DYNAMIC METHODOLOGIES FOR ASSESSING TRANSPORT POLICY IMPACTS

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1. INTRODUCTION

Transportation policy analysis and evaluation has benefited significantly from advances in demand estimation. With the emergence of demand models which are capable of capturing the causal relationships between transportation level-of-service characteristics and travel behavior and have the potential of transferability, a more meaningful analysis of policy options has become possible. However, major assumptions underlying existing analytical techniques have left a number of areas open to new research.

Under one assumption commonly made by transportation analysts, transportation demand and supply are at equilibrium. It is further assumed, although not usually stated, that the transportation system, when perturbed, returns to its equilibrium state. The system is perceived to be static and well-behaved, so that linear extrapolation of a past state into the future is allowed. But such cases are the least interesting to policy analysis, especially since transportation systems are profoundly nonlinear.

In addition, no consideration is given to delayed feedback effects between the various transportation sectors. As a result, existing techniques cannot treat transient policy impacts. Such impacts are of particular importance to the transportation decision maker during periods in which conditions exogenous to the transportation system, having created a trend, suddenly undergo major changes and force the system away from equilibrium. A dynamic tool is needed to analyze and evaluate policy impacts during such periods.

2. BACKGROUND

Recent work by research teams in Europe and the U.S. has addressed, for the first time, the dynamics of the transport system. One approach (Deneubourg, et al, 1979) deals almost exclusively with demand to which transportation supply is assumed to adjust. The crucial problem of supply analysis and the time dependent interaction between supply and demand are not treated. But such an approach is least interesting to policy analysts, since it is exactly the short-term and long-term interactions between supply and demand that determine the effectiveness of transport policies through time. Moreover, only the analysis of such interactions could lead to derivation of optimal service policies that satisfy stated management objectives under given constraints. Owing to these limitations this approach is largely theoretical in nature.

In contrast, an earlier method developed in the U.S.--and presented here--takes into account inherent fluctuations in management responsiveness to changes in passenger demand. It develops a dynamic representation of each of the three major transportation sectors--activity, demand, and supply--and the causal interactions amongst them and the economic development and energy sectors. It takes into account automobile industry characteristics, transportation finances and energy consumption. It addresses and evaluates time-dependent policies that act individually or in combination under a wide range of exogenous conditions across time. Owing to system complexity, simulation is used throughout.

Under several contracts from the U.S. Department of Transportation (Stephanedes (1978); Stephanedes et al (1981); Stephanedes and Eagle (1982)) this method has been applied to a number of urban and rural areas with encouraging results. It has been tested and validated as an efficient policy tool in the areas of transportation supply management, energy conservation and economic development.

3. DYNAMIC METHOD

The first two versions of the dynamic method, TRANSIT1 and TRANSIT2 were developed by the author to address the impacts of transport policies on urban and rural transport system efficiency and productivity (Stephanedes (1978); Adler et al (1980)). Later, TRANSIT1E was developed for transit supply and energy analysis in metropolitan areas (Stephanedes et al (1981)). Most recently TRANSIT3 was developed by a Minnesota team to investigate economic impacts of transport improvements (Eagle et al (1982)).

A simplified structure of TRANSIT is shown in Figure 1. The dynamic method addresses two major trip purposes, work and shopping. Each is broken down into four sectors, Demand, Supply, Energy and Economics. The demand sector is divided into three subsectors according to the chosen mode of travel, i.e., transit, drive alone, and share ride. Each subsector is segmented in terms of: a) trip generation, b) transit availability, c) auto availability, d) age, and e) income. The economics sector includes the unemployment and the enterprise subsectors.

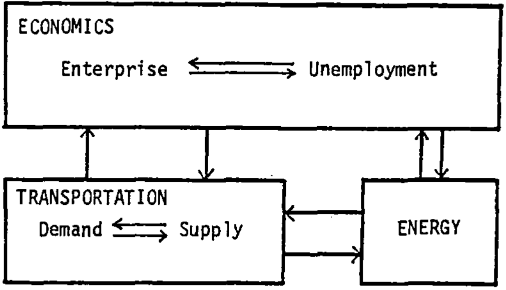

FIGURE 1. SIMPLIFIED TRANSIT STRUCTURE

At the most general level, TRANSIT may be pictured as a simple demand-supply model. Demand for transit grows if high-quality, affordable service is supplied. Service deteriorates with increasing demand, other things being equal. If energy availability and price make auto travel relatively unattractive, however, transit use increases. In turn, higher transit use improves overall national energy consumption. Improved transportation service may aid a locally depressed economy by making jobs more readily available to unemployed and attracting industry to the thus increased labor pool. Changing socioeconomic characteristics, then, contribute to modifications of the travel demand pattern.

Validated static specifications constitute the major components of each subsector. For example, disaggregate multinomial logit* is used for estimating work trip modal split and shopping trips by destination and mode in the transportation demand subsector (Adler and Ben-Akiva (1976); Stephanedes (1982); Ali et al (1982)). Variables included in the specifications are highlighted in Table 1. In the economic unemployment subsector, a Poisson

Table 1. Urban and rural work-trip modal choice model: definition of variables.

Variable Code	Definition
D_a	1 for drive alone, 0 otherwise
D_s	1 for shared ride, 0 otherwise
DPTC/HINC	Round-trip out-of-pocket travel cost (¢) ÷ household annual income (1968$)
IVTT	Round-trip in-vehicle travel time (min)
OVTT/DIST	Round-trip out-of-vehicle travel time (min) ÷ one-way distance (miles)
$AALD_a$	Number of automobiles per licensed driver for drive alone, 0 otherwise
$AALD_s$	Number of automobiles per licensed driver for shared ride, 0 otherwise
WPH_s	Number of workers in the household for shared ride, 0 otherwise
$AAPW_{a,s}$	Number of automobiles per household worker for automobile and shared ride, 0 otherwise
$RHINC_{a,s}$	Household annual income - 800 (number of persons in the household) for drive alone and shared ride (1968$), 0 otherwise
$DROWN_a$	1 for own residence and drive alone, 0 otherwise
$RESL_{t,s}$	Length of residence (years) for transit and shared ride, 0 otherwise
$DTWPWA_s$	One-way distance (miles) times workers per work area at the work zone (employees per commercial acre), for shared ride 0, otherwise

Note: a = drive alone, s = shared ride (carpool), and t = transit.

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* Properties of the logit model have been well documented (Domencich and McFadden (1975); McFadden (1973)).

model and disaggregate logit are used for job-search location estimation (Stephanedes and Eagle (1982)). Variables used in the economic specifications are summarized in Table 2.

Table 2. Job-search trip distribution model: definition of variables.

Variable Code	Definition
C	1 for searching in hometown and the nearby community 0 for searching in hometown only
ETT	Employment travel time (in hrs/mo)
EOPTC	Employment out-of-pocket travel cost (in $/mo)
EINC	Employment income (in $/mo)
ETF	Employment time fraction
EY	Employment income net of travel cost (in $/mo)
REY	Remaining employment income (in $/mo)
LY	Long-term income (in $/mo)
LTT	Long-term travel time (in hrs/mo)
LEY	Long-term employment income (in $/mo)
LETT	Long-term employment travel time (in hrs/mo)

Simulation is used to provide the link between rapidly changing traffic conditions and the remainder of TRANSIT. For example, auto travel time is estimated for varying highway characteristics via off-line use of the freeway priority entry control simulation model (FREQ6PE, Jovanis et al (1978)) which is validated and calibrated for use in the study area. Data on highway characteristics necessary for operating FREQ6PE (e.g., modal split, total number of autos, etc.) are provided by the TRANSIT demand sector.

Simulation is also employed to determine the impact of user-determined supply policies on transport system performance and area economic development. Policies of interest to system managers and area planners include transit scheduling and fare changes, initiation or shutdown of transit service between towns, and transport network modifications--such as link abandonment and road improvement.

4. APPLICATION TO ENERGY SCENARIOS

A wide range of energy policies and scenarios have been evaluated for metropolitan and less urbanized areas over a time horizon of one to five years. These include (a) vehicle efficiency improvement, (b) transit fare change, (c) transit service change, (d) gasoline availability reduction, (e) gasoline price increase, and (f) flexible work schedules.

TRANSIT simulates the effects of a typical energy scenario, such as one consisting of higher auto efficiency and transit fare incentives, by initiating changes in the energy sector during the desired i^{th} week of system operation. For example, auto efficiency improvement programs could be initiated at $i = 10$ and transit fare could decrease at $i = 40$. These changes impact the transport demand sector through the disaggregate logit specifications used to estimate equilibrium demand d^e at each i. From previous observations, it has been deduced that such demand changes occur subject to a time constant. It follows that at time $t = i^{th}$ week, transit demand d_i is

$$d_i = d_{i-1} + \Delta d_{i-1} \qquad (1)$$

where the increment Δd_{i-1} is estimated using d^e from the logit specification and a time constant T_d:

$$\Delta d_i = \frac{d_i^e - d_i}{T_d} \qquad (2)$$

$$d^e = POP \cdot P(\text{transit}) \qquad (3)$$

where POP is the total population eligible to use transit and P(transit) is taken from the logit model. The estimated equilibrium demand is, of course, a function not only of the changing energy conditions but also of other service conditions which may change through time.

The new demand value defines a new load factor and cost per passenger trip. Using the updated values, management acts according to the service subsector formulation and subject to a management decision delay T_m. To be sure, transit frequency will not change when there are not enough resources available. In that case, more capital is ordered and/or more government subsidies are applied for. Arrival of new capital P occurs subject to a j^{th}-order time delay:

$$P_i = P_{i-1} + \Delta P_{i-1} \qquad (4)$$

$$\Delta P_i = P^o_{i-j} - P_i/L \qquad (5)$$

where P_i^o is capital ordered at time = i and L, capital lifetime. In turn, capital ordered equals desired capital P^d less existing capital less capital-on-order subject to an order delay T_o:

$$P_i^o = (P_i^d - P_i - \sum_{k=1}^{j} P^o_{i-k})/T_o \qquad (6)$$

The new service produces a new equilibrium demand and the loop continues. Concurrently, demand for shared ride and driving alone is being determined through time via the same disaggregate specifications and is certainly a function of changing service.

While only the most basic TRANSIT1E internal mechanisms have been briefly described, others take care of factors such as minimum frequency allowed before a transit system closes down, minimum allowed headways, passenger arrivals at transit stop (e.g., Poisson, uniform), etc. Owing to the modular nature of TRANSIT1E, its various components can be operated individually or interactively. For example, making a work trip energy policy evaluation, a work-plus-shopping trip evaluation, a peak-time or off-peak evaluation are all possible user choices.

Two sets of scenarios, examples of this application, are presented in Figure 2. These scenarios examine the dynamic effects of varying transit fare and auto mpg in a less urbanized, low-income, slow-reacting community provided with high-quality transit service. Results indicate lowest energy consumption for the free-fare policy and the low-mpg autos. Intuitively the latter would be expected to result in higher energy consumption. In less urbanized low-income areas, however, where commuters are more dependent on their autos and may be suspicious of public transit programs (Stephanedes (1978)), energy performance is strongly influenced by auto-related conservation policies, rather than transit-related ones. Results also indicate that fuel efficient autos produce energy consumption patterns almost identical to those accompanying a high-fare transit policy; both cause increased auto travel and energy consumption.

5. APPLICATION TO ECONOMIC SCENARIOS

The basic structure of the economic sector includes the interactions of several variables between the enterprise subsector and the unemployment subsector. Job openings, wage offers, and turnover are outputs of the enterprise subsector and inputs to the unemployment subsector. Reservation wages and unemployed labor pool size are outputs of the unemployment subsector and inputs to the employment subsector (Stephanedes and Eagle (1982)).

Two are the major components of the enterprise subsector. In the job-opening-and-closing component, the enterprise subsector determines job openings and actual job turnover. In the profit-maximizing component, reservation wages and the size of the unemployed labor pool affect the net change in number of enterprises and determine wages offered.

In the unemployment subsector two major flows are examined. Workers losing their job are studied in the employed-to-unemployed flow. Unemployed finding a job are modeled in the unemployed-to-employed flow. Transportation variables such as accessibility, travel time and travel cost are inputs to this subsector and influence the job search and, therefore, the unemployed-to-employed flow and the labor pool.

The unemployed-to-employed flow UTE is a function of U, the size of the unemployment group; λ, the Poisson parameter defined as the number of job offers per jobseeker; and p, the probability of job acceptance:

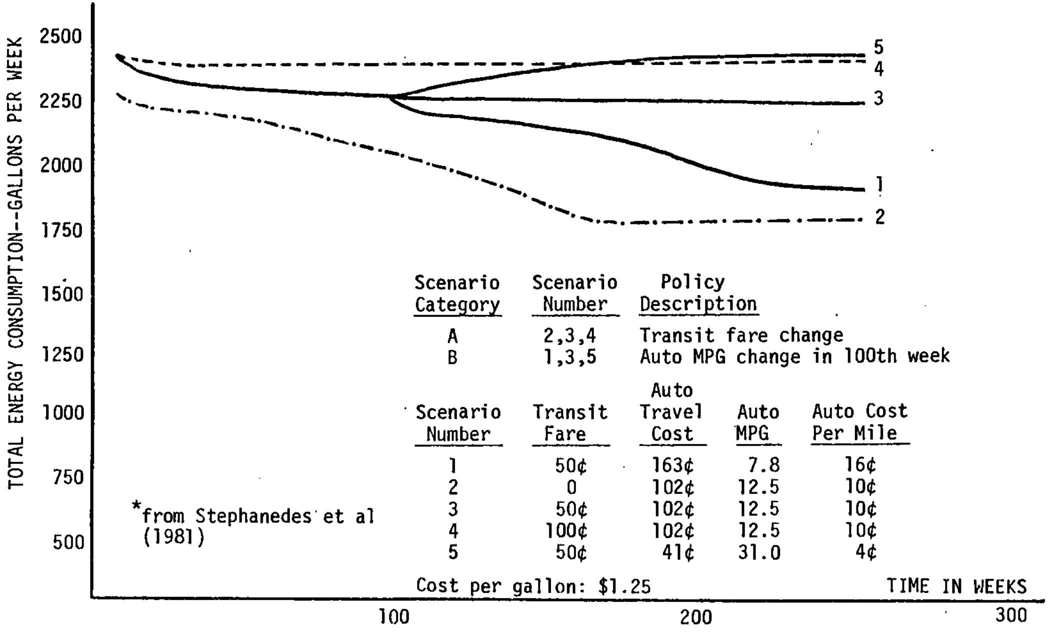
$$UTE = U * \lambda * p \qquad (7)$$

The probability of acceptance is related to the reservation wage. Let F(w) be the cumulative distribution function of wages and w^R the reservation wage, then $F(w^R)$ equals the probability that the wage offered for a job is lower than the reservation wage, i.e. the probability that the job is rejected. Thus, the probability of acceptance equals

$$p = 1 - F(w^R). \qquad (8)$$

FIGURE 2*

ENERGY CONSERVATION SCENARIOS



Scenario Category	Scenario Number	Policy Description
A	2,3,4	Transit fare change
B	1,3,5	Auto MPG change in 100th week

Scenario Number	Transit Fare	Auto Travel Cost	Auto MPG	Auto Cost Per Mile
1	50¢	163¢	7.8	16¢
2	0	102¢	12.5	10¢
3	50¢	102¢	12.5	10¢
4	100¢	102¢	12.5	10¢
5	50¢	41¢	31.0	4¢

Cost per gallon: $1.25

*from Stephanedes et al (1981)

The specific probability of acceptance of each unemployment group is determined by maximizing their present value of future wage earnings (Stephanedes and Eagle (1982)).

Phasing out government subsidy programs, and other budget and service problems occasionally force transit systems to discontinue operation. As an example, the scenario illustrated in Figure 3 considers a two-way transit system in which, after 8 years, service is discontinued for unemployed of town I looking for a job in town J. After 8 years of continuing drop in unemployment as a result of the transit service, unemployment in I suddenly rises while that of J falls even more sharply following the transit service change. This is an immediate result of the increased opportunities available to the J-unemployed. In the long term, however, the labor pool in J is reduced and firms leave the area. Unemployment in J rises sharply. Meanwhile, I's labor pool increases and attracts more firms there. As a result, unemployment in I falls below that of J and steadily decreases.

Validation tests indicate that prediction using the dynamic method is superior to conventional methods, such as the natural rate hypothesis, when accurate data on system lags are available. For example, for the city of Austin, Minnesota, the rms error ratio for employment prediction over ten years is 0.088 under the conventional method but only 0.067 under the dynamic method.

Transferability tests conducted in other U.S. cities indicate that TRANSIT has potential for transferability. In fact, the model performed better for some transferability tests than it did for the validation tests. For example, for employment prediction, the rms error ratio for the cities of DuBois and Brockway, Pennsylvania was 0.024 and 0.030 respectively over a ten-year period (Stephanedes and Eagle (1982)).

6. DISCUSSION AND CONCLUSION

A dynamic methodology, TRANSIT, was developed for evaluating transport policy impacts across time. Policies being assessed may have a wide spectrum of objectives, such as, to improve transportation system efficiency and productivity; contribute to economic development in the service area; and conserve energy and other resources.

TRANSIT is based on previously developed and validated disaggregate specifications of travel demand, and on hypotheses about travel and money budget constraints (Zahavi (1979)). In addition, it uses describing functions of service supply developed with decision-making information from transportation policy makers.

Nonlinear difference equations tie the TRANSIT sectors together and major time delays are explicitly included. While the nonlinearities are essential for capturing the major process of change, delays significantly modify transient behavior and equilibrium settling time. Delay characteristics are particularly important for policy implementation as they may enhance or hamper policy effectiveness by influencing traveler or management decisions in different ways over different periods during the policy horizon.

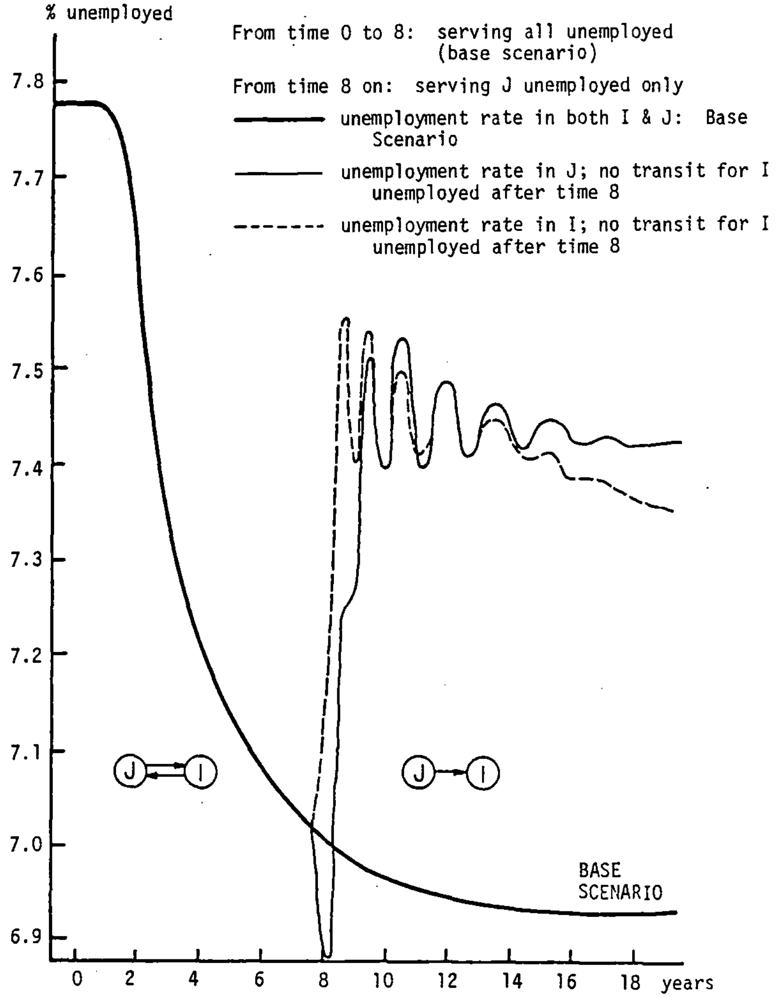


FIGURE 3*

UNEMPLOYMENT RATE AND PARTIAL DISCONTINUATION OF TRANSIT

*from Stephanedes and Eagle (1982)

It was found that impacts simple transport policies have on assessment indicators are often complex, and may be undesirable and hard to predict. For example, policies promoting transportation improvements in a service area adversely influence economic indicators in the short run, but also expand the labor pool, attract more business in the area and decrease unemployment in the long run. Time delays involved in such dynamic effects can be as long as eight to ten years. As another example, policies acting to increase the efficiency of private autos are in direct conflict to policies promoting transit service improvements. Depending on the relative values of time delays assossiated with public reaction to each, either policy may be judged effective or unsuccessful for a period of time during policy implementation.

This work is in the direction of developing low-cost, efficient computer-aided tools suitable for transportation policy evaluation for long time spans. The dynamic formulation does not require intermediate data or costly calibration, but only initial conditions to provide long- or short-term plans for transportation operations. It has been used interactively with traffic flow codes (e.g., FREQ6PE) to evaluate policies of interest to the transportation decision maker under a range of scenarios --such as energy emergency and price deregulation. It can interact with optimization algorithms which seek to achieve transportation management objectives under economic, service and network constraints by proper choice of management control actions.

The planning tool is available in DYNAMO and FORTRAN (one run costs $1.50 on a CDC Cyber 74). A PASCAL version has been successfully tested on an APPLE II microcomputer. Transportation decision makers, such as the Metropolitan Transit Commission in the Twin Cities, have estimated that the interactive package could improve the productivity of major transport management tasks--e.g., fare choice and service scheduling--by at least 100 percent.

7. ACKNOWLEDGEMENT

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