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The Role of Engineering Models in Assessing The Economic Implications of Changes in Highway Use: Interference and Congestion Costs

by A. D. St. John

INTRODUCTION

THIS PAPER is part of a series that explores the logic and the current capability to estimate and collect economically based charges for road use. The economic or efficient user charge equals the costs that would be saved were that use not to occur. The areas explored here are the costs associated with traffic delays and congestion.

TYPES OF MODELS

Two types of models employed in traffic engineering may be applicable in establishing user charges. One type quantifies traffic flow characteristics as a function of the highway geometries, the traffic controls, the traffic flow rate and the vehicle types in the traffic stream. The second type of model describes the variation, but not the trend of traffic flow over time. Both types of models are used currently by highway agencies in engineering studies, planning, and budget allocations. These applications frequently involve formal or informal economic analysis which differ from the economic applications considered here in their objectives and point of view.

CHARACTERISTICS OF TRAFFIC FLOWS AND TRAFFIC MODELS

On rural highways and on urban highways with controlled access the vehicles travel for long distances without stops for intersection signing or signals. When the traffic flow is light the vehicles travel at speeds set by legal limits, vehicle performance limitations or by the drivers' preferences as influenced by the qualities of the highway. When the traffic flow rate increases the vehicles interact and interfere more frequently with each other so that the fastest vehicles are delayed and the average speed drops. Speed continues to drop with flow increases until the maximum flow rate is reached with all vehicles traveling at about 30 miles per hour.

At high flow rates the traffic is vulnerable to a transition to a less desirable mode in which the inter-vehicle spacings are small, the speeds are less than 30 miles an hour, and speed may be unsteady. Once the congested mode is established in a highway section it may persist there until the traffic flow rate entering the section diminishes.

The traffic characteristics described above together with many others are quantified in the major traffic engineering references in use for over a decade. The contents of these references might be considered a set of semi-empirical models that are employed to obtain useful estimates. Some of the component models had conceptual bases; others consisted entirely of field observations assembled with statistics or engineering judgement. In many cases engineering judgement was used to bridge gaps in the models or in the data.

During the years since the major references were published, numerous projects have been sponsored by state and federal agencies to improve and update the traffic engineering capabilities. The projects have had specified goals to fill gaps in data bases, to correct known weaknesses in existing procedures, and to provide results in convenient forms for application. In these contracts additional field data have been collected and analyzed and additional traffic flow models have been developed and applied. The newly developed models tend to be more analytical in concept and form than those developed earlier. This trend has been augmented by the availability of computers with high capacity and high computational speed. Computer capabilities have made feasible the traffic simulation models that trace through time the progress of individual vehicles, groups of vehicles, or the traffic stream as an entity.

The character and applications of traffic models can be classified in a number of ways as shown in Table 1. Despite the variety, the models are similar in that they are used to estimate the capacity and service to road users as functions of geometries, traffic regulations, traffic controls, traffic flows and the characteristics of the vehicles.

TABLE 1

CLASSIFICATION OF TRAFFIC FLOW MODELS

By Entities Treated
- Individual Vehicles
- Groups of Vehicles
- Traffic Stream
- Traffic Parameters

By Environment
- Rural
- Urban

By Facility Types
- Surface Street or Highway At-grade Intersection
- Signalized Arterial
- Arterial Network
- Street Network
- Two-lane Highways
- Freeways
- Freeway Interchanges
- Freeway Access Ramps and Lanes
- Freeways and Interchanges
- Freeways with Bottlenecks (Tunnels or Bridges)
- Corridors (Freeways, Surface Streets and Connections)

By Application
- Estimate Service (Relation to Geometries, Flow Rates, Vehicle Types)
- Determine, Test, and Implement Optimized Traffic Controls
- Evaluate Novel Traffic Control Concepts
- Evaluate the Influence of Regulations
- Test the Methods for Detecting Freeway Incidents
- Test the strategies for alleviating the consequences of Freeway Incidents
- Evaluate and Implement Traffic Diversion strategies

TRAFFIC MODELS IN RECENT AND CURRENT ECONOMIC ANALYSIS

Economic analysis in the recent past often dealt with questions of new facilities or major reconstruction of existing facilities. Twenty year periods of analysis are used to support decisions that involve large capital investments. Currently, emphasis is placed on obtaining maximum benefits from existing facilities. Capital requirements remain large for projects that require equipment for traffic sensing, communications, control and computers. The current economic analysis takes a highly inclusive viewpoint. The road user and society in general receives the benefits while society provides the capital and operating funds through the responsible agencies.

The traffic models are useful in current engineering and economic studies. Despite this utility the traffic models might be challenged as insufficiently accurate in a controversial area such as pricing.

LIMITATIONS OF TRAFFIC FLOW MODELS

All of the traffic models in use have been adjusted and tested using data collected in the field. However, even data collected on a single facility will frequently exhibit variance that cannot be explained by observed features of the facility or of the vehicles. With neither correlation or causation available it is not possible to make the models duplicate exactly all observed features of the traffic. As would be expected, the traffic on several similar facilities exhibits additional variance that cannot be correlated with facility or vehicle characteristics. Thus the application of a well adjusted and tested model to a large number of apparently similar facilities will provide generally useful results, but not explain all observable variations on single facilities nor the differences between generally similar facilities. The models could be challenged as incomplete or imprecise.

For the most accurate representation it is frequently necessary to set variables in the model to correspond with facility data. As an example the input to the model may include the speeds that drivers choose to travel when not impeded by other traffic. These free-moving speeds are known to be influenced by properties of the facility such as the geometries and speed limit. However, there are unexplained variations between the free-moving speeds observed on similar facilities. If typical free-moving speeds are used for a class of facilities the model results might be challenged as employing inaccurate input data. The practical problems of making speed measurements in the field and associated model runs for each facility are obvious. For planned facilities only the estimates of free-moving speeds would be available.

TIME VARIATIONS IN TRAFFIC FLOWS

There are distinctive patterns in traffic flow rates. Probably the most familiar pattern is the twice daily rush hour peaks in and near urban areas. The trips are predominantly home to work and return. Rural highways flow rates exhibit peaks that are less pronounced. In an urban area the Friday evening rush hour peak may be increased by trips departing for recreation or visiting. The Sunday evening flow rates are swelled by trips returning to home from recreation or visits that may have encompassed a few hours, all day, or overnight stays.

There are annual patterns of traffic flow rates due to tourism, and seasonal aspects of farming and industry.

The patterns of traffic flow rates on streets and highways have been estimated from collected data. The patterns, which may be considered models, are included in the major references for traffic engineering. In addition the individual states may collect data to obtain estimates for the annual cycles in their traffic flows.

The models describing variations of traffic flow over time might be challenged as insufficiently accurate predictors/descriptors of flow rates on specified links of the highway and street network. Repeated measurements on a facility indicate flow variations that are due in part to the chance nature or irregular schedules of trips. Thus at the best a model could not be expected to predict the exact flow rate during an hour on any highway or street system link. If a flow rate model is applied to a set of similar highway or street links the averaging will introduce additional errors in the application to individual links.

The estimation of traffic flow rates is most difficult on facilities with predominantly recreational trips which are for the most part taken at irregular intervals. They are influenced by season, by economic conditions, and by the current and anticipated weather conditions.

The variation of traffic flows over time on a facility has two impacts related to user charges. They are:

(1) The service provided to users, and
(2) The need for capital outlays to provide additional facilities.

These impacts are described in the next section.

TRAFFIC MODELS AS A BASIS FOR ASSIGNMENT OF USER CHARGERS

We restrict attention to charges for the service provided by the highway and not for the use of part of the life of the physical plant itself. The general characteristics of traffic indicate that the connections between service and charges may be somewhat paradoxical.

Models relating traffic flows and traffic characteristics can estimate the service provided by a facility to specific vehicle types such as passenger cars, light trucks and recreational vehicles. The service provided to a user depends not only on the facility but also on the concurrent demand for service by other users, i.e., the traffic volume.

In general, the addition of a user or group of users to an existing flow will diminish the service provided to all. During a period of high demand (volume) all users on a facility will receive depressed service with longer travel times, more driver effort, possibly greater exposure to accidents, and altered fuel consumption. It has been the practice of responsible agencies to identify facilities that provided (or were projected to provide) greatly depressed service during a large number of hours in a year. These facilities became candidates for remedial treatments or construction. Note however, that the peak period user of an overburdened facility is already paying in terms of delay, driving effort, etc. If a charge were to be based on the quality of service provided the off-peak user would pay the largest fee; the peak period user would pay the smallest fee.

The logical basis for a fee is reversed when considering capital outlay as opposed to service provided. It is the user during the peak period who strains the capacity of existing facilities and necessitates consideration of investment to add to the facilities, to upgrade them, or to control them in a more favorable manner.

Finally, added increments of traffic volume on a facility decrease the service provided to all concurrent users. And, volume increments added during peak periods increase the pressure for additional capital outlays. With either effect there appears to be no way to distinguish the "added increments" of traffic from the total.

SUMMARY

Traffic models are capable of estimating the service and capacity on a variety of facilities. These estimates have been and continue to be useful for engineering, planning, and agency budget allotment functions. However, the models are at best not exact, and additional sources of error are introduced when applications are made for classes of highways and streets. Sensitivity analysis will be required to determine if the current models are adequate for application in setting user charges.

Traffic engineering relationships contain at least two aspects imparting user charges. The first is the service supplied to a user; the second is the pressure which the user imposes for additional capital outlays. Both aspects depend on the facility and on the time of use.