TRANSPORTATION IMPACT METHODOLOGY FOR MEASURING USER AND NON-USER BENEFITS
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by

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Abstract

A methodology for linking transport investment, user benefits, and succeeding economic development, so as to provide a basis for rational policy formation, is presented. The approach consists of developing relationships between variables in causal streams from policy parameters to measures of effectiveness and expressing them in the form of a generic model. The generic model is solved analytically and subjected to policy analysis.

Introduction

The tie between future economic growth and improved productivity is clear. What is unclear is whether transportation improvement contributes more to increasing productivity than other investments (whether they are public or private). Questions concerning cause and effect and how public capital stocks are incorporated as components of production are extremely relevant if transportation investment is to be used as an element of a fiscal policy for simulating growth beyond the localized benefits of individual transportation projects. If public investment simulates private investment or if they reinforce one another (i.e., there is feedback) then infrastructure investment could be interpreted as a policy variable for stimulating growth. Since causality between infrastructure and economic development may be mutual, it presents a major challenge in estimating how much of the observed change is attributable to the prior availability and how much to economic development and income growth. The frequently found correlation between the level of infrastructure services and income does not tell us much about which caused which.

State of the Art

It is ironic that the economist, who has contributed so much to the understanding of transportation demand analysis -- the process of relating the demand for transportation to the socioeconomic activities that generate it, could distance himself so far from this precept in trying to explain the impact of transportation supply on socioeconomic activities. In the fifties, 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" and the conceptual framework for the "Price-Volume Curves" used for determining transportation user benefits. In the nineties, transportation is being considered more and more as a sector of an economy, exchanging inputs and outputs with the rest. Macroeconomic models have been developed that attempts to deal, at an aggregate level, with the intersectoral flows of goods and services. The two approaches to macroeconomic modeling that are being applied are the econometric approach and input-output analysis.

Multiregional input-output models, in particular, provide a powerful tool for analyzing transport demands at the macroeconomic level. Despite their many restrictive assumptions, their proponents proclaim them the most feasible models for application in national and regional planning. And yet, translating the transportation requirements or demands of other sectors of the economy into transportation investment and improvement decisions on the ground requires great leaps of faith. The same is true for the inverse problem: predicting the effect of a transportation investment or improvement in a corridor on the socioeconomic well-being of the localities it serves.

Surely, transportation impact analysis is a corollary of transportation demand analysis and the models that serve one can serve the other. We need to expand the "Four-Step Transportation Planning Process" and the "Price-Volume Approach" to take into consideration explicitly the relationship between transportation cost reductions and increased productivity, recognizing that this increased productivity is going to increase demand and therefore transportation costs, reducing productivity. This feedback process can be easily modeled using system dynamics and the causal diagram display of the model readily comprehended by policy makers. Theories of the transportation-development interaction must be advanced and tested which requires communication between different professionals and, indeed, between transportation professionals and the society served. The significance of the causal diagramming tool in the modeling paradigm proposed is that it takes us out of a communication cul-de-sac, providing a common vocabulary and structure of reasoning for all concerned.

Towards a Transportation/Development Paradigm

Impact studies, whether they state it or not, attempt to establish and measure the cause and effect relationships associated with a transportation change and, in doing so, evaluate its socioeconomic consequences. The effects of a transportation change can be categorized in several different ways but most analysts make a fundamental distinction between changes in the physical environment and changes in the personal well-being of individuals in the community. The most often studied impact in the first category has been land use changes. Studies of effects in the second category attempt to evaluate transportation in terms that relate it to groups in the community. An important distinction is between impacts on users and impacts on non-users. An example of a user impact is the effect of a new highway on the amount of time that it takes to make certain trips. Nonuser impacts include such effects as increased employment opportunities and lower prices on goods for which transportation costs are reduced.

The major reason for developing a transportation/development model is not just to forecast the future, but to influence the future and to help the decision-maker to decide which of the candidate alternatives is the preferred one. Models need to be built that are explicitly directed toward particular policy or planning issues. This means that variables under the control or sensitive to the policy in question must be included in the model and that the scale of the modeling effort involved with regard to model construction, data collection, calibration, and application must be commensurate with the nature of the decision being considered.

A body of dynamic behavior and principles of structure is emerging that allows us to organize and understand the development process of a region or a whole nation -- a process dominated by feedback in that it features the synthesis of demand and supply functions. For the demand function, we are seeking the transportation improvement required to accommodate a certain socio-economic load, for the supply function we want to know the level of service obtained for a certain transportation improvement. Since higher levels of service attract socio-economic activity, the feedback loop is closed.

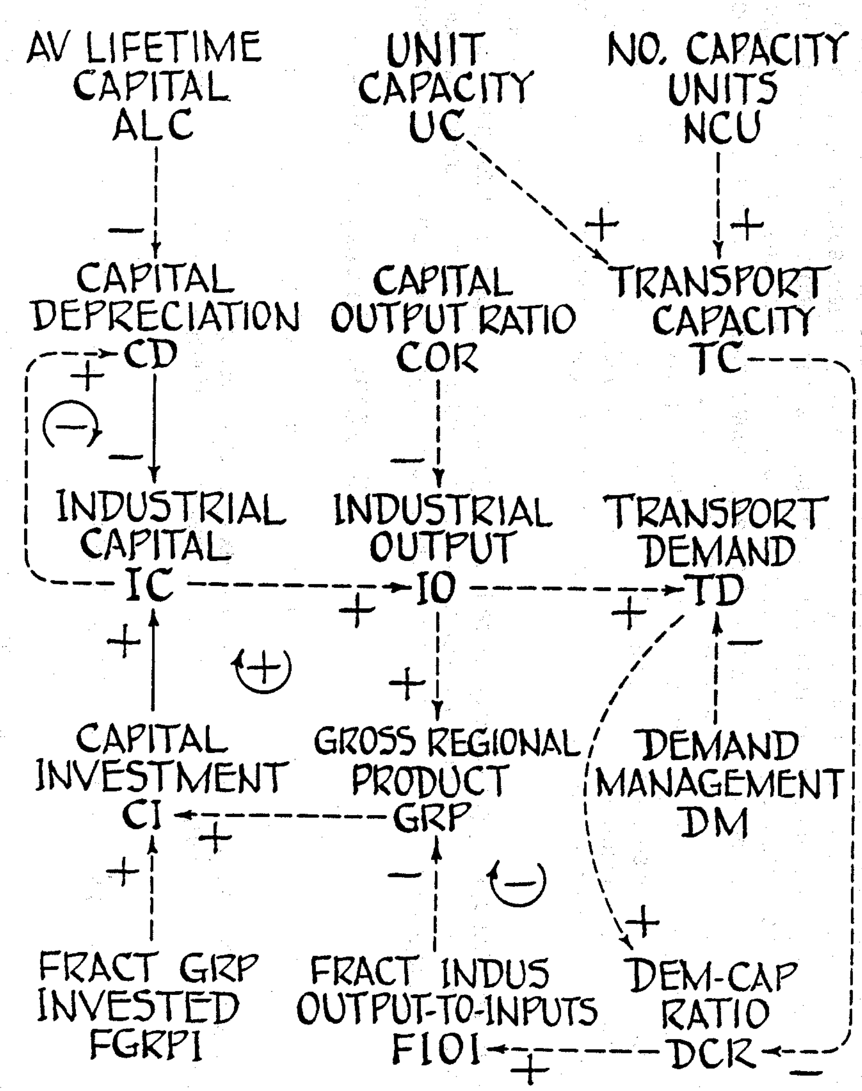
Objectives and Approach

There is a growing concern that current transportation policies are not providing the necessary level, type, or quality of services that are required to maintain or improve national productivity and international competitiveness, or to enhance regional and local economic development. In response to this concern, there is a need for research that will document and critically evaluate the quality and content of the current state of knowledge and research in progress, relating to transportation (all modes) and the local, regional, and national economies.

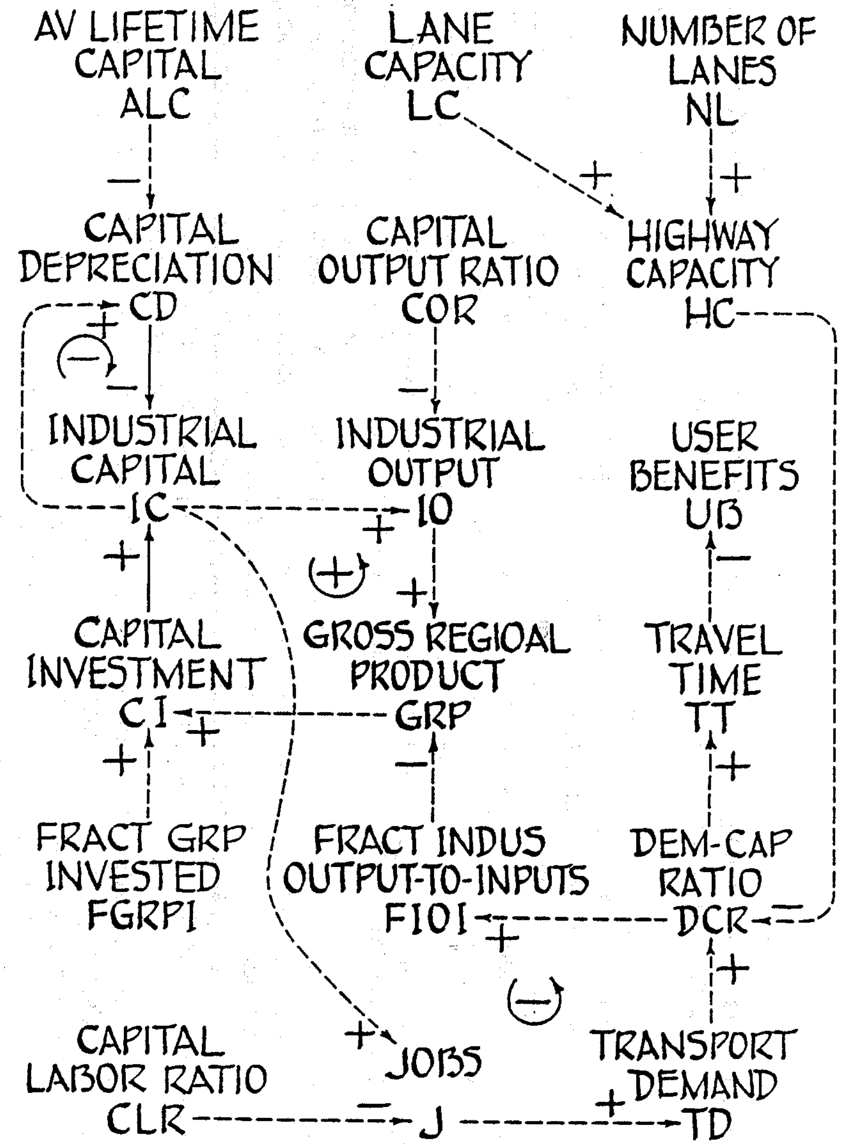
The objectives of the project from which this paper is derived is to develop a methodology for generating models that can be used by planners and decision makers as instrumentalities:

1. for making reliable estimates of the economic health and productivity benefits of potential transportation investments and management actions; and

2. for linking transport investments, user benefits, and succeeding economic development to provide a basis for rational policy formation.



TRANSPORT-ECO DEVELOPMENT RELATIONSHIPS
FIG 1



INCORPORATION OF HWY USER BENEFITS
FIG 2

To accomplish the objective of this project, the plan of research was envisaged as consisting of the following steps:

1. To critically evaluate existing methodologies and the state of knowledge resulting from their use;

2. To develop relationships between variables in causal streams from policy parameters to measures of effectiveness and express them in the form of a generic model; and

3. To solve the generic model and perform policy analysis.

Requirements of the Methodology

Basically transportation impact analysis 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 geographic scale G for a transportation investment H on mode I at time T?

There is no solution to this problem at present. In fact some would doubt the wisdom of trying to develop an all purpose transportation impact methodology. Yet, we know that a transportation investment impacts all these things. We routinely calculate the Benefit-Cost Ratio, based on user benefits to three significant figures, to determine project feasibility. Owners and investors project rates of returns to the nearest cent. Exhaustive environmental impact statements are written and rewritten. But when it comes to measuring the socio-economic effects of transportation initiatives, all sorts of justifications are used for treating the problem subjectively such as: (1) it would be double counting; (2) it would usurp the judgment of the decision maker; (3) it would eliminate the micro approach to analysis; etc. For the purpose of this discussion, let's assume that such an all-encompassing methodology would be desirable, if for no other reason than to have a useful conceptualizing device. What would be the requirements of our transportation impact methodology (TIM)?

1. Our first requirement for TIM is that it depict transportation initiatives and impact relationships in terms of variables such as shown in the causal diagram in Fig. 1.

2. Our second requirement for TIM 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). In Fig. 1, "capacity units" can refer to traffic lanes, port berths, airport gates, etc.

3. Out third requirement for TIM is that it be capable of developing theories so as to verify or refute conclusions regarding transportation and development interactions (see Fig. 1).

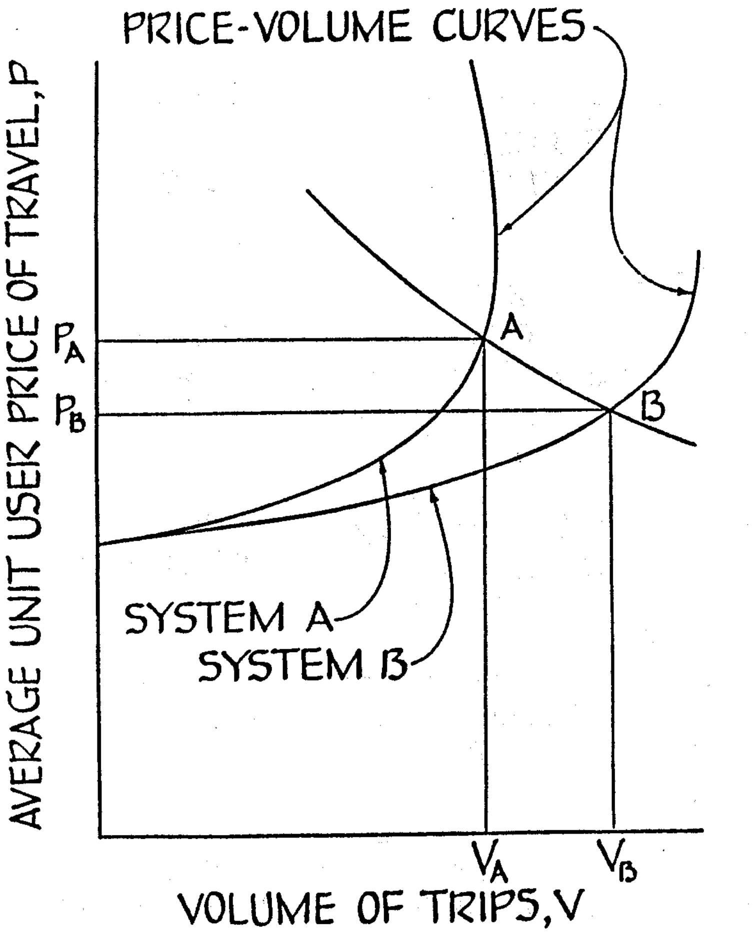
4. In choosing between a casual or causal methodology for TIM, we must remember that the design of a system (such as transportation) to serve society requires that we account for the fact that the design itself will influence the inputs that the system must accommodate. This rules out casual or correlative approaches for TIM.

5. The advantage of a causal approach is that it shows us how cause and effect relationships close on themselves to form feedback loops. Our fourth requirement of TIM is that it handle feedback endogenously and explicitly as shown in the causal diagram in Fig. 1.

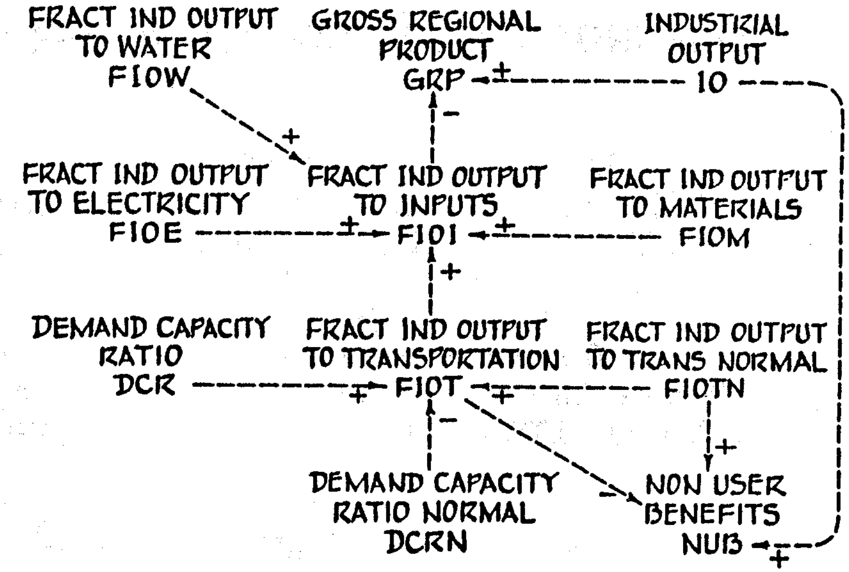
6. Since transportation development interactions are governed by feedback between supply and demand, analyzing supply and demand separately and in isolation will not even hint at overall behavior. Our sixth requirement is that TIM be comprehensive taking into consideration transportation investment to increase supply (capacity) and transportation management to smooth demand (see Fig. 1).

7. In order to forecast development impacts, our TIM must model the development process explicitly. In Fig. 1 we see the development process represented as the positive feedback loop IC-IO-GRP-CI-IC.

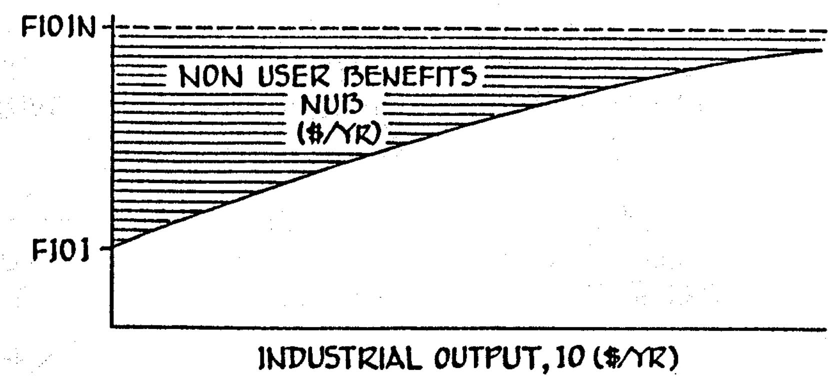
8. Our eighth requirement is that TIM accommodate the three orientations --- user, provider and society --- and their values and goals so as to effectively trade off different policies and combinations of



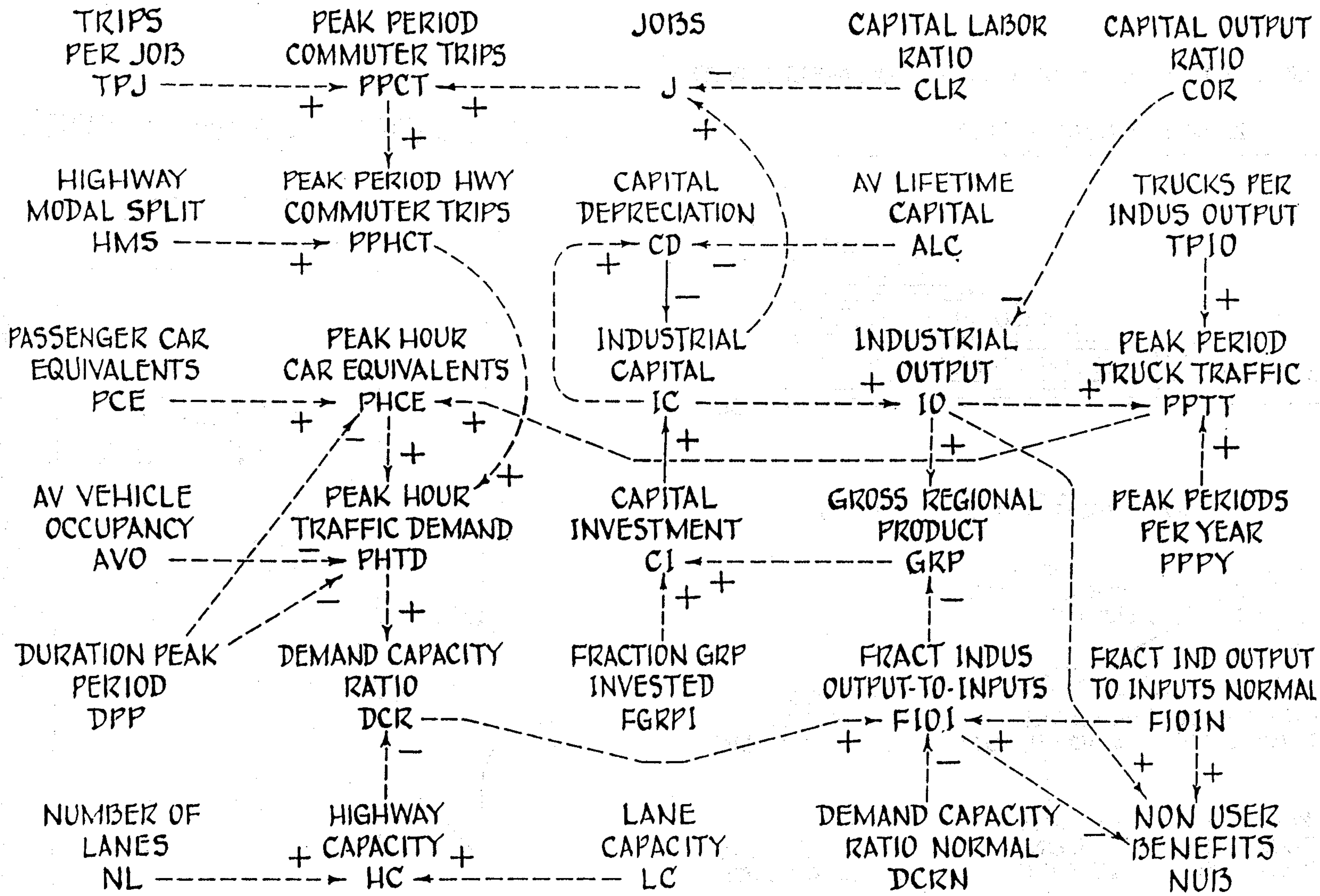
USER BENEFIT AND COST RELATIONSHIPS
FIG. 3



CAUSAL DIAGRAM OF BREAKDOWN OF FI01
FIG 5



GRAPH SHOWING DETERMINATION OF NON USER BENEFITS
FIG 6



HIGHWAY TRANSPORTATION - ECONOMIC DEVELOPMENT RELATIONSHIPS

FIG 4

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* EQUATIONS RELATING HIGHWAY TRANSPORTATION AND ECONOMIC DEVELOPMENT (FIG 7)
NOTE
L IC.K=IC.J+(DT)(CI.JK-CD.JK)
N IC=ICN
NOTE IC-INDUSTRIAL CAPITAL ($)
C ICN=889.1E6
NOTE ICN-INDUS CAPITAL INITIAL VALUE ($)
R CD.KL=IC.K/ALC
NOTE CD-CAPITAL DEPRECIATION ($/YR)
C ALC=16.67
NOTE ALC-AVER LIFETIME CAPITAL (YR)
R CI.KL=GRP.K*FGRPI
NOTE CI-CAPITAL INVESTMENT ($/YR)
C FGRPI=0.2
NOTE FGRPI-FRACT GROSS REGINAL PROD INVESTED (DIM)
A GRP.K=IO.K*(1-FIOI.K)
NOTE GRP-GROSS REGIONAL PRODUCT ($/YR)
A IO.K=IC.K/COR
NOTE IO-INDUS OUTPUT ($)
C COR=2
NOTE COR-CAPITAL OUTPUT RATIO (YR)
A FIOI.K=FIOIN*DCR.K/DCRN
NOTE FIOI-FRACT INDUS OUTPUT TO INPUTS (DIM)
C FIOIN=.4
NOTE FIOIN-FIOI NORMAL (DIM)
C DCRN=1.0
NOTE DCRN-DEMAND CAPACITY RATIO NORMAL (DIM)
A DCR.K=PHTD.K/HC
NOTE DCR-DEMAND CAPACITY RATIO (DIM)
N HC=NL*LC
NOTE HC-HIGHWAY CAPACITY (VEH/YR)
C NL=4
NOTE NL-NUMBER OF LANES (LANES)
C LC=2000
NOTE LC-LANE CAPACITY (VEH/HR-LANE)
A PHTD.K=PHCE.K+PPHCT.K/(AVO*DPP)
NOTE PHTD-PEAK HOUR TRAFFIC DEMAND (VEH/HR)
C AVO=1.0
NOTE AVO-AVER VEH OCCUPANCY (PERSONS/VEH)
C DPP=2.0
NOTE DPP-DURATION OF PEAK PERIOD (HR/PERIOD)
A PHCE.K=PPTT.K*PCE/DPP
NOTE PHCE-PEAK HOUR CAR EQUIVALENTS (VEH/HR)
C PCE=4
NOTE PCE-PASSENGER CAR EQUIVALENTS (VEH/TRUCK)
A 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/$)
C PPPY=300
NOTE PPPY-PEAK PERIODS PER YEAR (PERIODS/YR)
A PPHCT.K=PPCT.K*HMS
NOTE PPHCT-PK PERIOD HWY COMMUTER TRIPS (TRIPS/PERIOD)
C HMS=0.8
NOTE HMS-HWY MODEL SPLIT (DIM)
A PPCT.K=J.K*TPJ
NOTE PPCT-PEAK PERIOD COMMUTER TRIPS (TRIPS/PERIOD)
C TPJ=1.0
NOTE TPJ-TRIPS PER JOB (TRIPS/PERSON)
A J.K=IC.K/CLR
NOTE J-JOBS (PERSON)
C CLR=50000
NOTE CLR-CAPITAL LABOR RATIO ($/PERSON)
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policies. In Fig. 2, the variable user benefits UB is incorporated into a causal diagram for highway transportation and economic development interactions. User benefit analysis is performed using the price-volume format shown in Fig. 3.

9. TIM should be capable of generating productivity curves for every policy variable - measure of effectiveness combination. For example, in Fig. 2 three measures of effectiveness are GRP (Gross Regional Product), J (Jobs) and UB (User Benefits); two policy variables are NL (Number of Lanes) and LC (Line Capacity).

10. A tenth requirement for TIM is that it make use of the existing data bases generated in conjunction with the Urban Transportation Planning Process (UTPP) mandated during the period of Interstate Highway Planning. In Fig. 4, the trip generation, trip distribution, modal split and network assignment steps associated with the UTPP have been incorporated in the Highway Transportation/Economic Development Relationship.

11. Requirement eleven for TIM is that it be equally applicable to non-investment as well as investment initiatives. The advantage of incorporating the UTPP into TIM 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. (see Fig. 4).

12. TIM 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 (see Fig. 4) to show how reductions in transportation costs impact users and non-users. Fig. 5 shows the breakdown of the Fraction of Industrial Output to Inputs (FIOI) and how the Demand Capacity Ratio (DCR) affects the Gross Regional Product (GRP) through the Fraction of Industrial Output to Transportation (FIOT).

13. Continuing from the previous requirement, TIM should be capable of separating user benefits and non-user benefits so as to eliminate double counting. This hinges on the extent that a transportation initiative either reduces the Demand Capacity Ratio (DCR) therefore benefitting the user or increases the Gross Regional Product (GRP) therefore benefitting the non-user. Fig. 6 is a graph showing the determination of non-user benefits analogous to Fig. 3 for the determination of user benefits.

Policy Analysis

The DYNAMO equations for the model depicted in the causal diagram of Fig. 4 are given in Fig. 7. By examining the computer outputs for various parameter changes corresponding to policy interventions, a form of policy analysis can be performed. For the simple model shown, an analytical solution is available and is instructive. In its purest form, policy analysis would simply consist of an equation in which the dependent variable was the measure of effectiveness expressed in terms of constants corresponding to the policy parameters (see Fig. 8). From equations 6 and 7 one can prepare a policy summary such as shown in Fig. 9 that tells which policy variables affect user benefits (the Demand-Capacity Ration, DCR_e) and non-user benefits (the Gross Regional Product, GRP_e).

Emphasis on Managing Development

Cities play a preeminent role as the nodal points in the process of development. They are the holders of power, the seedbeds of change, the seats of learning, engines of production and confluences of control. Cities are the result of the division of labor and specialization, made possible by transportation. If transportation is a precursor of urbanization and suburbanization, it can be used to guide their growth and distribution, thereby influencing selective economic development.

Too often, transportation's impact on economic development is conceptualized solely in terms of the investment alternative, meaning the construction of new facilities. Forgotten are low cost improvement and zero cost policy alternatives. Consider, again, the simple model depicted in the causal diagram of Fig. 4. The policy variable associated with the investment strategy is NL for Number of Lanes, and it corresponds to increasing Highway Capacity HC through new construction. However, equally effective for increasing non-user benefits by raising the Gross Regional Product GRP (see Fig. 9) are increasing Average Vehicle Occupancy AVO through the use of high occupancy vehicle (HOV) lanes, increasing the Duration of the

FIG. 8 ANALYTICAL SOLUTION

- STEADY STATE ANALYSIS IS PERFORMED BY EQUATING THE RATES AND SUBSTITUTING IN EACH SIDE UNTIL THE EQUILIBRIUM VALUE OF THE LEVEL VARIABLE, IC_e, IS FOUND:

$$CI_e = CD_e \tag{1}$$

$$IC_e = \frac{(DPP \times LC \times NL)\left(\frac{DCRN}{FIOIN}\right)\left(1 - \frac{COR}{FGRPI \times ALC}\right)}{\frac{TPIO \times PCE}{COR \times PPPY} + \frac{TPJ \times HMS}{CLR \times AVO}} \tag{2}$$

- THE TRANSIENT IS FOUND BY SOLVING THE DIFFERENTIAL EQUATION OF THE SYSTEM:

$$dIC_t/dt = CI_t - CD_t = (IC_e - IC_t)(IC_t)(K) \text{ WHERE} \tag{3}$$

$$K = \left(\frac{FGRPI}{COR}\right)\left(\frac{FIOIN}{NL \times LC \times DCRN}\right)\left(\frac{TPIO \times PCE}{COR \times PPPY} + \frac{TPJ \times HMS}{CLR \times AVO}\right)\left(\frac{1}{DPP}\right) \tag{4}$$

$$\text{GIVING } IC_t = \frac{IC_e}{1 + \left(\frac{IC_e}{IC_o} - 1\right) e^{\left(\frac{FGRPI}{COR} - \frac{1}{ALC}\right)t}} \tag{5}$$

- THE "SOLUTION" IS OBTAINED BY EXPRESSING THE MEASURES OF EFFECTIVENESS, DCR_e AND GRP_e, IN TERMS OF POLICY VARIABLES:

$$DCR_e = \left(\frac{DCRN}{FIOIN}\right)\left(1 - \frac{COR}{FGRPI \times ALC}\right) \tag{6}$$

$$GRP_e = \frac{DCR_e}{\left(\frac{ALC \times FGRPI}{DPP \times LC \times NL}\right)\left(\frac{TPIO \times PCE}{COR \times PPPY} + \frac{TPJ \times HMS}{CLR \times AVO}\right)} \tag{7}$$

FIG. 9 POLICY SUMMARY

POLICY VARIABLE	CHANGE IN POLICY VARIABLE REQUIRED TO DECREASE DCR_e	CHANGE IN POLICY VARIABLE REQUIRED TO INCREASE GRP_e
TJP	HAS NO EFFECT	DECREASE
HMS	HAS NO EFFECT	DECREASE
PCE	HAS NO EFFECT	DECREASE
AVO	HAS NO EFFECT	INCREASE
DPP	HAS NO EFFECT	INCREASE
NL	HAS NO EFFECT	INCREASE
LC	HAS NO EFFECT	INCREASE
FGRPI	INCREASE	INCREASE
ALC	INCREASE	INCREASE
CLR	HAS NO EFFECT	INCREASE
COR	DECREASE	DECREASE
TPIO	HAS NO EFFECT	DECREASE
PPPY	HAS NO EFFECT	INCREASE
FIOIN	DECREASE	DECREASE

Peak Period DPP through the staggering of work hours, increasing Lane Capacity LC through ramp metering, decreasing Trips Per Job TPJ through telecommunications, decreasing Highway Modal Split HMS by improving mass transit, and decreasing Passenger Car Equivalents by raising truck performance. The impact of these non-investment initiatives are the same but are achieved at a fraction of the costs. The importance of Transportation Systems Management (TSM) as a substitute for transportation facility expansion through construction can not be overestimated.

TSM employs three basic strategies for affecting the supply-demand relationships: (1) making more efficient use of roadways, (2) reducing vehicle use, and (3) improving transit service. Within each there are various tactics. Changes in traffic flow which can yield substantial benefits with respect to improved level of service and increased capacity can be achieved through such traffic engineering measures as (1) traffic operations improvements, (2) traffic signalization improvements, (3) special roadway designations and (4) freeway surveillance and control. TSM actions to alter vehicle demand include: (1) priority treatment of high-occupancy vehicles (HOV), (2) work-schedule management, (3) intermodal coordination, (4) use of economic disincentives and (5) management of freight movement and operations. TSM steps for improving transit service include: (1) improved flexibility in route scheduling and dispatching, (2) express bus services, (3) shuttle services from fringe parking areas, (4) park and ride facilities, etc.

Ruling out long term, high capital solutions like building more roads and making massive investments in mass transit, interest is shifting to proven concepts like freeway surveillance and control, and promising initiatives like "Intelligent Vehicle/Highway Systems."

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