$   
 NOTE AFD-ACTUAL FINAL DEMAND  
 P  $OF11=0.9038/OF12=-0.0683/OF13=-0.0184$   
 P  $OF21=-0.0192/OF22=0.9134/OF23=-0.0257$   
 P  $OF31=-0.0962/OF32=-0.0866/OF33=0.8713$   
 NOTE OF-OUTPUT-TO-FINAL DEMAND COEFFICIENT  
 L  $C1.K=C1.J+(DT)(CI1.JK-CD1.JK)$   
 L  $C2.K=C2.J+(DT)(CI2.JK-CD2.JK)$   
 L  $C3.K=C3.J+(DT)(CI3.JK-CD3.JK)$   
 N  $C1=C1N$   
 N  $C2=C2N$   
 N  $C3=C3N$   
 C  $C1N=250E6$   
 C  $C2N=900E6$   
 C  $C3N=450E6$   
 NOTE C-CAPITAL  
 R  $CI1.KL=AFD1.K*CIR1$   
 R  $CI2.KL=AFD2.K*CIR2$   
 R  $CI3.KL=AFD3.K*CIR3$   
 C  $CIR1=0.3$   
 C  $CIR2=0.15$   
 C  $CIR3=0.15$   
 NOTE CIRN-CAPITAL INVESTMENT NORMAL  
 R  $CD1.KL=C1.K/CLN1$   
 R  $CD2.KL=C2.K/CLN1$   
 R  $CD3.KL=C3.K/CLN1$   
 NOTE CD-CAPITAL DEPRECIATION  
 C  $CLN1=20$   
 C  $CLN2=20$   
 C  $CLN3=20$   
 NOTE CLN-CAPITAL LIFETIME NORMAL  
 NOTE  
 NOTE EMPLOYMENT SECTOR  
 NOTE  
 A  $L.K=POP.K*FLR$   
 NOTE L-LABORFORCE (PERSONS)  
 C  $FLR=.55$   
 NOTE FLR=FRACTION OF LABOR TO POPULATION  
 A  $J.K=J1.K+J2.K+J3.K$   
 NOTE J-JOBS  
 A  $J1.K=AO1.K*LOR1$   
 A  $J2.K=AO2.K*LOR2$   
 A  $J3.K=AO3.K*LOR3$   
 P  $LOR1=60E-6/LOR2=23E-6/LOR3=30E-6$   
 NOTE LOR-LABOR OUTPUT RATIO  
 A  $UR.K=MAX(((L.K-J.K)/L.K),0)$   
 NOTE UR-UNEMPLOYMENT RATE  
 A  $GRP.K=AFD1.K+AFD2.K+AFD3.K$

SPEC DT=.125/LENGTH=20/SAVPER=1/PLTPER=1/PRTPER=.25  
SAVE POP,GRP,FD,AFD,O,UR,AO1,AO2,AO3,AFD1,AFD2,AFD3  
SAVE LO1,LO2,LO3,CO1,CO2,CO3,CI1,CI2,CI3,J,L,C1,C2,C3

□

## Appendix D. Programming: Multiregional I-O Model

1. A planner needs to estimate the impacts of a regional economy after adding two more lanes to the existing interstate highway. A hypothetical input-output table and interregional trade flow matrix are introduced. Region 1 has the same transactions matrix as found in Appendix C. 1. Region 2 has the direct requirement coefficient matrix in Table 1.

Table 1. The I-O Model Direct Requirements Matrix including household sector

<i>Output-&gt; Input</i>	<i>Agri &amp; Manuf</i>	<i>Transp.</i>	<i>Whole &amp; Services</i>	<i>Household</i>
<i>Agri &amp; M</i>	.1003	.0082	.0291	.0705
<i>Transp.</i>	.0210	.0885	.0152	.0025
<i>Whole</i>	.0683	.1164	.1272	.2935
<i>Househ.</i>	.2334	.4131	.3910	.0997
<i>Payment</i>	.5770	.3738	.4374	.5334
<i>Total S.</i>	1.0000	1.0000	1.0000	1.0000

Regarding the household sector as endogenous or exogenous reflects the researcher's viewpoints. Obviously there is inter-industry feedback from households, but the linearity in the I-O table gives an exaggeration of impacts. Table 2 concerns the interregional trade flow table for two regions.

Table 2. Interregional trade flow table

### A. Agriculture and Manufacturing

<i>Destination (D) Origin (O)</i>	<i>Virginia</i>	<i>Rest of U.S.</i>
Virginia	0.3	0.05
Rest of the U.S.	0.7	0.95

### B. Transportation

<i>Destination (D) Origin (O)</i>	<i>Virginia</i>	<i>Rest of U.S.</i>
Virginia	0.25	0.05
Rest of the U.S.	0.75	0.95

### C. Whole/Retail Sales & Services

<i>Destination (D) Origin (O)</i>	<i>Virginia</i>	<i>Rest of U.S.</i>
Virginia	0.85	0.05
Rest of the U.S.	0.15	0.95

### D. Household

<i>Destination (D) Origin (O)</i>	<i>Virginia</i>	<i>Rest of U.S.</i>
Virginia	0.95	0.01
Rest of the U.S.	0.05	0.99

The total economic activity generated including the household is in table 4 and that excluding the household is in table 5. A total increase of 2,133 million dollars is expected including the household sector: \$1,569.9 million for Virginia and \$563 million for the rest of the U.S. The table 3 gives the labor/output ratios. Table 4 shows labor (man yrs.) needed: 77,419 (Virginia) and 24,446 (the rest of U.S.). According to the table 5, the total output of Virginia is \$968.8 million and that of the rest of the U.S. is \$241.2 million. The labor needed is 67,513 for Virginia and 15,789 for the rest of the U.S.

Table 3. The Input-Output Model Labor/Output Ratios

<i>Processing Sector</i>	<i>Labor/Output Ratio (man yrs. of labor/\$1000 Output)</i>
<i>Agri &amp; Manufacturing</i>	0.05
<i>Transp.</i>	0.04
<i>Whole Sale &amp; Services</i>	0.07

Table 4. Output after construction (with household) -- using Type II multiplier

	<i>Sector</i>	<i>Output(\$1,000,000)</i>	<i>Labor (man yrs.)</i>
Virginia	Agri & Manuf	21.3	1,065
	Transportation	5.2	208
	Whole & Service	1,087.8	76,146
	Household	455.6	
Rest of the U.S.	Agri & Manuf	75.1	3,755
	Transportation	24.3	972
	Whole & Service	281.9	19,719
	Household	181.7	

Table 5. Output after the construction (without household) -- using Type I multiplier

	<i>Sector</i>	<i>Output(\$1,000,000)</i>	<i>Labor (man yrs.)</i>
Virginia	Agri & Manuf	9.06	453
	Transportation	4.09	164
	Whole & Service	955.67	66,896
Rest of the U.S.	Agri & Manuf	28.40	1,420
	Transportation	17.49	700
	Whole & Service	195.27	13,669

### **Programming in MATLAB**

```
A1 = [.1003 .0082 .0291 .0704
      .0210 .0885 .0152 .0025
      .0683 .1164 .1272 .2935
      .2334 .4131 .3910 .0997]
A2 = [.1 .001 .03 .08
      .03 .1 .02 .003
      .01 .15 .13 .3
      .25 .4 .4 .1]
C11 = [0.3 0 0 0
      0 0.25 0 0
```

```

    0 0 0.85 0
    0 0 0 0.95]
C12 = [0.05 0 0 0
    0 0.05 0 0
    0 0 0.05 0
    0 0 0 0.01]
C21 = [0.7 0 0 0
    0 0.75 0 0
    0 0 0.15 0
    0 0 0 0.05]
C22 = [0.95 0 0 0
    0 0.95 0 0
    0 0 0.95 0
    0 0 0 0.99]
I = [1 0 0 0
    0 1 0 0
    0 0 1 0
    0 0 0 1]
O = [0 0 0 0
    0 0 0 0
    0 0 0 0
    0 0 0 0]
A = [A1 O; O A2]
C = [C11 C12; C21 C22]
II = [I O
      O I]
B = inv(II-C*A)*C
D = inv(inv(C)-A)
Y1 = [0; 0; 1000; 0]
Y2 = [0; 0; 0; 0]
Y = [Y1; Y2]
X = D*Y

```

### Results

```

A =
0.1003  0.0082  0.0291  0.0704   0   0   0   0
0.0210  0.0885  0.0152  0.0025   0   0   0   0
0.0683  0.1164  0.1272  0.2935   0   0   0   0
0.2334  0.4131  0.3910  0.0997   0   0   0   0
0   0   0   0  0.1000  0.0010  0.0300  0.0800
0   0   0   0  0.0300  0.1000  0.0200  0.0030
0   0   0   0  0.0100  0.1500  0.1300  0.3000
0   0   0   0  0.2500  0.4000  0.4000  0.1000

```

```

C =
0.3000   0   0   0  0.0500   0   0   0
0  0.2500   0   0   0  0.0500   0   0
0   0  0.8500   0   0   0  0.0500   0
0   0   0  0.9500   0   0   0  0.0100

```

0.7000	0	0	0	0.9500	0	0	0
0	0.7500	0	0	0	0.9500	0	0
0	0	0.1500	0	0	0	0.9500	0
0	0	0	0.0500	0	0	0	0.9900

B =

0.3179	0.0082	0.0213	0.0305	0.0598	0.0055	0.0069	0.0079
0.0036	0.2611	0.0052	0.0026	0.0025	0.0574	0.0022	0.0011
0.0577	0.0932	1.0878	0.3413	0.0206	0.0443	0.0898	0.0355
0.1065	0.1595	0.4556	1.1991	0.0284	0.0518	0.0463	0.0319
0.8350	0.0711	0.0751	0.0922	1.0932	0.0741	0.0973	0.1294
0.0366	0.8606	0.0243	0.0134	0.0402	1.0674	0.0337	0.0183
0.1251	0.3364	0.2819	0.1215	0.1457	0.3957	1.2940	0.4418
0.3065	0.5546	0.1817	0.1546	0.3835	0.6661	0.6126	1.3376

Y = [ 0; 0; 1000; 0; 0; 0; 0; 0]

X = 1.0e+003 \* [0.0213; 0.0052; 1.0878; 0.4556; 0.0751; 0.0243; 0.2819; 0.1817]

## 2. Programming for MRIO: system dynamics approach

### Tables & Data

- I-O model transaction matrices for city A and city B (\$1,000,000).

#### -City A

Output-> Input	Agri.	Manuf.	Whole & Services	Househ.	Final Demand	Total Sales
Agri	5	30	5	2	10	52
Manuf.	1	38	7	20	373	439
Whole	5	38	35	98	96	272
Househ.	19	125	105	35	46	330
Payment	22	208	120	175		
Total S.	52	439	272	330		

#### -City B

Output-> Input	Agri.	Manuf.	Whole & Services	Househ.	Final Demand	Total Sales
Agri	9	59	11	3	26	108
Manuf.	3	113	20	61	1234	1431
Whole	12	96	88	256	238	690
Househ.	46	324	270	87	145	872
Payment	38	839	301	465		
Total S.	108	1431	690	872		

- Interregional trade flow tables for city A and city B.

Destination	Agriculture		Manufacturing		Wholesale & Services	
	A	B	A	B	A	B
From City A	0.5	0.6	0.3	0.15	0.9	0.1
From City B	0.5	0.4	0.7	0.75	0.1	0.9

- The I-O model labor/output ratio, land/output ratio, and pollution/output ratio (both cities)

	Labor/output ratio (man-year/\$million)	Land/output ratio (acres/\$million)	Pollution/output (/\$million)
Agriculture	60	800	0.4
Manufacturing	25	80	1.1
Whole & Service	30	120	0.4

- Population and labor force

	City A	City B
Labor force (LF)	.55*POP (persons)	.55*POP (persons)
Population (POP)	42,000 (persons)	78,000 (persons)
Net Growth Factor (NGF)	.015	.015

- Constraints: pollution, labor, and land

### Programming in DYNAMO

NOTE ESTIMATION OF POPULATION, TRANSPORTATION NEEDS AND SOCIO-ECO IMPACT  
NOTE

NOTE POPULATION SECTOR FOR BOTH CITIES (A & B)

NOTE \*\*\*\*\*

L PA.K=PA.J+(DT)(NPGA.JK)

N PA=PAN

NOTE PA-POPULATION (PERSON)

C PAN=42000

NOTE PAN,PBN-POPULATION AT TIME 0 (PERSONS)

R NPGA.KL=PA.K\*NGFA

NOTE NPGA,NPGB-NET POPULATION GROWTH (PERSONS/YR)

C NGFA=.015

NOTE NGFA,NGFB-NET GROWTH FACTOR (1/YR)

L PB.K=PB.J+(DT)(NPGB.JK)

N PB=PBN

C PBN=78000

R NPGB.KL=PB.K\*NGFB

C NGFB=.015



NOTE

NOTE ECONOMIC SECTOR

NOTE

L FDA1.K=FDA1.J+(DT)(NFDA1.JK)

L FDA2.K=FDA2.J+(DT)(NFDA2.JK)

L FDA3.K=FDA3.J+(DT)(NFDA3.JK)

L FDB1.K=FDB1.J+(DT)(NFDB1.JK)

L FDB2.K=FDB2.J+(DT)(NFDB2.JK)

L FDB3.K=FDB3.J+(DT)(NFDB3.JK)

R NFDA1.KL=FDA1.K\*IGFA1

R NFDA2.KL=FDA2.K\*IGFA2

R NFDA3.KL=FDA3.K\*IGFA3

R NFDB1.KL=FDB1.K\*IGFB1

R NFDB2.KL=FDB2.K\*IGFB2

R NFDB3.KL=FDB3.K\*IGFB3

A FDA.K=FDA1.K+FDA2.K+FDA3.K

A FDB.K=FDB1.K+FDB2.K+FDB3.K

A FD.K=FDA.K+FDB.K

NOTE FD-EXPECTED FINAL DEMAND, A(CITY A) & B(CITY B)

NOTE 1-AGRICULTURE, 2-MANUFACTURING, 3-SERVICES

N FDA1=FDA1N

N FDA2=FDA2N

N FDA3=FDA3N

N FDB1=FDB1N

N FDB2=FDB2N

N FDB3=FDB3N

C FDA1N=12E6

C FDA2N=393E6

C FDA3N=194E6

C FDB1N=29E6

C FDB2N=1295E6

C FDB3N=494E6

P IGFA1=.017/IGFA2=.017/IGFA3=.017/IGFB1=.017/IGFB2=.017/IGFB3=.017

NOTE IGF-INDUSTRIAL GROWTH FACTOR

A OA1.K=FOA1A1\*FDA1.K+FOA1A2\*FDA2.K+FOA1A3\*FDA3.K+FOA1B1\*FDB1.K+FOA1B2\*FDB2.K+FOA1B3\*FDB3.K

A OA2.K=FOA2A1\*FDA1.K+FOA2A2\*FDA2.K+FOA2A3\*FDA3.K+FOA2B1\*FDB1.K+FOA2B2\*FDB2.K+FOA2B3\*FDB3.K

A OA3.K=FOA3A1\*FDA1.K+FOA3A2\*FDA2.K+FOA3A3\*FDA3.K+FOA3B1\*FDB1.K+FOA3B2\*FDB2.K+FOA3B3\*FDB3.K

A OB1.K=FOB1A1\*FDA1.K+FOB1A2\*FDA2.K+FOB1A3\*FDA3.K+FOB1B1\*FDB1.K+FOB1B2\*FDB2.K+FOB1B3\*FDB3.K

A OB2.K=FOB2A1\*FDA1.K+FOB2A2\*FDA2.K+FOB2A3\*FDA3.K+FOB2B1\*FDB1.K+FOB2B2\*FDB2.K+FOB2B3\*FDB3.K

A OB3.K=FOB3A1\*FDA1.K+FOB3A2\*FDA2.K+FOB3A3\*FDA3.K+FOB3B1\*FDB1.K+FOB3B2\*FDB2.K+FOB3B3\*FDB3.K

P FOA1A1=.9897/FOA1A2=.0648/FOA1A3=.0217

P FOA1B1=.1195/FOA1B2=.0131/FOA1B3=.0038

P FOA2A1=.0205/FOA2A2=.9225/FOA2A3=.0263

P FOA2B1=.0062/FOA2B2=.1172/FOA2B3=.0053

P FOA3A1=.1059/FOA3A2=.0941/FOA3A3=1.0876

P FOA3B1=.0202/FOA3B2=.0169/FOA3B3=.0660  
 P FOB1A1=.1194/FOB1A2=.0150/FOB1A3=.0039  
 P FOB1B1=.9774/FOB1B2=.0413/FOB1B3=.0183  
 P FOB2A1=.0076/FOB2A2=.1759/FOB2A3=.0069  
 P FOB2B1=.0302/FOB2B2=.9739/FOB2B3=.0314  
 P FOB3A1=.0212/FOB3A2=.0202/FOB3A3=.0661  
 P FOB3B1=.1204/FOB3B2=.0764/FOB3B3=1.0860  
 A AOA1.K=MIN(OA1.K,MOA1.K)  
 A MOA1.K=MIN(LOA1.K,POA1.K)  
 A AOA2.K=MIN(OA2.K,MOA2.K)  
 A MOA2.K=MIN(LOA2.K,POA2.K)  
 A AOA3.K=MIN(OA3.K,MOA3.K)  
 A MOA3.K=MIN(LOA3.K,POA3.K)  
 A AOB1.K=MIN(OB1.K,MOB1.K)  
 A MOB1.K=MIN(LOB1.K,POB1.K)  
 A AOB2.K=MIN(OB2.K,MOB2.K)  
 A MOB2.K=MIN(LOB2.K,POB2.K)  
 A AOB3.K=MIN(OB3.K,MOB3.K)  
 A MOB3.K=MIN(LOB3.K,POB3.K)  
 NOTE AO-ACTUAL OUTPUT  
 A LOA1.K=LA1.K/LORA1  
 A LOA2.K=LA2.K/LORA2  
 A LOA3.K=LA3.K/LORA3  
 A LOB1.K=LB1.K/LORB1  
 A LOB2.K=LB2.K/LORB2  
 A LOB3.K=LB3.K/LORB3  
 P LORA1=60E-6/LORA2=25E-6/LORA3=30E-6/LORB1=60E-6/LORB2=25E-6/LORB3=30E-6  
 A POA1.K=MPOLA1/POLORA1  
 A POA2.K=MPOLA2/POLORA2  
 A POA3.K=MPOLA3/POLORA3  
 A POB1.K=MPOLB1/POLORB1  
 A POB2.K=MPOLB2/POLORB2  
 A POB3.K=MPOLB3/POLORB3  
 P MPOLA1=250/MPOLA2=450/MPOLA3=300/MPOLB1=500/MPOLB2=1000/MPOLB3=1000  
 P POLORA1=0.4E-6/POLORA2=1.1E-6/POLORA3=0.4E-6/POLORB1=0.4E-6  
 P POLORB2=1.1E-6/POLORB3=0.4E-6  
 A AFDA1.K=OFA1A1\*AOA1.K+OFA1A2\*AOA2.K+OFA1A3\*AOA3.K+  
 OFA1B1\*AOB1.K+OFA1B2\*AOB2.K+OFA1B3\*AOB3.K  
 A AFDA2.K=OFA2A1\*AOA1.K+OFA2A2\*AOA2.K+OFA2A3\*AOA3.K+  
 OFA2B1\*AOB1.K+OFA2B2\*AOB2.K+OFA2B3\*AOB3.K  
 A AFDA3.K=OFA3A1\*AOA1.K+OFA3A2\*AOA2.K+OFA3A3\*AOA3.K+  
 OFA3B1\*AOB1.K+OFA3B2\*AOB2.K+OFA3B3\*AOB3.K  
 A AFDB1.K=OFB1A1\*AOA1.K+OFB1A2\*AOA2.K+OFB1A3\*AOA3.K+  
 OFB1B1\*AOB1.K+OFB1B2\*AOB2.K+OFB1B3\*AOB3.K  
 A AFDB2.K=OFB2A1\*AOA1.K+OFB2A2\*AOA2.K+OFB2A3\*AOA3.K+  
 OFB2B1\*AOB1.K+OFB2B2\*AOB2.K+OFB2B3\*AOB3.K  
 A AFDB3.K=OFB3A1\*AOA1.K+OFB3A2\*AOA2.K+OFB3A3\*AOA3.K+  
 OFB3B1\*AOB1.K+OFB3B2\*AOB2.K+OFB3B3\*AOB3.K  
 P OFA1A1=1.0288/OFA1A2=.0683/OFA1A3=.0184  
 P OFA1B1=1.1250/OFA1B2=0.0/OFA1B3=.0  
 P OFA2A1=.0192/OFA2A2=1.1134/OFA2A3=.0257

P OFA2B1=0.0/OFA2B2=.1333/OFA2B3=.0  
 P OFA3A1=.0962/OFA3A2=.0866/OFA3A3=.9269  
 P OFA3B1=.0/OFA3B2=.0/OFA3B3=.0556  
 P OFB1A1=.1250/OFB1A2=.0/OFB1A3=.0  
 P OFB1B1=1.0417/OFB1B2=.0412/OFB1B3=.0159  
 P OFB2A1=0/OFB2A2=.20/OFB2A3=0  
 P OFB2B1=.0278/OFB2B2=1.0544/OFB2B3=.0290  
 P OFB3A1=0/OFB3A2=0/OFB3A3=.0556  
 P OFB3B1=.1111/OFB3B2=.0671/OFB3B3=.9280

NOTE

NOTE EMPLOYMENT SECTOR

A L.K=LA.K+LB.K  
 A LA.K=PA.K\*FLR  
 A LB.K=PB.K\*FLR  
 C FLR=.55  
 A LA1.K=LA.K\*.18  
 A LA2.K=LA.K\*.43  
 A LA3.K=LA.K\*.39  
 A LB1.K=LB.K\*.14  
 A LB2.K=LB.K\*.50  
 A LB3.K=LB.K\*.36  
 A J.K=JA.K+JB.K  
 A JA.K=JA1.K+JA2.K+JA3.K  
 A JB.K=JB1.K+JB2.K+JB3.K  
 A JA1.K=AOA1.K\*LORA1  
 A JA2.K=AOA2.K\*LORA2  
 A JA3.K=AOA3.K\*LORA3  
 A JB1.K=A0B1.K\*LORB1  
 A JB2.K=A0B2.K\*LORB2  
 A JB3.K=A0B3.K\*LORB3  
 A POL.K=POLA.K+POLB.K  
 A POLA.K=POLA1.K+POLA2.K+POLA3.K  
 A POLB.K=POLB1.K+POLB2.K+POLB3.K  
 A POLA1.K=AOA1.K\*POLORA1  
 A POLA2.K=AOA2.K\*POLORA2  
 A POLA3.K=AOA3.K\*POLORA3  
 A POLB1.K=A0B1.K\*POLORB1  
 A POLB2.K=A0B2.K\*POLORB2  
 A POLB3.K=A0B3.K\*POLORB3  
 A GRPA.K=AFDA1.K+AFDA2.K+AFDA3.K  
 A GRPB.K=AFDB1.K+AFDB2.K+AFDB3.K  
 A URA.K=(LA.K-JA.K)/LA.K  
 A URB.K=(LB.K-JB.K)/LB.K

SPEC DT=.1/LENGTH=50/SAVPER=1/PLTPER=1/PRTPER=.25

SAVE PA,PB,GRPA,GRPB,FDA,FDB,AOA1,AOA2,AOA3,AOB1,AOB3,AFDA1,AFDA2  
 SAVE AFDA3,AFDB1,AFDB2,AFDB3,LA,LB,L,POL,POLA,POLB,J,JA,JB,URA,URB

## Appendix E. Programming and Analysis: Transportation/Development Model

### 1. A prototype of regional TDM

#### \* Equations Relating Highway Transportation and Economic Development

NOTE

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

$$N \quad IC = ICN$$

NOTE IC-INDUSTRIAL CAPITAL (\$)

$$C \quad ICN = 889.1E6$$

NOTE ICN-INDUS CAPITAL INITIAL VALUE (\$)

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

NOTE CD-CAPITAL DEPRECIATION (\$/YR)

$$C \quad ALC = 16.67$$

NOTE ALC-AVER LIFETIME CAPITAL (YR)

$$R \quad CI.KL = GRP.K * FGRPI$$

NOTE CI-CAPITAL INVESTMENT (\$/yr)

$$C \quad FGRPI = 0.2$$

NOTE FGRPI-FRACT GROSS REGIONAL PROD INVESTED (DIM)

$$A \quad GRP.K = IO.K * (1 - FIOI.K)$$

NOTE GRP-GROSS REGIONAL PRODUCT (\$/YR)

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

NOTE IO-INDUS OUTPUT (\$)

$$C \quad COR = 2$$

NOTE COR-CAPITAL OUTPUT RATIO (YR)

$$A \quad FIOI.K = FIOIN * DCR.K / DCRN$$

NOTE FIOI-FRACT INDUS OUTPUT TO INPUTS (DIM)

$$C \quad FIOIN = .4$$

NOTE FIOIN-FIOI NORMAL (DIM)

$$C \quad DCRN = 1.0$$

NOTE DCRN-DEMAND CAPACITY RATIO NORMAL (DIM)

$$A \quad DCR.K = PHTD.K / HC$$

NOTE DCR-DEMAND CAPACITY RATIO (DIM)

$$N \quad HC = NL * LC$$

NOTE HC-HIGHWAY CAPACITY (VEH/YR)

$$C \quad NL = 4$$

NOTE NL-NUMBER OF LANES (LANES)

$$C \quad LC = 2000$$

NOTE LC-LANE CAPACITY (VEH/HR-LANE)

$$A \quad PHTD.K = PHCE.K + PPHCT.K / (AVO * DPP)$$

NOTE PHTD-PEAK HOUR TRAFFIC DEMAND (VEH/HR)

$$C \quad AVO = 1.0$$

NOTE AVO-AVER VEH OCCUPANCY (PERSONS/VEH)

$$C \quad DPP = 2.0$$

NOTE DPP-DURATION OF PEAK PERIOD (HR/PERIOD)

$$A \quad PHCE.K = PPTT.K * PCE / DPP$$

NOTE PHCE-PEAK HOUR CAR EQUIVALENTS (VEH/HR)

$$C \quad PCE = 4$$

NOTE PCE-PASSENGER CAR EQUIVALENTS (VEH/TRUCK)

$$A \quad PPTT.K = IO.K * TPIO / PPPY$$

NOTE PPTT-PEAK PERIOD TRUCK TRAFFIC (TRUCKS/PERIOD)

C TPIO=0.0003

NOTE TPIO-TRUCKS PER INDUS OUTPUT (TRUCKS/\$)

C PPPY=300

NOTE PPPY-PEAK PERIODS PER YEAR (PERIODS/YT)

A PPHCT.K=PPCT.K\*HMS

NOTE PPHCT-PK PERIOD HWY COMMUTER TRIPS (TRIPS/PERIOD)

C HMS=0.8

NOTE HMS-HWY MODEL SPLIT (DIM)

A PPCT.K=J.K\*TPJ

NOTE PPCT-PEAK PERIOD COMMUTER TRIPS (TRIPS/PERIOD)

C TPJ=1.0

NOTE TPJ-TRIPS PER JOB (TRIPS/PERSON)

A J.K=IC.K/CLR

NOTE J-JOBS (PERSON)

C CLR=50000

NOTE CLR-CAPITAL LABOR RATIO (\$/PERSON)

SPEC DT=.125/LENGTH=20/SAVPER=1/PLTPER=1/PRTPER=.25

SAVE IC,CD,CI,GRP,IO,FIOI,DCR,PHTD,PHCE,PPTT,PPHCT,PPCT,J

□

Steady State Analysis

$$IC_e = \frac{(DPP \times LC \times NL) \left( \frac{DCRN}{FIOIN} \right) \left( 1 - \frac{COR}{FGRPI \times ALC} \right)}{\frac{TPIO \times PCE}{COR \times PPPY} + \frac{TPJ \times HMS}{CLR \times AVO}}$$

Transient Analysis

$$IC_t = \frac{IC_e}{1 + \left( \frac{IC_e}{IC_o} - 1 \right) e^{\left( \frac{FGRPI}{COR} - \frac{1}{ALC} \right) t}}$$

The solution is obtained by expressing the measures of effectiveness,  $DCR_e$  and  $GRP_e$ , in terms of policy variables.

$$DCR_e = \left( \frac{DCRN}{FIOIN} \right) \left( 1 - \frac{COR}{FGRPI \times ALC} \right)$$

$$GRP_e = \frac{DCR_e}{\left( \frac{ALC \times FGRPI}{DPP \times LC \times NL} \right) \left( \frac{TPIO \times PCE}{COR \times PPPY} + \frac{TPJ \times HMS}{CLR \times AVO} \right)}$$

## 2. Multiregional TDM

Two regions are connected by a freeway with two lanes each direction. Commuter traffic and commodity flows are major sources for peak-hour traffic. Commuter traffic is calculated with natural growth and number of jobs in the regions and interregional commodity flows are calculated through multiregional I-O analysis. In this example, congestion increases travel times and costs, reducing economic productivity and pollution affects capital-output ratios, also reducing economic productivity. Hypothetical data are used. DYNAMO programming and graphs are shown for the scenario, no improvement of highways. Other scenarios can be tested for scenario analysis.

- MATLAB programming

```
A1 = [.096154 .068337 .018382
      .019231 .08656 .025735
      .096154 .08656 .128676]
A2 = [.083333 .04123 .015942
      .027778 .078966 .028986
      .111111 .067086 .127536]
C11 = [0.9 0 0
       0 0.85 0
       0 0 .95 ]
C12 = [0.1 0 0
       0 0.1 0
       0 0 .05 ]
C21 = [0.1 0 0
       0 0.15 0
       0 0 .05 ]
C22 = [0.9 0 0
       0 0.9 0
       0 0 .95 ]
I = [1 0 0
     0 1 0
     0 0 1]
O = [0 0 0
     0 0 0
     0 0 0]
A = [A1 O; O A2]
C = [C11 C12; C21 C22]
II = [I O
      O I]
B = inv(II-C*A)*C
B1 = inv(II-C*A)
D1 = II-C*A
```

Y = 1000000\*[12; 393; 194; 29; 1295; 494]

X = B\*Y

XX = diag(X')

D = A\*XX

K = D'

KK = (sum(K))'

G = KK+Y

T = C\*diag(G)

- Results

X = 1.0e+009 \* [ 0.0638; 0.5225; 0.3043; 0.0990; 1.3481; 0.6598]

D = 1.0e+008 \*

0.0614	0.3571	0.0559	0	0	0
0.0123	0.4523	0.0783	0	0	0
0.0614	0.4523	0.3915	0	0	0
0	0	0	0.0825	0.5558	0.1052
0	0	0	0.0275	1.0645	0.1913
0	0	0	0.1100	0.9044	0.8415

G = 1.0e+009 \* [0.0594; 0.4473; 0.2845; 0.1033; 1.4233; 0.6796]

T = 1.0e+009 \*

0.0535	0	0	0.0103	0	0
0	0.3802	0	0	0.1423	0
0	0	0.2703	0	0	0.0340
0.0059	0	0	0.0930	0	0
0	0.0671	0	0	1.2810	0
0	0	0.0142	0	0	0.6456

- DYNAMO programming

NOTE MULTIREGIONAL TRANSPORTATION/DEVELOPMENT METHODOLOGY

NOTE

NOTE POPULATION SECTOR FOR BOTH CITIES (A & B)

NOTE \*\*\*\*\*

L PA.K=PA.J+(DT)(NPGA.JK+IMA.JK-OMA.JK)

N PA=PAN

NOTE PA-POPULATION (PERSON)

C PAN=27000  
 NOTE PAN,PBN-POPULATION AT TIME 0 (PERSONS)  
 R NPGA.KL=PA.K\*NGFA  
 NOTE NPGA,NPGB-NET POPULATION GROWTH (PERSONS/YR)  
 C NGFA=.015  
 NOTE NGFA,NGFB-NET GROWTH FACTOR (1/YR)  
 R OMA.KL=PA.K\*OMAN  
 NOTE OMA,OMB-OUT-MIGRATION (PERSONS/YR)  
 C OMAN=0.01  
 NOTE OMAN,OMBN-OUT-MIGRATION NORMAL (/YR)  
 R IMA.KL=DELAY1(PA.K\*IMAN\*JAMA.K,3)  
 NOTE IMA,IMB-IN-MIGRATION (PERSONS/YR)  
 C IMAN=0.01  
 NOTE IMAN,IMBN-IN-MIGRATION NORMAL (/YR)  
 A JAMA.K=TABHL(JAMAT,(1-URAA.K),0.4,3.4,0.2)  
 T JAMAT=0/0.4/0.75/1/1.05/1.1/1.2/1.3/1.4/1.5/1.6/1.7/1.8/1.9/2/2.1  
 NOTE JAMA,JAMB-JOB AVAILABILITY MULTIPLIER (DIM)  
 L PB.K=PB.J+(DT)(NPGB.JK+IMB.JK-OMB.JK)  
 N PB=PBN  
 C PBN=60000  
 R NPGB.KL=PB.K\*NGFB  
 C NGFB=.015  
 R OMB.KL=PB.K\*OMBN  
 C OMBN=0.01  
 R IMB.KL=DELAY1(PB.K\*IMBN\*JAMB.K,3)  
 C IMBN=0.01  
 A JAMB.K=TABHL(JAMBT,(1-URBB.K),0.4,3.4,0.2)  
 T JAMBT=0/0.4/0.75/1/1.05/1.1/1.2/1.3/1.4/1.5/1.6/1.7/1.8/1.9/2/2.1  
 NOTE  
 NOTE ECONOMIC SECTOR  
 NOTE  
 A ICA.K=IC1.K+IC2.K+IC3.K  
 A ICB.K=IC4.K+IC5.K+IC6.K  
 NOTE ICA,ICB-INDUSTRIAL CAPITAL IN REGION A, B  
 L IC1.K=IC1.J+(DT)(CI1.JK\*(1+AROI\*DT)-CD1.JK)  
 N IC1=IC1N  
 C IC1N=63.8E6  
 L IC2.K=IC2.J+(DT)(CI2.JK\*(1+AROI\*DT)-CD2.JK)  
 N IC2=IC2N  
 C IC2N=522.5E6  
 L IC3.K=IC3.J+(DT)(CI3.JK\*(1+AROI\*DT)-CD3.JK)  
 N IC3=IC3N  
 C IC3N=304.3E6  
 L IC4.K=IC4.J+(DT)(CI4.JK\*(1+AROI\*DT)-CD4.JK)  
 N IC4=IC4N  
 C IC4N=99.0E6  
 L IC5.K=IC5.J+(DT)(CI5.JK\*(1+AROI\*DT)-CD5.JK)  
 N IC5=IC5N  
 C IC5N=1348.1E6  
 L IC6.K=IC6.J+(DT)(CI6.JK\*(1+AROI\*DT)-CD6.JK)  
 N IC6=IC6N



C IC6N=659.8E6

NOTE IC-INDUSTRIAL CAPITAL (\$), CN-INITIAL

C AROI=.01

NOTE ARI0-ANNUAL RATE OF INFLATION (NT\$/YR)

R CD1.KL=IC1.K/ALC1

R CD2.KL=IC2.K/ALC2

R CD3.KL=IC3.K/ALC3

R CD4.KL=IC4.K/ALC4

R CD5.KL=IC5.K/ALC5

R CD6.KL=IC6.K/ALC6

NOTE CD-CAPITAL DEPRECIATION (\$/YR)

P ALC1=20/ALC2=18/ALC3=25/ALC4=20/ALC5=16/ALC6=25

NOTE ALC-AVERAGE LIFETIME CAPITAL (YR)

R CI1.KL=GRPA.K\*0.012

R CI2.KL=GRPA.K\*0.065

R CI3.KL=GRPA.K\*0.032

R CI4.KL=GRPB.K\*0.01

R CI5.KL=GRPB.K\*0.05

R CI6.KL=GRPB.K\*0.022

NOTE CI-CAPITAL INVESTMENT (\$/YR)

A GRPA.K=IP1.K+IP2.K+IP3.K

A GRPB.K=IP4.K+IP5.K+IP6.K

NOTE GRP-GROSS REGIONAL PRODUCT (\$/YR)

A IO1.K=IC1.K/COR1.K

A IO2.K=IC2.K/COR2.K

A IO3.K=IC3.K/COR3.K

A IO4.K=IC4.K/COR4.K

A IO5.K=IC5.K/COR5.K

A IO6.K=IC6.K/COR6.K

NOTE IO-INDUSTRIAL OUTPUT (\$/YR)

NOTE COR-CAPITAL OUTPUT RATIO

A IOA.K=IO1.K+IO2.K+IO3.K

A IOB.K=IO4.K+IO5.K+IO6.K

NOTE

A IP1.K=(CC11-A11)\*IO1.K+(CC12-A12)\*IO2.K+(CC13-A13F.K)\*IO3.K+  
(CC14-A14)\*IO4.K+(CC15-A15)\*IO5.K+(CC16-A16F.K)\*IO6.K

A IP2.K=(CC21-A21)\*IO1.K+(CC22-A22)\*IO2.K+(CC23-A23F.K)\*IO3.K+  
(CC24-A24)\*IO4.K+(CC25-A25)\*IO5.K+(CC26-A26F.K)\*IO6.K

A IP3.K=(CC31-A31)\*IO1.K+(CC32-A32)\*IO2.K+(CC33-A33F.K)\*IO3.K+  
(CC34-A34)\*IO4.K+(CC35-A35)\*IO5.K+(CC36-A36F.K)\*IO6.K

A IP4.K=(CC41-A41)\*IO1.K+(CC42-A42)\*IO2.K+(CC43-A43F.K)\*IO3.K+  
(CC44-A44)\*IO4.K+(CC45-A45)\*IO5.K+(CC46-A46F.K)\*IO6.K

A IP5.K=(CC51-A51)\*IO1.K+(CC52-A52)\*IO2.K+(CC53-A53F.K)\*IO3.K+  
(CC54-A54)\*IO4.K+(CC55-A55)\*IO5.K+(CC56-A56F.K)\*IO6.K

A IP6.K=(CC61-A61)\*IO1.K+(CC62-A62)\*IO2.K+(CC63-A63F.K)\*IO3.K+  
(CC64-A64)\*IO4.K+(CC65-A65)\*IO5.K+(CC66-A66F.K)\*IO6.K

NOTE IP-INDUSTRIAL PRODUCT (\$/YR)

P CC11=1.1250/CC12=0/CC13=0/CC14=-.125/CC15=0/CC16=0

P CC21=0/CC22=1.2/CC23=0/CC24=0/CC25=-.1333/CC26=0

P CC31=0/CC32=0/CC33=1.0556/CC34=0/CC35=0/CC36=-.0556

P CC41=-.1250/CC42=0/CC43=0/CC44=1.125/CC45=0/CC46=0

P CC51=0/CC52=-.2/CC53=0/CC54=0/CC55=1.1333/CC56=0

P CC61=0/CC62=0/CC63=-.0556/CC64=0/CC65=0/CC66=1.0556

NOTE CC-INVERSE MATRIX COEFFICIENT OF INTERREGIONAL TRADE FLOW

P A11=.0962/A12=.0683/A13=.0184/A14=0/A15=0/A16=0

P A21=.0192/A22=.0866/A23=.0257/A24=0/A25=0/A26=0

P A31=.0962/A32=.0866/A33=.1287/A34=0/A35=0/A36=0

P A41=0/A42=0/A43=0/A44=.0833/A45=.0412/A46=.0159

P A51=0/A52=0/A53=0/A54=.0278/A55=.0790/A56=.029

P A61=0/A62=0/A63=0/A64=.1111/A65=.0671/A66=.1275

NOTE A-TECHNICAL COEFFICIENT FOR A MATRIX

A A13F.K=(1-FHWY)\*A13+A13\*FHWY\*TCM.K

A A16F.K=(1-FHWY)\*A16+A16\*FHWY\*TCM.K

A A23F.K=(1-FHWY)\*A23+A23\*FHWY\*TCM.K

A A26F.K=(1-FHWY)\*A26+A26\*FHWY\*TCM.K

A A33F.K=(1-FHWY)\*A33+A33\*FHWY\*TCM.K

A A36F.K=(1-FHWY)\*A36+A36\*FHWY\*TCM.K

A A43F.K=(1-FHWY)\*A43+A43\*FHWY\*TCM.K

A A46F.K=(1-FHWY)\*A46+A46\*FHWY\*TCM.K

A A53F.K=(1-FHWY)\*A53+A53\*FHWY\*TCM.K

A A56F.K=(1-FHWY)\*A56+A56\*FHWY\*TCM.K

A A63F.K=(1-FHWY)\*A63+A63\*FHWY\*TCM.K

A A66F.K=(1-FHWY)\*A66+A66\*FHWY\*TCM.K

C FHWY=0.10

NOTE FHWY-PROPORTION OF HWY COST IN SERVICE SECTOR

A TCM.K=1/TMI.K

NOTE TCM-TRANSPORTATION COST MULTIPLIER

A TMI.K=TTN/TT.K

NOTE TMI-TRANSPORTATION MOBILITY INDEX

A IO1AA.K=CC11\*IO1.K

A IO2AA.K=CC22\*IO2.K

A IO3AA.K=CC33\*IO3.K

A IO1AB.K=CC14\*IO4.K

A IO2AB.K=CC25\*IO5.K

A IO3AB.K=CC36\*IO6.K

A IO4BA.K=CC41\*IO1.K

A IO5BA.K=CC52\*IO2.K

A IO6BA.K=CC63\*IO3.K

A IO4BB.K=CC44\*IO4.K

A IO5BB.K=CC55\*IO5.K

A IO6BB.K=CC66\*IO6.K

NOTE IO\*AB-iTH INDUSTRIAL OUTPUT FROM A TO B

NOTE

NOTE \*\*\*\*\* EMPLOYMENT SECTOR \*\*\*\*\*

NOTE

A J1.K=IC1.K/CLR1

A J2.K=IC2.K/CLR2

A J3.K=IC3.K/CLR3

A J4.K=IC4.K/CLR4

A J5.K=IC5.K/CLR5

A J6.K=IC6.K/CLR6

NOTE J-JOBS

A  $JA.K=J1.K+J2.K+J3.K$   
 A  $JB.K=J4.K+J5.K+J6.K$   
 P  $CLR1=42000/CLR2=120000/CLR3=50000$   
 P  $CLR4=42000/CLR5=120000/CLR6=50000$   
 NOTE CLR-CAPITAL LABOR RATIO  
 A  $URA.K=MAX((LFA.K-JA.K)/LFA.K,0)$   
 A  $URB.K=MAX((LFB.K-JB.K)/LFB.K,0)$   
 A  $URAA.K=(LFA.K-JA.K)/LFA.K$   
 A  $URBB.K=(LFB.K-JB.K)/LFB.K$   
 NOTE UR-UNEMPLOYMENT RATE  
 A  $LFA.K=PA.K*LPF$   
 A  $LFB.K=PB.K*LPF$   
 NOTE LF-LABOR FORCE (PERSONS)  
 C  $LPF=.50$   
 NOTE LPF-LABOR FORCE PARTICIPATION FACTOR  
 NOTE  
 NOTE \*\*\*\*\* ENVIRONMENT SECTOR \*\*\*\*\*  
 NOTE  
 A  $POLA.K=POL1.K+POL2.K+POL3.K$   
 A  $POLB.K=POL4.K+POL5.K+POL6.K$   
 L  $POL1.K=POL1.J+(DT)(POLG1.JK-POLA1.JK)$   
 L  $POL2.K=POL2.J+(DT)(POLG2.JK-POLA2.JK)$   
 L  $POL3.K=POL3.J+(DT)(POLG3.JK-POLA3.JK)$   
 L  $POL4.K=POL4.J+(DT)(POLG4.JK-POLA4.JK)$   
 L  $POL5.K=POL5.J+(DT)(POLG5.JK-POLA5.JK)$   
 L  $POL6.K=POL6.J+(DT)(POLG6.JK-POLA6.JK)$   
 NOTE POL-POLLUTION UNITS  
 N  $POL1=POL1N$   
 N  $POL2=POL2N$   
 N  $POL3=POL3N$   
 N  $POL4=POL4N$   
 N  $POL5=POL5N$   
 N  $POL6=POL6N$   
 N  $POL1N=3*IC1N$   
 N  $POL2N=3*IC2N$   
 N  $POL3N=3*IC3N$   
 N  $POL4N=3*IC4N$   
 N  $POL5N=3*IC5N$   
 N  $POL6N=3*IC6N$   
 NOTE POLN-POLLUTION INITIAL VALUE (GRAM)  
 R  $POLA1.KL=POL1.K/ALPOL$   
 R  $POLA2.KL=POL2.K/ALPOL$   
 R  $POLA3.KL=POL3.K/ALPOL$   
 R  $POLA4.KL=POL4.K/ALPOL$   
 R  $POLA5.KL=POL5.K/ALPOL$   
 R  $POLA6.KL=POL6.K/ALPOL$   
 NOTE POLA-POLLUTION ABSORPTION TIME (GRAM/YR)  
 C  $ALPOL=10$   
 NOTE ALPOL-AVERAGE LENGTH OF POLLUTION  
 R  $POLG1.KL=IO1.K*UPG1$   
 R  $POLG2.KL=IO2.K*UPG2$

R POLG3.KL=IO3.K\*UPG3  
R POLG4.KL=IO4.K\*UPG4  
R POLG5.KL=IO5.K\*UPG5  
R POLG6.KL=IO6.K\*UPG6  
NOTE POLG-POLLUTION GENERATION (GRAM/YR)  
P UPG1=.3/UPG2=.4/UPG3=.2/UPG4=.3/UPG5=.4/UPG6=.2  
NOTE UPG-UNIT POLLUTION GENERATION (GRAM/\$)  
A POLAR.K=(POL1.K+POL2.K+POL3.K)/(POL1N+POL2N+POL3N)  
A POLBR.K=(POL4.K+POL5.K+POL6.K)/(POL4N+POL5N+POL6N)  
NOTE POLR-POLLUTION RATIO (DIM)  
NOTE  
NOTE SUSTAINABLE DEVELOPMENT  
NOTE  
A COR1.K=COR1N\*COR1M.K  
A COR2.K=COR2N\*COR2M.K  
A COR3.K=COR3N\*COR3M.K  
A COR4.K=COR4N\*COR4M.K  
A COR5.K=COR5N\*COR5M.K  
A COR6.K=COR6N\*COR6M.K  
NOTE COR-CAPITAL OUTPUT RATIO (YR)  
P COR1N=1/COR2N=1/COR3N=1/COR4N=1/COR5N=1/COR6N=1  
NOTE CORN-CAPITAL OUTPUT RATIO NORMAL (1/YR)  
A COR1M.K=TABXT(COR1T,POLAR.K,1,11.4,10.4)  
A COR2M.K=TABXT(COR2T,POLAR.K,1,11.4,10.4)  
A COR3M.K=TABXT(COR3T,POLAR.K,1,11.4,10.4)  
A COR4M.K=TABXT(COR4T,POLBR.K,1,11.4,10.4)  
A COR5M.K=TABXT(COR5T,POLBR.K,1,11.4,10.4)  
A COR6M.K=TABXT(COR6T,POLBR.K,1,11.4,10.4)  
NOTE CORM-CAPITAL OUTPUT RATION MULTIPLIER (DIM)  
T COR1T=1/1.5  
T COR2T=1/1.5  
T COR3T=1/1.5  
T COR4T=1/1.5  
T COR5T=1/1.5  
T COR6T=1/1.5  
NOTE CORT-CORM TABLE VALUES (DIM)  
A PCIA.K=GRPA.K/PA.K  
A PCIB.K=GRPB.K/PB.K  
NOTE PCI-PER CAPITA INCOME (\$/YR-PERSON)  
NOTE  
NOTE \*\*\*\*\*TRANSPORTATION SECTOR\*\*\*\*\*  
NOTE  
A TT.K=FFT\*(1-(1-LSF)\*Q.K/(NF\*CF))/(1-Q.K/(NF\*CF))  
NOTE TT-TRAVEL TIME (MIN)  
N FFT=60\*X/80  
NOTE FFT-FREE FLOW TRAVEL TIME  
C LSF=0.2  
NOTE LSF-LEVEL OF SERVICE SECTOR (DIM)  
C TTN=41.743  
NOTE TTN-INITIAL TRAVEL TIME (MIN)  
C NF=2

NOTE NF-NUMBER OF LANES IN FREEWAY  
C CF=2000  
NOTE CF-CAPACITY (VEH/HOUR)  
A  $Q.K=QF.K+QT.K$   
A  $QF.K=FDTPH*PV.K/ACO$   
A  $QT.K=FDTPH*TCE*TV.K$   
NOTE Q,QF,QT-VOLUME FOR PASSENGER AND TRUCK  
C TCE=4  
NOTE TCE-TRUCK CAR EQUIVALENCY (DIM)  
C FDTPH=0.1  
NOTE FDTPH-FRACT DAILY TRAFFIC IN PEAK-HOUR (DIM)  
C ACO=1.2  
NOTE ACO-AVERAGE CAR OCCUPNACY (PERSONS/HOUR)  
A  $PV.K=(JA.K+JB.K)*PTGF*PCAF.K$   
A  $TV.K=IO1AA.K*TG1+IO2AA.K*TG2+IO3AA.K*TG3+IO1AB.K*TG4+IO2AB.K*TG5+IO3AB.K*TG6+IO4BA.K*TG7+IO5BA.K*TG8+IO6BA.K*TG9+IO4BB.K*TG10+IO5BB.K*TG11+IO6BB.K*TG12$   
NOTE PV,TV-PASSENGER, TRUCK DEMAND  
A  $PCAF.K=TABLE(PCAF,TIME.K,0,50,50)$   
T PCAFT=1/2.5  
NOTE PCAF-PASSENGER CAR ADJUSTMENT FOR TIME  
C PTGF=.4  
NOTE PTGF-PASSENGER TRAFFIC GENERATION FACTOR (/HR)  
C TG1=.0000002  
C TG2=.0000002  
C TG3=.0000002  
C TG4=.0000008  
C TG5=.0000008  
C TG6=.0000008  
C TG7=.0000008  
C TG8=.0000008  
C TG9=.0000008  
C TG10=.0000002  
C TG11=.0000002  
C TG12=.0000002  
NOTE TG-TRUCK GENERATION FACTOR (/HR)  
C X=50  
NOTE X-DISTANCE (MILES)  
NOTE  
SAVE PCIA,PCIB,TT,IC1,IC2,IC3,IC4,IC5,IC6,GRPA,GRPB  
SAVE IO1,IO2,IO3,IO4,IO5,IO6,IOA,IOB,IP1,IP2,IP3,IP4,IP5,IP6  
SAVE Q,QF,QT,TMI,PA,PB,URA,URB,POLA,POLB,POL1,POL2,POL3,POL4,POL5,POL6  
SAVE JA,JB,COR1,COR2,COR3,COR4,COR5,COR6,PV,TV,POLAR,POLBR  
SAVE IOA,IOB  
SPEC DT=.125/LENGTH=20/SAVPER=2

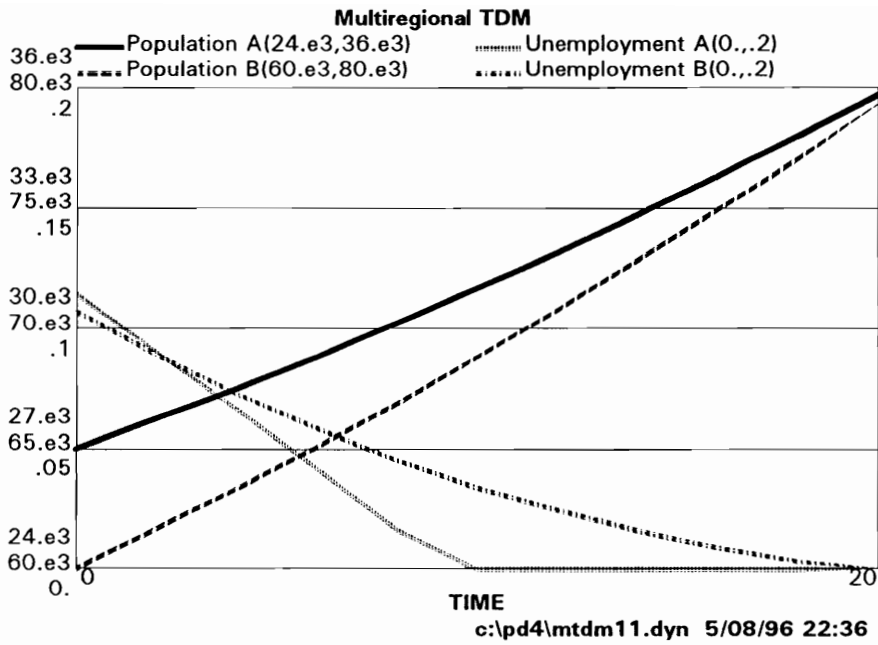


Fig. E.1. Simulation Result 1: MTDM

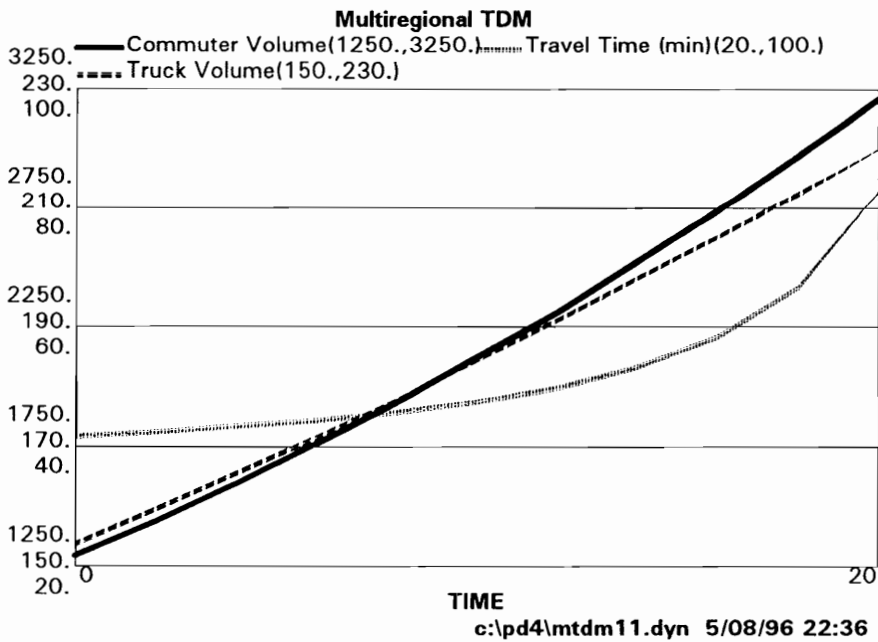


Fig. E.2. Simulation Result 2: MTDM

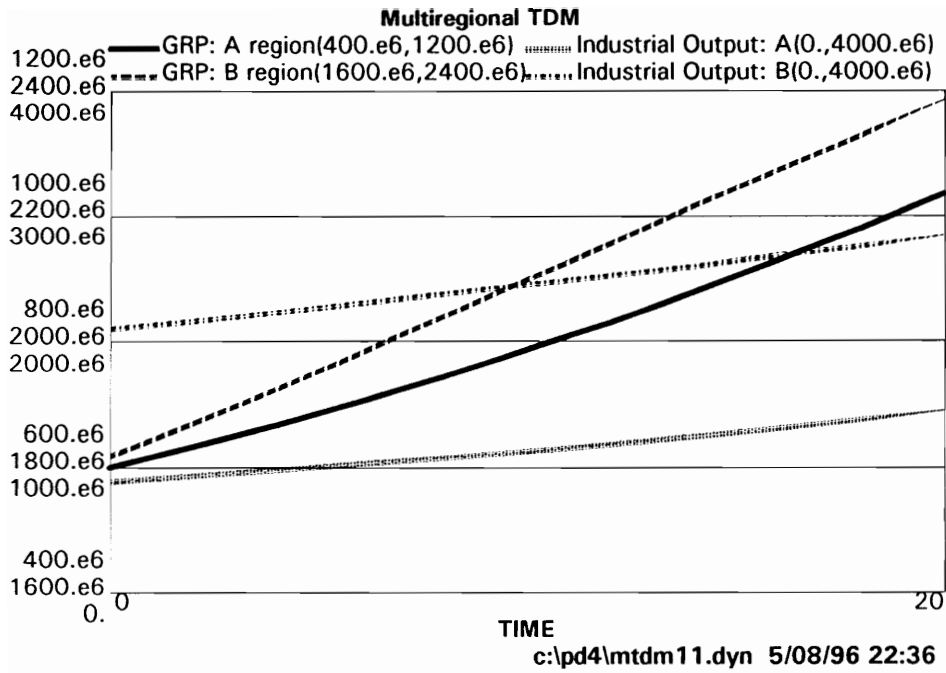


Fig. E.3. Simulation Result 3: MTDM

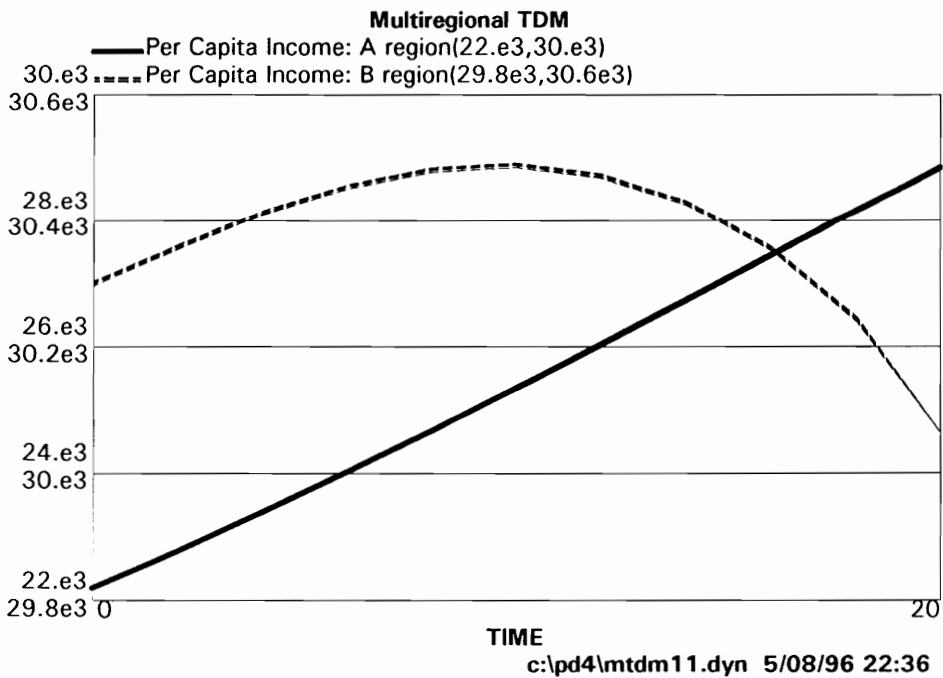


Fig. E.4. Simulation Result 4: MTDM

## Appendix F. Study Area

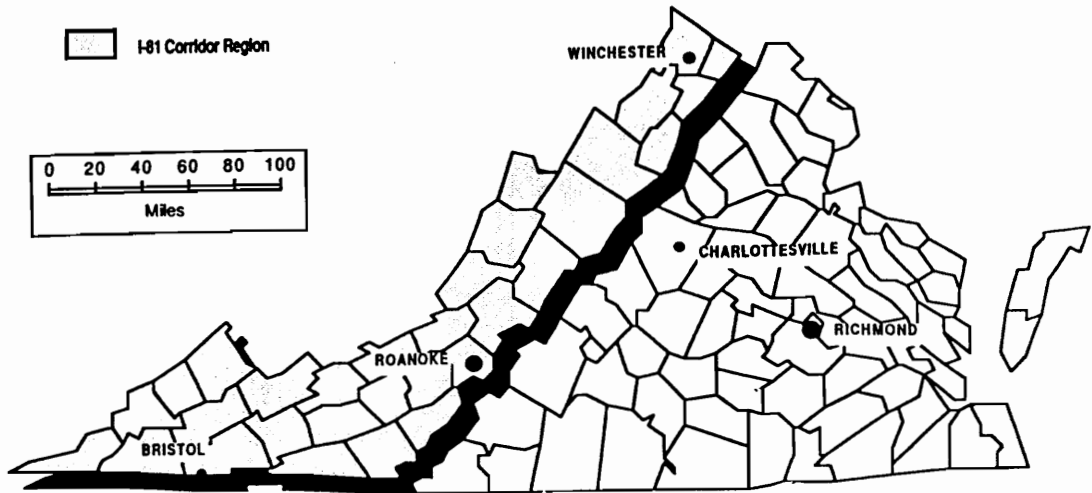


Fig. F.1. I-81 Corridor (Hensley, 1991)

## Route 81 Corridor

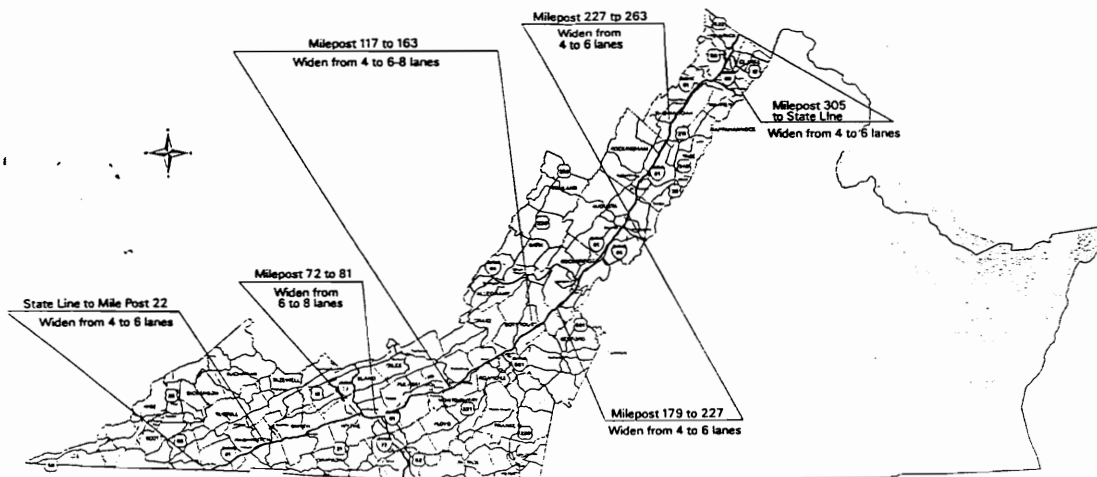


Fig. F.2. Proposed improvements in the I-81 corridor



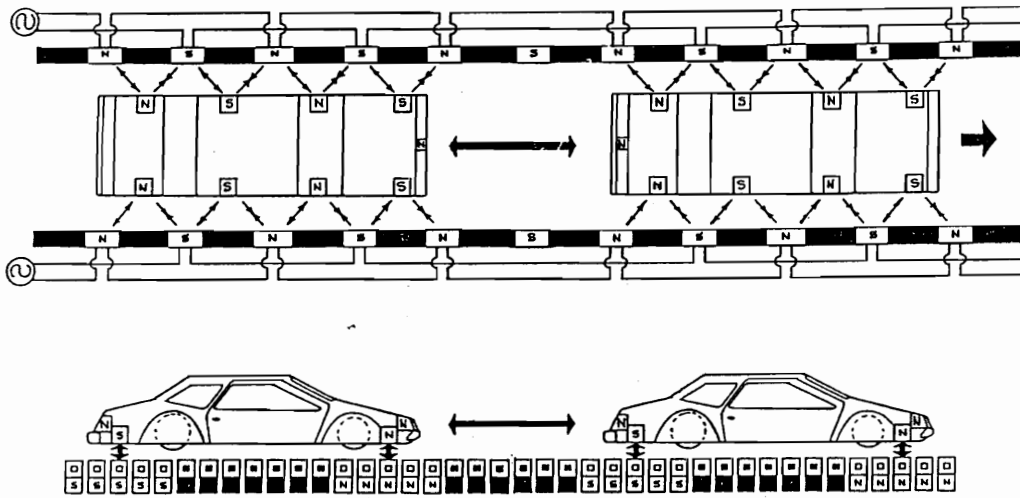


Fig. F.3. HPM levitation, propulsion, and guidance (Drew et al., 1996)

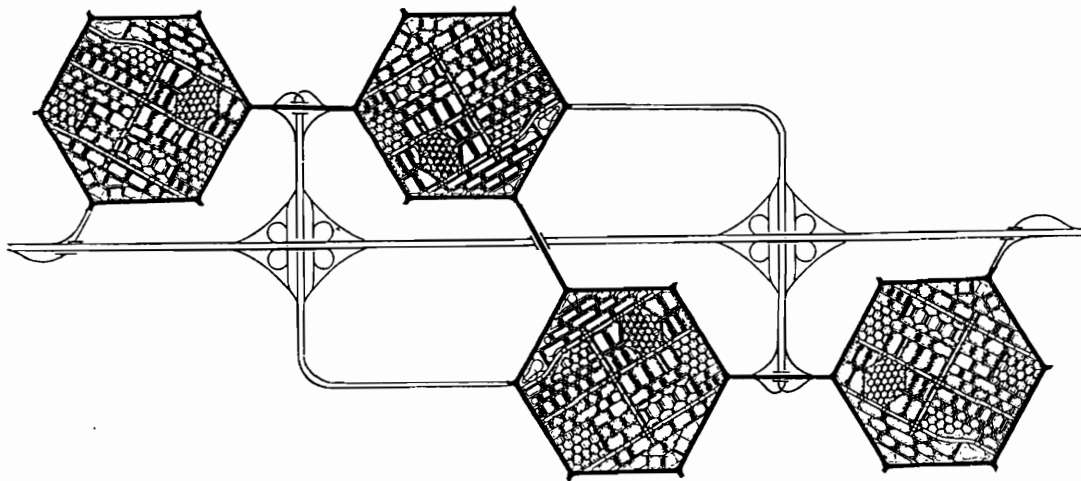


Fig. F.4. AVCS serving medium linear metropolitan area (Drew et al., 1996)

## Appendix G. ITS Technologies

- Characteristics

	Characteristics
ATMS	<ul style="list-style-type: none"> <li>• Collection of real-time traffic data</li> <li>• Reaction to changes in traffic flow with timely traffic management strategies -- based on real-time information, providing routing information to motorists</li> <li>• Area-wide surveillance and detection systems</li> <li>• Integration of the management of various functions, including transportation information, demand management, freeway ramp metering, automated toll collection, and arterial signal control</li> <li>• Collaborative action on the part of transportation management agencies and jurisdictions</li> </ul>
ATIS	<ul style="list-style-type: none"> <li>• Visual and auditory presentations to inform drivers of their current locations, aid them in planning their routes, help guide them to their desired destinations, and provide various informational services</li> <li>• Continuous information regarding traffic conditions, roadway congestion, alternate routes, parking, and other up-to-date information</li> <li>• Real-time information (locations of accidents, weather and road conditions, optimal routes, recommended speeds, and lane restrictions)</li> <li>• Safety warning information</li> </ul>
AVCS	<ul style="list-style-type: none"> <li>• Visual or auditory warning</li> <li>• Automated “co-pilot” system</li> <li>• Automated controls (autonomous vehicle-based systems, automated braking, and autonomous adaptive cruise control)</li> </ul>
CVO	<ul style="list-style-type: none"> <li>• More specialized data</li> <li>• Automating the collection of information by the government agencies</li> <li>• Requiring more safety and reliability</li> </ul>
APTS	<ul style="list-style-type: none"> <li>• Providing a more flexible, cost effective, user-friendly service to the customers</li> <li>• Applying ATMS, ATIS, and AVCS technologies to make transit and ride-sharing options more attractive to the traveling public</li> </ul>
ARTS	<ul style="list-style-type: none"> <li>• Multi-jurisdictional, including state highways, county roads, and rural city streets</li> <li>• Limited sight distances and numerous opportunities for driver misjudgment</li> <li>• Long travel distances, Animals</li> <li>• Difficult to keep clear of snow and pavement ice</li> <li>• Difficult to provide adequate locations for transit vehicles and school buses</li> <li>• Less maintenance attention</li> </ul>

• Plan Elements of ITS (Operational Testing and Deployment)

	Near Term (5 - year timeframe)	Middle Term (10 - year)	Longer Term (20 - year)
ATMS	<ul style="list-style-type: none"> <li>•Advanced Detection Devices</li> <li>•Freeway Variable Speed Limit Systems</li> <li>•Advanced Control Hardware</li> <li>•Expert System/AI-based Management Strategies</li> <li>•Automated Toll Collection</li> <li>•Lane Control System</li> <li>•Integrated Traffic Management Systems</li> <li>•Vehicles as Probes</li> <li>•Predictive Control Algorithms</li> <li>•Advanced Communication Systems</li> </ul>	<ul style="list-style-type: none"> <li>•Real-time Traffic Assignment</li> <li>•Integrated Traffic Management Systems II</li> <li>•Integrated ATMS/ATIS System</li> <li>•Roadway User Fee Collection</li> </ul>	<ul style="list-style-type: none"> <li>•Fully operational, area-wide integrated systems</li> </ul>
ATIS	<ul style="list-style-type: none"> <li>•Autonomous navigation and route guidance systems</li> <li>•Assisted navigation and route guidance systems -- general traffic information</li> <li>•Automated (electric) toll collection systems at tollbooths</li> <li>•Vehicle condition warning systems</li> <li>•In-vehicle display of road sign information</li> <li>•Manual Mayday systems using cellular phone or other communication means</li> </ul>	<ul style="list-style-type: none"> <li>•Assisted navigation and route guidance systems based on current traffic conditions</li> <li>•Automated toll collection at highway speed</li> <li>•Improved visual and audible user interfaces</li> <li>•Real-time, changeable message road sign display systems</li> <li>•Semi-automated Mayday systems</li> <li>•Systems with AVCS warnings</li> </ul>	<ul style="list-style-type: none"> <li>•Route guidance systems that interact cooperatively with a traffic management center</li> <li>•Fully automate Mayday signaling and coordinated service dispatching</li> </ul>
AVCS	<ul style="list-style-type: none"> <li>•Stand-alone, electronic control systems</li> <li>•Simple vehicle performance monitoring</li> <li>•Warning systems for side and near obstacles</li> <li>•Adaptive cruise control</li> </ul>	<ul style="list-style-type: none"> <li>•Warning systems for distant obstacles, lane departure, lane change and merge, and roadway conditions</li> <li>•Electronic control system for brake application and steering</li> <li>•Vehicle performance monitoring</li> <li>•Automated collision avoidance</li> <li>•Vision enhancement</li> </ul>	<ul style="list-style-type: none"> <li>•Warning systems for intersection hazards</li> <li>•Automated vehicle operation on specially equipped roadways</li> </ul>
CVO	<ul style="list-style-type: none"> <li>•Automated weight reporting</li> <li>•Automated vehicle identification reporting (AVI)</li> <li>•Automated fleet vehicle location systems</li> <li>•Static network routing and scheduling</li> </ul>	<ul style="list-style-type: none"> <li>•Vehicle safety monitoring systems for driver use</li> <li>•Hwy speed toll collection</li> <li>•Automated vehicle and driver credential reporting</li> <li>•Hwy safety warning systems</li> <li>•Computerized fleet tracking and dispatching</li> <li>•Automated HAZMAT</li> </ul>	<ul style="list-style-type: none"> <li>•Electronic tax and permit systems</li> <li>•Automated vehicle and driver condition monitoring and reporting</li> </ul>

		identification and location •State-line beacon network •Dynamic or combined static/dynamic network routing	
APTS	•Static transit schedule information and route displays •Changeable message signs •Electronic billing through smart cards •Automated vehicle location systems •Automated fleet maintenance tracking	•Rout displays and real-time ride sharing connection inf. •Interactive kiosks •Automated route guidance •Computer-aided dispatching and fleet control •Interactive, personalized multi-modal routing •Dynamic, real-time ride-sharing matching •Automated HOV lane use verification	•Transit dispatching with ATMS •Personalized passenger pickup services •Electronic reservations, ticketing, and billing •Automated transit vehicle Mayday services •Automated HOV

- A full-fledged Stage of ITS

	Requirements	Required techniques and models
ATMS	Real-time traffic monitoring and data management capabilities, including advanced detection technologies <ul style="list-style-type: none"> <li>• image processing systems</li> <li>• automated vehicle location and identification</li> <li>• the use of vehicles</li> </ul>	New traffic models using artificial intelligence and expert systems <ul style="list-style-type: none"> <li>• Real-time dynamic traffic assignment models</li> <li>• Real-time traffic simulation models</li> <li>• Corridor optimization techniques</li> <li>• Responsive demand management concepts</li> </ul>
ATIS	<ul style="list-style-type: none"> <li>• On-board route guidance instructions</li> <li>• Real-time traffic information</li> <li>• Traffic management center</li> <li>• Automated emergency service feature</li> </ul>	<ul style="list-style-type: none"> <li>• Human factors and behavioral studies</li> <li>• Performance issues</li> <li>• Approaches for real-time route selection and guidance</li> <li>• Optimizing traffic flow throughout the network</li> </ul>
AVCS	<ul style="list-style-type: none"> <li>• Remote automated parking</li> <li>• Closer longitudinal and lateral spacing</li> <li>• Automated reaction time (collision)</li> <li>• Comprehensively integrated system</li> <li>• Vehicle-to-vehicle or roadside-to-vehicle communication</li> </ul>	<ul style="list-style-type: none"> <li>• Vehicles are capable of origin-to-destination trips without driver control, which solves transit system traveler collection and distribution problems</li> </ul>
CVO	<ul style="list-style-type: none"> <li>• Identification by physical characteristics or by the type of function</li> <li>• System designs with greater safety and reliability</li> </ul>	<ul style="list-style-type: none"> <li>• Automated vehicle identification, classification, and location</li> <li>• Weigh-In-Motion</li> <li>• Two-way real-time communications</li> <li>• Dynamic network routing and scheduling</li> </ul>

	<ul style="list-style-type: none"> <li>• Creation of “transparent” state and international borders</li> </ul>	
<p><b>APTS</b></p>	<ul style="list-style-type: none"> <li>• Mass transit, ride-sharing, and red-matching inf.</li> <li>• Mass transit and ride-sharing services</li> <li>• Automated monitoring and enforcement</li> <li>• Fleet operation</li> <li>• Electronic data communications</li> <li>• Automated vehicle control</li> </ul>	<ul style="list-style-type: none"> <li>• Fleet operation and control techniques</li> <li>• Real-time update</li> </ul>

## Appendix H. IMPLAN analysis: I-81 Corridor

Micro IMPLAN is a microcomputer program that performs regional input-output analysis. A model can be defined for any region in the United States using secondary source data which are available by state and county, with the county being the smallest unit of measure.

Model II81 created 4/11/96

\*\*\* Model II81 study area selected 4/15/96

-----  
 1 data files included:  
 C:\MI91-FD\DATA92\VA92-069.ODF

Name	Location	Population (thousands)	Area (sq.mi.)	FIPS Code	Year
VA92-069	FREDERICK	47.6	415.	51 69	1992
II81	Study Area	47.6	415.		1992

\*\*\* Model II81 study area selected 4/15/96

-----  
 45 data files included:

Name	Location	Population (thousands)	Area (sq.mi.)	FIPS Code	Year
VA92-005	ALLEGHANY	13.3	446.	51 5	1992
VA92-015	AUGUSTA	60.0	972.	51 15	1992
VA92-017	BATH	4.8	532.	51 17	1992
VA92-021	BLAND	6.4	359.	51 21	1992
VA92-023	BOTETOURT	25.5	543.	51 23	1992
VA92-027	BUCHANAN	30.9	504.	51 27	1992
VA92-035	CARROLL	27.1	477.	51 35	1992
VA92-043	CLARKE	12.0	177.	51 43	1992
VA92-045	CRAIG	4.6	330.	51 45	1992
VA92-051	DICKENSON	17.8	333.	51 51	1992
VA92-063	FLOYD	12.2	381.	51 63	1992
VA92-069	FREDERICK	47.6	415.	51 69	1992
VA92-071	GILES	16.4	358.	51 71	1992
VA92-077	GRAYSON	16.0	443.	51 77	1992
VA92-091	HIGHLAND	2.6	416.	51 91	1992
VA92-105	LEE	24.4	437.	51105	1992
VA92-121	MONTGOMERY	73.5	388.	51121	1992
VA92-139	PAGE	22.0	311.	51139	1992
VA92-155	PULASKI	34.4	321.	51155	1992
VA92-161	ROANOKE	80.2	251.	51161	1992
VA92-163	ROCKBRIDGE	18.7	600.	51163	1992

VA92-165 ROCKINGHAM	58.3	851.	51165	1992
VA92-167 RUSSELL	28.8	475.	51167	1992
VA92-169 SCOTT	23.1	537.	51169	1992
VA92-171 SHENANDOAH	32.1	512.	51171	1992
VA92-173 SMYTH	32.5	452.	51173	1992
VA92-580 COVINGTON	7.0	4.	51580	1992
VA92-185 TAZEWELL	46.8	520.	51185	1992
VA92-187 WARREN	27.0	214.	51187	1992
VA92-191 WASHINGTON	47.1	564.	51191	1992
VA92-195 WISE	39.8	403.	51195	1992
VA92-197 WYTHE	25.7	463.	51197	1992
VA92-520 BRISTOL	17.8	12.	51520	1992
VA92-530 BUENA VISTA	6.4	7.	51530	1992
VA92-560 CLIFTON FORGE	4.6	3.	51560	1992
VA92-640 GALAX	6.5	8.	51640	1992
VA92-660 HARRISONBURG	31.3	18.	51660	1992
VA92-678 LEXINGTON	7.1	2.	51678	1992
VA92-840 WINCHESTER	21.8	9.	51840	1992
VA92-720 NORTON	4.3	7.	51720	1992
VA92-750 RADFORD	16.2	10.	51750	1992
VA92-770 ROANOKE	97.2	43.	51770	1992
VA92-775 SALEM	23.8	15.	51775	1992
VA92-790 STAUNTON	22.0	20.	51790	1992
VA92-820 WAYNESBORO	16.7	14.	51820	1992

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II81	Study Area	1194.3	14157.	1992
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\*\*\* Model II81 social accounts constructed 4/15/96

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RSC	---Rpc Change---	Production	Alternate
Change	Commodity Industry	Function	Structural
NO	NO NO	NO	NO

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\*\*\* Model II81 I/O accounts constructed 4/15/96

\*\*\* Model II81 accounts aggregated 4/15/96

---

Original number of industries	366
Number of aggregated industries	10

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\*\*\* Model II81 aggregated multipliers estimated 4/15/96

II81 \$MM 1992 (AGGREGATED)  
REPORT # 401

AGGREGATION/LISTER

DIRECT PURCHASES PER ONE DOLLAR OF OUTPUT (INDUSTRY-BY-INDUSTRY)  
4/21/96

	1	28	48	58	433	447	456	463	510	528	
1	.07251	.00003	.00285	.03338	.00021	.00089	.00296	.00052	.00006	.00006	.0
28	.00004	.02489	.00091	.00086	.00565	.00004	.00000	.00005	.00020	.00020	.0
48	.00690	.01498	.00120	.01080	.06295	.01316	.03541	.01750	.02682	.02682	.0
58	.01646	.02603	.07641	.11094	.00949	.02122	.00865	.04205	.00144	.00144	.0
433	.02891	.05151	.02856	.04497	.10060	.02670	.02004	.01648	.01150	.01150	.0
447	.01334	.01263	.06706	.02469	.01243	.00769	.00328	.01209	.00070	.00070	.0
456	.01333	.01427	.01011	.00528	.01141	.01780	.10185	.02321	.00116	.00116	.0
463	.01507	.01432	.06086	.02007	.03475	.04161	.05028	.05151	.00352	.00352	.0
510	.00216	.00229	.00121	.00432	.00385	.00519	.01056	.00719	.00103	.00103	.0
528	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.0

II81 \$MM 1992 (AGGREGATED)  
REPORT #403A

AGGREGATION/LISTER

REGIONAL CONSUMPTION DEMAND

4/21/96

II81 \$MM 1992 (AGGREGATED)  
REGIONAL INVESTMENT & TRADE DEMAND

AGGREGATION/LISTER REPORT #403B  
4/21/96

	-----INVESTMENT-----		-----TRADE-----		-----TOTAL-----			
IND	INVENTORY ADDITIONS	CAPITAL FORMATION	DOMESTIC EXPORTS	FOREIGN EXPORTS	INTERMED DEMAND	FINAL DEMAND	INDUSTRY OUTPUT	
1	1.0012	.0443	473.7081	79.3090	712.3887	616.7678	1329.1560	*
28	12.6412	.0001	1169.0390	293.0130	366.5718	1477.8400	1844.4110	*
48	.0000	2323.2670	241.0611	.0000	772.7505	3046.3500	3819.1010	*
58	26.8002	663.4999	9572.8100	1473.8610	3927.1200	12865.64	16792.76	*
433	5.5231	41.3765	527.0267	160.9381	1703.4770	1493.1920	3196.6690	*
447	2.4198	102.9723	379.3796	95.3586	921.4275	3344.2120	4265.6390	*
456	.0004	19.8729	1017.2550	110.2678	946.5971	3403.6190	4350.2160	*
463	.0333	11.4039	653.3616	21.6190	1402.0950	4399.5510	5801.6460	*
510	.0013	1.3588	55.1493	4.6655	204.2047	2547.1020	2751.3060	*
528	.0000	.0000	.0000	.0000	-27.6279	.0000	-27.6279	*
TOTALS	48.4204	3163.795	14088.79	2239.031	10929.0000	33194.270	44123.270	*



II81 \$MM 1992 (AGGREGATED)  
 FINAL PAYMENTS: FACTORS

AGGREGATION/LISTER REPORT #404A  
 4/21/96

	EMPLOYEE --COMPENSATION	INDIRECT BUSINESS TAXES	PROPRIETARY INCOME	OTHER PROP. INCOME	TOTAL VALUE ADDED	INDUSTRY EMPLOYMENT
1	101.4197	12.8821	184.1325	212.0743	510.5086	30854.00
28	525.4664	108.3334	95.0514	259.5221	988.3734	11079.00
48	919.8063	11.8620	269.9806	402.0103	1603.6590	49627.00
58	3680.7840	151.4810	123.8754	1703.2840	5659.4280	124699.00
433	916.9359	162.2296	87.9139	616.1298	1783.2090	27506.00
447	1865.4150	648.8417	147.7848	358.8184	3020.8590	128064.00
456	560.9569	611.2549	-30.3698	1247.3860	2389.2290	32578.00
463	2549.2920	78.4458	622.4712	536.6378	3786.8470	146790.00
510	2452.1260	.1684	.0000	102.0722	2554.3670	94918.00
528	.0000	.0000	.0000	-27.6279	-27.6279	.00
TOTAL	13572.2000	1785.4990	1500.8400	5410.3080	22268.8500	646115.00

## Appendix I. Programming: I-81 Corridor

### 1. Scenario1: No Improvement

NOTE

NOTE Regional Development Model (I-81)

NOTE Scenario 1: No Improvement

NOTE

NOTE \*\*\* Industrial Sector \*\*\*

NOTE

A  $IC.K=IC1.K+IC2.K+IC3.K+IC4.K+IC5.K+IC6.K+IC7.K+IC8.K+IC9.K$

NOTE FOR A=1,9=AG,MI,CO,MA,TR,WH,FI,SE,OT

L  $IC1.K=IC1.J+(DT)(CI1.JK*(1+AROI*DT)-CD1.JK)$

N  $IC1=IC1N$

C  $IC1N=398.7468E6$

L  $IC2.K=IC2.J+(DT)(CI2.JK*(1+AROI*DT)-CD2.JK)$

N  $IC2=IC2N$

C  $IC2N=922.2055E6$

L  $IC3.K=IC3.J+(DT)(CI3.JK*(1+AROI*DT)-CD3.JK)$

N  $IC3=IC3N$

C  $IC3N=5728.652E6$

L  $IC4.K=IC4.J+(DT)(CI4.JK*(1+AROI*DT)-CD4.JK)$

N  $IC4=IC4N$

C  $IC4N=10075.66E6$

L  $IC5.K=IC5.J+(DT)(CI5.JK*(1+AROI*DT)-CD5.JK)$

N  $IC5=IC5N$

C  $IC5N=3196.669E6$

L  $IC6.K=IC6.J+(DT)(CI6.JK*(1+AROI*DT)-CD6.JK)$

N  $IC6=IC6N$

C  $IC6N=2132.82E6$

L  $IC7.K=IC7.J+(DT)(CI7.JK*(1+AROI*DT)-CD7.JK)$

N  $IC7=IC7N$

C  $IC7N=1305.065E6$

L  $IC8.K=IC8.J+(DT)(CI8.JK*(1+AROI*DT)-CD8.JK)$

N  $IC8=IC8N$

C  $IC8N=1740.494E6$

L  $IC9.K=IC9.J+(DT)(CI9.JK*(1+AROI*DT)-CD9.JK)$

N  $IC9=IC9N$

C  $IC9N=825.3918E6$

NOTE IC-INDUSTRIAL CAPITAL(\$), CN-Initial

C  $AROI=.03$

NOTE AROI-ANNUAL RATE OF INFLATION (NT\$/YR)

R  $CD1.KL=IC1.K/ALC$

R  $CD2.KL=IC2.K/ALC$

R  $CD3.KL=IC3.K/ALC$

R  $CD4.KL=IC4.K/ALC$

R  $CD5.KL=IC5.K/ALC$

R  $CD6.KL=IC6.K/ALC$

R  $CD7.KL=IC7.K/ALC$

R  $CD8.KL=IC8.K/ALC$

R  $CD9.KL=IC9.K/ALC$

NOTE CD-CAPITAL DEPRECIATION (\$/YR)

C ALC=30

NOTE ALC-AVERAGE LIFETIME CAPITAL (YR)

R CI1.KL=GRP.K\*0.000031\*CIA1

R CI2.KL=GRP.K\*0.000381\*CIA2

R CI3.KL=GRP.K\*0.006999\*CIA3

R CI4.KL=GRP.K\*0.020796\*CIA4

R CI5.KL=GRP.K\*0.001413\*CIA5

R CI6.KL=GRP.K\*0.003175\*CIA6

R CI7.KL=GRP.K\*0.000599\*CIA7

R CI8.KL=GRP.K\*0.000345\*CIA8

R CI9.KL=GRP.K\*0.000041\*CIA9

P CIA1=8/CIA2=1.2/CIA3=.9/CIA4=.9/CIA5=2.5/CIA6=.9/CIA7=1.2

P CIA8=1.5/CIA9=1.3

NOTE CI-CAPITAL INVESTMENT (\$/YR)

A GRP.K=IP1.K+IP2.K+IP3.K+IP4.K+IP5.K+IP6.K+IP7.K+IP8.K+IP9.K

NOTE GRP-GROSS REGIONAL PRODUCT (\$/YR)

A IO1.K=IC1.K/COR7

A IO2.K=IC2.K/COR6

A IO3.K=IC3.K/COR1

A IO4.K=IC4.K/COR5

A IO5.K=IC5.K/COR3

A IO6.K=IC6.K/COR6

A IO7.K=IC7.K/COR7

A IO8.K=IC8.K/COR7

A IO9.K=IC9.K/COR7

NOTE IO-INDUSTRIAL OUTPUT (\$/YR)

C COR1=1.5

C COR2=1.2

C COR3=1

C COR4=.8

C COR5=.6

C COR6=.5

C COR7=.3

NOTE COR-CAPITAL OUTPUT RATIO

A TO.K=IO1.K+IO2.K+IO3.K+IO4.K+IO5.K+IO6.K+IO7.K+IO8.K+IO9.K

NOTE

A IP1.K=(1-F11)\*IO1.K-F12\*IO2.K-F13\*IO3.K-F14\*IO4.K-F15\*IO5.K<sup>^</sup>  
-F16\*IO6.K-F17\*IO7.K-F18\*IO8.K-F19\*IO9.K

A IP2.K=-F21\*IO1.K+(1-F22)\*IO2.K-F23\*IO3.K-F24\*IO4.K-F25\*IO5.K<sup>^</sup>  
-F26\*IO6.K-F27\*IO7.K-F28\*IO8.K-F29\*IO9.K

A IP3.K=-F31\*IO1.K-F32\*IO2.K+(1-F33)\*IO3.K-F34\*IO4.K-F35\*IO5.K<sup>^</sup>  
-F36\*IO6.K-F37\*IO7.K-F38\*IO8.K-F39\*IO9.K

A IP4.K=-F41\*IO1.K-F42\*IO2.K-F43\*IO3.K+(1-F44)\*IO4.K-F45\*IO5.K<sup>^</sup>  
-F46\*IO6.K-F47\*IO7.K-F48\*IO8.K-F49\*IO9.K

A IP5.K=-F51F.K\*IO1.K-F52F.K\*IO2.K-F53F.K\*IO3.K-F54F.K\*IO4.K+<sup>^</sup>  
(1-F55F.K)\*IO5.K-F56F.K\*IO6.K-F57F.K\*IO7.K-F58F.K\*IO8.K-F59F.K\*IO9.K

A IP6.K=-F61\*IO1.K-F62\*IO2.K-F63\*IO3.K-F64\*IO4.K-F65\*IO5.K<sup>^</sup>  
+(1-F66)\*IO6.K-F67\*IO7.K-F68\*IO8.K-F69\*IO9.K

A IP7.K=-F71\*IO1.K-F72\*IO2.K-F73\*IO3.K-F74\*IO4.K-F75\*IO5.K<sup>^</sup>  
-F76\*IO6.K+(1-F77)\*IO7.K-F78\*IO8.K-F79\*IO9.K

A IP8.K=F81\*IO1.K-F82\*IO2.K-F83\*IO3.K-F84\*IO4.K-F85\*IO5.K^  
 -F86\*IO6.K-F87\*IO7.K+(1-F88)\*IO8.K-F89\*IO9.K  
 A IP9.K=F91\*IO1.K-F92\*IO2.K-F93\*IO3.K-F94\*IO4.K-F95\*IO5.K^  
 -F96\*IO6.K-F97\*IO7.K-F98\*IO8.K+(1-F99)\*IO9.K

NOTE IP-INDUSTRIAL PRODUCT (\$/YR)

P F11=.07251/F12=.00003/F13=.00285/F14=.03338/F15=.00021  
 P F16=.00089/F17=.00296/F18=.00052/F19=.00006  
 P F21=.00004/F22=.02489/F23=.00091/F24=.00086/F25=.00565  
 P F26=.00004/F27=.00000/F28=.00005/F29=.00020  
 P F31=.00690/F32=.01498/F33=.00120/F34=.01080/F35=.06295  
 P F36=.01316/F37=.03541/F38=.01750/F39=.02682  
 P F41=.01646/F42=.02603/F43=.07641/F44=.11094/F45=.00949  
 P F46=.02122/F47=.00865/F48=.04205/F49=.00144  
 P F51=.02891/F52=.05151/F53=.02856/F54=.04497/F55=.10060  
 P F56=.02670/F57=.02004/F58=.01648/F59=.01150  
 P F61=.01334/F62=.01263/F63=.06706/F64=.02469/F65=.01243  
 P F66=.00769/F67=.00328/F68=.01209/F69=.00070  
 P F71=.01333/F72=.01427/F73=.01011/F74=.00528/F75=.01141  
 P F76=.01780/F77=.10185/F78=.02321/F79=.00116  
 P F81=.01507/F82=.01432/F83=.06086/F84=.02007/F85=.03475  
 P F86=.04161/F87=.05028/F88=.05151/F89=.00352  
 P F91=.00216/F92=.00229/F93=.00121/F94=.00432/F95=.00385  
 P F96=.00519/F97=.01056/F98=.00719/F99=.00103

NOTE F\*\*-INPUT-OUTPUT COEFFICIENT (A MATRIX)

A F51F.K=(1-FHWY)\*F51+F51\*FHWY\*TCM.K  
 A F52F.K=(1-FHWY)\*F52+F52\*FHWY\*TCM.K  
 A F53F.K=(1-FHWY)\*F53+F53\*FHWY\*TCM.K  
 A F54F.K=(1-FHWY)\*F54+F54\*FHWY\*TCM.K  
 A F55F.K=(1-FHWY)\*F55+F55\*FHWY\*TCM.K  
 A F56F.K=(1-FHWY)\*F56+F56\*FHWY\*TCM.K  
 A F57F.K=(1-FHWY)\*F57+F57\*FHWY\*TCM.K  
 A F58F.K=(1-FHWY)\*F58+F58\*FHWY\*TCM.K  
 A F59F.K=(1-FHWY)\*F59+F59\*FHWY\*TCM.K

NOTE F5\*-FRACTION OF TRANSPORTATION AND PUBLIC UTILITY

NOTE C FHWY=0.15

C FHWY=0.3

NOTE FHWY-HWY PROPORTION IN TRANSPORTATION SECTOR

A TCM.K=1/TM1.K

NOTE TCM-TRANSPORTATION COST MULTIPLIER

A TM1.K=TTN/TT.K

NOTE

NOTE \*\*\* Employment Sector \*\*\*

NOTE

A J1.K=IC1.K/(CLR1)  
 A J2.K=IC2.K/(CLR2)  
 A J3.K=IC3.K/(CLR3)  
 A J4.K=IC4.K/(CLR4)  
 A J5.K=IC5.K/(CLR5)  
 A J6.K=IC6.K/(CLR6)  
 A J7.K=IC7.K/(CLR7)  
 A J8.K=IC8.K/(CLR8)

A  $J9.K = IC9.K / (CLR9)$   
 NOTE J-JOBS (PERSONS)  
 P  $CLR1 = 86157.78 / CLR2 = 332956.2 / CLR3 = 153912.2$   
 P  $CLR4 = 269332.7 / CLR5 = 232434.3 / CLR6 = 66617.3$   
 P  $CLR7 = 267064.6 / CLR8 = 79046.88 / CLR9 = 57972.27$   
 NOTE CLR-CAPITAL LABOR RATIO  
 A  $TJ.K = J1.K + J2.K + J3.K + J4.K + J5.K + J6.K + J7.K + J8.K + J9.K$   
 NOTE TJ-TOTAL JOBS (PERSONS)  
 A  $UR.K = MAX((LF.K - TJ.K) / LF.K, 0)$   
 NOTE UR-UNEMPLOYMENT RATE  
 A  $LF.K = POP.K * LPF$   
 NOTE LF-LABOR FORCE (PERSONS)  
 C  $LPF = 0.5710$   
 NOTE LPF-LABOR FORCE PARTICIPATION FACTOR  
 NOTE  
 NOTE \*\*\* Demographic Sector \*\*\*  
 NOTE  
 L  $POP.K = POP.J + (DT)(IM.JK - OM.JK + NPG.K)$   
 N  $POP = POPN$   
 C  $POPN = 1194300$   
 NOTE POP-Population (Persons)  
 R  $NPG.KL = POP.K * NGF$   
 NOTE NPG-Net Population Growth (Persons/yr)  
 C  $NGF = .008$   
 NOTE NGF-Natural Growth Factor (DIM)  
 R  $OM.KL = POP.K * OMN$   
 NOTE OM-Out-migration (Persons/yr)  
 R  $IM.KL = DELAY1(POP.K * IMN * JAM.K, 3)$   
 NOTE IM-In-migration (Persons/yr)  
 C  $IMN = 0.01$   
 C  $OMN = 0.01$   
 NOTE IMN-In-migration Normal (/yr)  
 A  $JAM.K = TABHL(JAMT, (1 - UR.K), 0.4, 3.4, 0.2)$   
 T  $JAMT = 0/0.4/0.75/1/1.05/1.1/1.2/1.3/1.4/1.5/1.6/1.7/1.8/1.9/2/2.1$   
 NOTE JAM-Job Availability Multiplier (DIM)  
 NOTE  
 NOTE \*\*\* Environment Sector \*\*\*  
 NOTE  
 A  $TPGR.K = PGR1.K + PGR2.K + PGR3.K + PGR4.K + PGR5.K + PGR6.K + PGR7.K + PGR8.K + PGR9.K$   
 NOTE TPGR-Total Pollution Generation (DIM)  
 A  $PGR1.K = IO1.K / PPO$   
 A  $PGR2.K = IO2.K / PPO$   
 A  $PGR3.K = IO3.K / PPO$   
 A  $PGR4.K = IO4.K / PPO$   
 A  $PGR5.K = IO5.K / PPO$   
 A  $PGR6.K = IO6.K / PPO$   
 A  $PGR7.K = IO7.K / PPO$   
 A  $PGR8.K = IO8.K / PPO$   
 A  $PGR9.K = IO9.K / PPO$   
 NOTE PGR-POLLUTION GENERATION  
 C  $PPO = .2$

NOTE PPO-Unit Pollution Generation (Units/\$-yr)  
NOTE  
NOTE \*\*\* Sustainable Development \*\*\*  
NOTE  
A  $PCI.K=GRP.K/POP.K$   
NOTE PCI-Per Capita Income (\$/yr-person)  
NOTE  
NOTE FURTHER APPLICATION IS REQUIRED  
NOTE  
NOTE \*\*\* Transportation Sector \*\*\*  
NOTE  
A  $TT.K=FFT*(1-(1-LSF)*Q.K/(NF*CF))/(1-Q.K/(NF*CF))$   
NOTE A  $TF.K=FFT*(1-(1-LSF)*QF.K/(NF*CF))/(1-QF.K/(NF*CF))$   
NOTE A  $TT.K=FTT*(1-(1-LST)*QT.K/(NT*CT))/(1-QT.K/(NT*CT))$   
NOTE TF,TT-Travel Time (MIN.)  
N  $FFT=60*X/80$   
N  $FTT=60*X/70$   
NOTE FFT,FTT-Free Flow Travel Time for Freeway and Truckway (MIN.)  
C  $LSF=0.15$   
C  $LST=0.3$   
NOTE LSF,LST-Level of Service Factor (DIM)  
A  $ACC.K=TTN/TT.K$   
NOTE ACC-Accessibility  
C  $TTN=361.16$   
NOTE TTN-Initial Truck Travel Time (MIN.)  
C  $NF=3$   
NOTE NF,NT,NM-Number of Lanes  
C  $CF=2000$   
NOTE CF,CT,CM-Capacity (VEH/LANE)  
A  $Q.K=QF.K+QT.K$   
A  $QF.K=FDTPH*PV.K/ACO$   
A  $QT.K=FDTPH*4*TV.K+THTV.K$   
NOTE Q,QT,QF-Volume (VEH/HOUR)  
C  $FDTPH=0.11$   
NOTE FDTPH-Fract Daily Traffic in Peak-Hour (DIM)  
C  $ACO=1.3$   
NOTE ACO-Average Car Occupancy (PERSONS/HOUR)  
A  $PV.K=POP.K*PTGF*PCAF.K/(X*5)$   
A  $TV.K=(TO.K*TTGF)/X$   
NOTE PV,TV-Passenger, Truck Demand (PERSONS/HR)  
A  $PCAF.K=TABLE(PCAF.T,TIME.K,0,50,50)$   
T  $PCAF.T=1/2.5$   
NOTE PCAF-PASSENGER CAR ADJUSTMENT FOR TIME  
N  $PTGF=52*.848568$   
N  $TTGF=0.00002325/2$   
NOTE PTGF-Passenger Traffic Generation Factor (/HOUR)  
NOTE TTGF-Truck Traffic Generation Factor (/HOUR)  
A  $THTV.K=THTVN*THTAF.K$   
NOTE THTV-THRU-TRUCK TRAFFIC  
C  $THTVN=1154.55$   
A  $THTAF.K=TABLE(THTAF.T,TIME.K,0,50,50)$

T THTAFT=1/2.5  
 NOTE THTAFT-THRU-TRUCK TRAFFIC ADJUSTMENT FOR TIME  
 C X=325  
 NOTE X-Distance (MILES)  
 NOTE  
 SAVE PCI,POP,TT,IC,TO,GRP,TJ,TPGR,UR,LF,Q,QF,QT,TMI  
 SAVE IP1,IP2,IP3,IP4,IP5,IP6,IP7,IP8,IP9  
 SAVE IO1,IO2,IO3,IO4,IO5,IO6,IO7,IO8,IO9  
 SAVE PV,TV,TJ  
 SPEC DT=.125/LENGTH=8/SAVPER=1  
 □

## 2. Scenario 2: Expansion of Lanes

NOTE \*\*\* Transportation Sector \*\*\*  
 NOTE  
 A  $TT.K = FFT * (1 - (1 - LSF) * Q.K / (NF.K * CF)) / (1 - Q.K / (NF.K * CF))$   
 NOTE A  $TF.K = FFT * (1 - (1 - LSF) * QF.K / (NF.K * CF)) / (1 - QF.K / (NF.K * CF))$   
 NOTE A  $TT.K = FTT * (1 - (1 - LST) * QT.K / (NT * CT)) / (1 - QT.K / (NT * CT))$   
 NOTE TF,TT-Travel Time (MIN.)  
 N  $FFT = 60 * X / 80$   
 N  $FTT = 60 * X / 70$   
 NOTE FFT,FTT-Free Flow Travel Time for Freeway and Truckway (MIN.)  
 C  $LSF = 0.15$   
 C  $LST = 0.3$   
 NOTE LSF,LST-Level of Service Factor (DIM)  
 A  $ACC.K = TTN / TT.K$   
 NOTE ACC-Accessibility  
 C  $TTN = 361.16$   
 NOTE TTN-Initial Truck Travel Time (MIN.)  
 A  $NF.K = CLIP(5, 3, TIME.K, 3)$   
 NOTE C  $NF = 3$   
 NOTE NF,NT,NM-Number of Lanes  
 C  $CF = 2000$   
 NOTE CF,CT,CM-Capacity (VEH/LANE)  
 A  $Q.K = QF.K + QT.K$   
 A  $QF.K = FDTPH * PV.K / ACO$   
 A  $QT.K = FDTPH * 4 * TV.K + THTV.K$   
 NOTE Q,QT,QF-Volume (VEH/HOUR)  
 C  $FDTPH = 0.11$   
 NOTE FDTPH-Fract Daily Traffic in Peak-Hour (DIM)  
 C  $ACO = 1.3$   
 NOTE ACO-Average Car Occupancy (PERSONS/HOUR)  
 A  $PV.K = POP.K * PTGF * PCAF.K / (X * 5)$   
 A  $TV.K = (TO.K * TTGF) / X$   
 NOTE PV,TV-Passenger, Truck Demand (PERSONS/HR)  
 A  $PCAF.K = TABLE(PCAF.T, TIME.K, 0, 50, 50)$   
 T  $PCAF.T = 1/2.5$   
 NOTE PCAF-PASSENGER CAR ADJUSTMENT FOR TIME  
 N  $PTGF = 52 * .848568$

N TTGF=0.0002325/2  
 NOTE PTGF-Passenger Traffic Generation Factor (/HOUR)  
 NOTE TTGF-Truck Traffic Generation Factor (/HOUR)  
 A THTV.K=THTVN\*THTAF.K  
 NOTE THTV-THRU-TRUCK TRAFFIC  
 C THTVN=1154.55  
 A THTAF.K=TABLE(THTAFT,TIME.K,0,50,50)  
 T THTAFT=1/2.5  
 NOTE THTAF-THRU-TRUCK TRAFFIC ADJUSTMENT FOR TIME  
 C X=325  
 NOTE X-Distance (MILES)

### 3. Scenario 3: Exclusive Truckway

NOTE \*\*\* Transportation Sector \*\*\*  
 NOTE  
 A  $TT.K = \text{CLIP}(\text{FTT} * (1 - (1 - \text{LST}.K) * \text{QT}.K / (\text{NT} * \text{CT})) / (1 - \text{QT}.K / (\text{NT} * \text{CT})), ^\wedge$   
 $\text{FFT} * (1 - (1 - \text{LST}.K) * \text{Q}.K / (\text{NF} * \text{CF})) / (1 - \text{Q}.K / (\text{NF} * \text{CF})), \text{TIME}.K, 3)$   
 A  $TF.K = \text{CLIP}(\text{FFT} * (1 - (1 - \text{LSF}) * \text{QF}.K / (\text{NF} * \text{CF})) / (1 - \text{QF}.K / (\text{NF} * \text{CF})), ^\wedge$   
 $\text{FFT} * (1 - (1 - \text{LST}.K) * \text{Q}.K / (\text{NF} * \text{CF})) / (1 - \text{Q}.K / (\text{NF} * \text{CF})), \text{TIME}.K, 3)$   
 NOTE A  $TT.K = \text{FTT} * (1 - (1 - \text{LST}) * \text{QT}.K / (\text{NT} * \text{CT})) / (1 - \text{QT}.K / (\text{NT} * \text{CT}))$   
 NOTE TF,TT-Travel Time (MIN.)  
 N  $\text{FTT} = 60 * X / 80$   
 N  $\text{FTT} = 60 * X / 80$   
 NOTE FTT,FTT-Free Flow Travel Time for Freeway and Truckway (MIN.)  
 C LSF=0.12  
 A  $\text{LST}.K = \text{CLIP}(0.2, 0.15, \text{TIME}.K, 3)$   
 NOTE LSF,LST-Level of Service Factor (DIM)  
 A  $\text{ACC}.K = \text{TTN} / \text{TT}.K$   
 NOTE ACC-Accessibility  
 C TTN=361.16  
 NOTE TTN-Initial Truck Travel Time (MIN.)  
 NOTE A  $\text{NF}.K = \text{CLIP}(5, 3, \text{TIME}.K, 3)$   
 C NF=3  
 C NT=2  
 NOTE NF,NT,NM-Number of Lanes  
 C CF=2000  
 C CT=2000  
 NOTE CF,CT,CM-Capacity (VEH/LANE)  
 A  $\text{Q}.K = \text{QF}.K + \text{QT}.K$   
 A  $\text{QF}.K = \text{FDTPH} * \text{PV}.K / \text{ACO}$   
 A  $\text{QT}.K = \text{CLIP}(\text{FDTPH} * 3 * \text{TV}.K + \text{THTV}.K, \text{FDTPH} * 4 * \text{TV}.K + \text{THTV}.K, \text{TIME}.K, 3)$   
 NOTE Q,QT,QF-Volume (VEH/HOUR)  
 C FDTPH=0.11  
 NOTE FDTPH-Fract Daily Traffic in Peak-Hour (DIM)  
 C ACO=1.3  
 NOTE ACO-Average Car Occupancy (PERSONS/HOUR)  
 A  $\text{PV}.K = \text{POP}.K * \text{PTGF} * \text{PCAF}.K / (X * 5)$   
 A  $\text{TV}.K = (\text{TO}.K * \text{TTGF}) / X$   
 NOTE PV,TV-Passenger, Truck Demand (PERSONS/HR)



A PCAF.K=TABLE(PCAF.T,TIME.K,0,50,50)  
 T PCAFT=1/2.5  
 NOTE PCAF-PASSENGER CAR ADJUSTMENT FOR TIME  
 N PTGF=52\*.848568  
 N TTGF=0.00002325/2  
 NOTE PTGF-Passenger Traffic Generation Factor (/HOUR)  
 NOTE TTGF-Truck Traffic Generation Factor (/HOUR)  
 A THTV.K=THTVN\*THTAF.K  
 NOTE THTV-THRU-TRUCK TRAFFIC  
 C THTVN=1154.55  
 A THTAF.K=TABLE(THTAFT,TIME.K,0,50,50)  
 T THTAFT=1/2.5  
 NOTE THTAF-THRU-TRUCK TRAFFIC ADJUSTMENT FOR TIME  
 C X=325  
 NOTE X-Distance (MILES)

#### 4. Scenario 4: ATMS applications and expansion of lanes

NOTE \*\*\* Transportation Sector \*\*\*  
 NOTE  
 NOTE A  $TT.K = \text{CLIP}(\text{FTT} * (1 - (1 - \text{LST}.K) * \text{QT}.K / (\text{NT} * \text{CT})) / (1 - \text{QT}.K / (\text{NT} * \text{CT})), ^\wedge$   
 $\text{FFT} * (1 - (1 - \text{LST}.K) * \text{Q}.K / (\text{NF} * \text{CF})) / (1 - \text{Q}.K / (\text{NF} * \text{CF})), \text{TIME}.K, 3)$   
 NOTE A  $TF.K = \text{CLIP}(\text{FFT} * (1 - (1 - \text{LSF}) * \text{QF}.K / (\text{NF} * \text{CF})) / (1 - \text{QF}.K / (\text{NF} * \text{CF})), ^\wedge$   
 $\text{FFT} * (1 - (1 - \text{LST}.K) * \text{Q}.K / (\text{NF} * \text{CF})) / (1 - \text{Q}.K / (\text{NF} * \text{CF})), \text{TIME}.K, 3)$   
 A  $TT.K = \text{FTT} * (1 - (1 - \text{LST}) * \text{Q}.K / (\text{NF}.K * \text{CT})) / (1 - \text{Q}.K / (\text{NF}.K * \text{CT}))$   
 NOTE TF,TT-Travel Time (MIN.)  
 N  $\text{FFT} = 60 * X / 80$   
 N  $\text{FTT} = 60 * X / 80$   
 NOTE FFT,FTT-Free Flow Travel Time for Freeway and Truckway (MIN.)  
 NOTE C LSF=0.12  
 NOTE A  $\text{LST}.K = \text{CLIP}(0.2, 0.15, \text{TIME}.K, 3)$   
 C LST=0.15  
 NOTE LSF,LST-Level of Service Factor (DIM)  
 A  $\text{ACC}.K = \text{TTN} / \text{TT}.K$   
 NOTE ACC-Accessibility  
 C TTN=361.16  
 NOTE TTN-Initial Truck Travel Time (MIN.)  
 A  $\text{NF}.K = \text{CLIP}(5, 3, \text{TIME}.K, 3)$   
 NOTE C NF=3  
 NOTE C NT=2  
 NOTE NF,NT,NM-Number of Lanes  
 C CF=2000  
 C CT=2000  
 NOTE CF,CT,CM-Capacity (VEH/LANE)  
 A  $\text{Q}.K = \text{QF}.K + \text{QT}.K$   
 A  $\text{QF}.K = \text{FDTPH}.K * \text{PV}.K / \text{ACO}$   
 A  $\text{QT}.K = \text{CLIP}(\text{FDTPH}.K * 4 * \text{TV}.K + \text{THTV}.K, \text{FDTPH}.K * 4 * \text{TV}.K + \text{THTV}.K, \text{TIME}.K, 3)$   
 NOTE Q,QT,QF- Volume (VEH/HOUR)  
 A  $\text{FDTPH}.K = \text{CLIP}(0.10, 0.11, \text{TIME}.K, 3)$   
 NOTE C FDTPH=0.11  
 NOTE FDTPH-Fract Daily Traffic in Peak-Hour (DIM)

C ACO=1.3  
 NOTE ACO-Average Car Occupancy (PERSONS/HOUR)  
 A  $PV.K = POP.K * PTGF * PCAF.K / (X * 5)$   
 A  $TV.K = (TO.K * TTGF) / X$   
 NOTE PV,TV-Passenger, Truck Demand (PERSONS/HR)  
 A  $PCAF.K = TABLE(PCAF.T, TIME.K, 0, 50, 50)$   
 T  $PCAF.T = 1/2.5$   
 NOTE PCAF-PASSENGER CAR ADJUSTMENT FOR TIME  
 N  $PTGF = 52 * .848568$   
 N  $TTGF = 0.00002325/2$   
 NOTE PTGF-Passenger Traffic Generation Factor (/HOUR)  
 NOTE TTGF-Truck Traffic Generation Factor (/HOUR)  
 A  $THTV.K = THTVN * THTAF.K$   
 NOTE THTV-THRU-TRUCK TRAFFIC  
 C  $THTVN = 1154.55$   
 A  $THTAF.K = TABLE(THTAF.T, TIME.K, 0, 50, 50)$   
 T  $THTAF.T = 1/2.5$   
 NOTE THTAF-THRU-TRUCK TRAFFIC ADJUSTMENT FOR TIME  
 C  $X = 325$   
 NOTE X-Distance (MILES)

#### 5. Scenario 5: Hybrid Personal Maglev

NOTE \*\*\* Transportation Sector \*\*\*  
 NOTE  
 NOTE A  $TT.K = CLIP(FTT * (1 - (1 - LST.K) * QT.K / (NT * CT)) / (1 - QT.K / (NT * CT)), ^$   
 $FFT * (1 - (1 - LST.K) * Q.K / (NF * CF)) / (1 - Q.K / (NF * CF)), TIME.K, 3)$   
 NOTE A  $TF.K = CLIP(FFT * (1 - (1 - LSF) * QF.K / (NF * CF)) / (1 - QF.K / (NF * CF)), ^$   
 $FFT * (1 - (1 - LST.K) * Q.K / (NF * CF)) / (1 - Q.K / (NF * CF)), TIME.K, 3)$   
 A  $TT.K = FTT * (1 - (1 - LST) * Q.K / (NF * CT)) / (1 - Q.K / (NF * CT))$   
 A  $TM.K = FMT * (1 - (1 - LSM) * QM.K / (NM * CM)) / (1 - QM.K / (NM * CM))$   
 NOTE TF,TT-Travel Time (MIN.)  
 N  $FFT = 60 * X / 80$   
 N  $FFT = 60 * X / 80$   
 N  $FMT = 60 * X / 250$   
 NOTE FFT,FTT-Free Flow Travel Time for Freeway and Truckway (MIN.)  
 NOTE C  $LSF = 0.12$   
 NOTE A  $LST.K = CLIP(0.2, 0.15, TIME.K, 3)$   
 C  $LST = 0.15$   
 C  $LSM = 0.001$   
 NOTE LSF,LST-Level of Service Factor (DIM)  
 A  $ACC.K = TTN / TT.K$   
 NOTE ACC-Accessibility  
 C  $TTN = 361.16$   
 NOTE TTN-Initial Truck Travel Time (MIN.)  
 NOTE A  $NF.K = CLIP(5, 3, TIME.K, 3)$   
 C  $NF = 3$   
 C  $NM = 1$   
 NOTE C  $NT = 2$   
 NOTE NF,NT,NM-Number of Lanes  
 C  $CF = 2000$

C CT=2000  
 C CM=44000  
 NOTE CF,CT,CM-Capacity (VEH/LANE)  
 A Q.K=QF.K+QT.K  
 A QF.K=FDTPH\*PV.K\*FVF.K/ACO  
 A QT.K=FDTPH\*4\*TV.K+THTV.K  
 NOTE A QT.K=CLIP(FDTPH.K\*3\*TV.K+THTV.K,FDTPH.K\*4\*TV.K+THTV.K,TIME.K,3)  
 A QM.K=(FDTPH/ACO)\*(1-FVF.K)\*PV.K  
 NOTE Q,QT,QF-Volume (VEH/HOUR)  
 A FVF.K=CLIP(FVFF.K,1,TIME.K,5)  
 NOTE TABHL(FVFT,TIME.K,0,50,5)  
 A FVFF.K=TABHL(FVFFT,TIME.K,0,50,50)  
 C FVFFT=1/0  
 NOTE C FVFT=1/.8/.7/.5/.4/.3/.25/.2/.15/.12/.1  
 C FDTPH=.11  
 NOTE A FDTPH.K=CLIP(.10,.11,TIME.K,3)  
 NOTE C FDTPH=0.11  
 NOTE FDTPH-Fract Daily Traffic in Peak-Hour (DIM)  
 C ACO=1.3  
 NOTE ACO-Average Car Occupancy (PERSONS/HOUR)  
 A PV.K=POP.K\*PTGF\*PCAF.K/(X\*5)  
 A TV.K=(TO.K\*TTGF)/X  
 NOTE PV,TV-Passenger, Truck Demand (PERSONS/HR)  
 A PCAF.K=TABLE(PCAF.T,TIME.K,0,50,50)  
 T PCAFT=1/2.5  
 NOTE PCAF-PASSENGER CAR ADJUSTMENT FOR TIME  
 N PTGF=52\*.848568  
 N TTGF=0.00002325/2  
 NOTE PTGF-Passenger Traffic Generation Factor (/HOUR)  
 NOTE TTGF-Truck Traffic Generation Factor (/HOUR)  
 A THTV.K=THTVN\*THTAF.K  
 NOTE THTV-THRU-TRUCK TRAFFIC  
 C THTVN=1154.55  
 A THTAF.K=TABLE(THTAFT,TIME.K,0,50,50)  
 T THTAFT=1/2.5  
 NOTE THTAF-THRU-TRUCK TRAFFIC ADJUSTMENT FOR TIME  
 C X=325  
 NOTE X-Distance (MILES)

## Appendix J. User Cost-Benefit Analysis

- Demand Function

Demand function is exogenous in this research and can be obtained by the following equation:

$$T_{KL} = K / Q_{KL}$$

For the base year, K is 27,800. Therefore, the equation is the following:

$$T_{KL} = 27800 / Q_{KL}$$

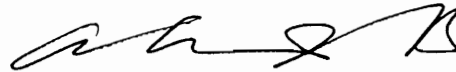
- Supply Function and Cost-Benefit Analysis

Equations (4.1), (4.2), and (4.3) are used to estimate user benefits. Value of travel time is assumed to be 10.80 \$/veh-hr (Lee, 1994) for an average value for PCE (passenger car equivalency) or 0.18 \$/veh-min and  $j$  (the L.O.S. factor) is assumed as 0.15. Travel times are obtained using Davidson's formula, the equation (4.3). Volumes can be obtained by the demand function. Annual volume is calculated by multiplying peak hour volume and yearly adjustment number, 2000. Construction and maintenance costs can be obtained by multiplying 325 miles, and unit construction and maintenance costs in Table 6.1. It can be assumed that scenario 3, an exclusive highway, has the same benefits as scenario 2, although reduced accidents and incident costs induce more savings. In scenario 5, 200 mph was considered as design speed. Discount rate is 10% annually. Physical lifetime is assumed to be 30 to 50 years. Fig. 4.1 and Fig. 6.1. explain determination of user benefits. Computation of B/C ratio is in equation (4.4).

In scenario 4, user benefits from demand management, i.e., reduced demands, are calculated. Peak hour travel time is decreased from 0.11 to 0.10, which decreases the equilibrium travel time and traffic volume. Using the equation (4.1) with additional costs, 150 million dollars for the whole corridor, the user B/C ratio was obtained.

## VITA

Seung Bum Ahn was born on November, 1964 in Seoul, Korea. He received a Bachelor of Science degree in the Department of Architectural Engineering in Yonsei University in 1991. During his undergraduate studies, he served in the Army for about two and half years. He began studies toward a Masters' degree in Urban and Regional Planning in the Department of Urban Affairs and Planning at Virginia Tech, and earned the Masters' degree in May, 1994. He entered his Ph.D. program in January, 1994.

A handwritten signature in black ink, appearing to read 'S. B. Ahn', is centered on the page.