Demand-Supply Modeling for Transportation System Management

ADOLF D. MAY

A review is given of the development and application of a family of operational planning models that are used to predict impacts and traveler responses resulting from traffic management strategies in freeway corridors, arterial networks, dense networks, and rural highways. An overview of the long-term research program and the identification of current research efforts are also included. One of the major goals of the research program is to propose policy guidelines for implementing traffic management strategies. Initial policy guidelines for freeway priority lanes, freeway-entrance control, arterial priority lanes, arterial-signal control, dense networks, and rural highways are included. The following conclusions are drawn: (a) increased attention should be given to controlling the demand side of operational problems by spreading demand over space, time, and mode and by reducing the total demand level; (b) increased attention should be given to assessing energy and environmental impacts of improvement alternatives as well as to continuing the assessment of safety and levels of service; (c) creative techniques need to be devised to generate and screen traffic management strategies prior to analytical evaluation; and (d) greater use of operational planning models by facility operators is essential if our existing transportation system is to be managed effectively.

Operational problems are encountered in the existing transportation system, and inefficient use results when traffic demands exceed traffic capacities. The byproducts of such operational situations are increased travel time, less-reliable service, higher accident rates, greater fuel consumption, and increased vehicle emissions. Historically in the United States, the normal approach to a solution was to increase capacity when such operational problems were encountered. Such actions were generally very expensive, often disrupted the environment, and encouraged further growth in the traffic demand.

Transportation system management (TSM) proposes that greater attention be given to controlling the demand side of the equation by spreading demand over space, time, and mode and/or reducing the total demand level. It is implied that such actions may be accomplished through low-cost improvements, may improve the environment, may conserve energy, and tend to curtail further growth in traffic demand.

Demand-supply computerized models have been developed and applied for impact assessment and traveler responses to traffic management strategies along freeway corridors, arterial networks, dense networks, and rural highways. The traffic management strategies included priority lanes, ramp metering, priority entry, signal optimization, bus priority signals, redesign improvements, parking restrictions, speed-limit control, traffic-resistant measures, and other related actions.

Impact assessment included traveler impacts (travel time, fuel, emissions, noise, and safety), fleet costs, and facility costs. Traveler responses included spatial, temporal, modal, and total demand-level responses as well as public acceptability. The computerized models provide a time series of impact and traveler-response evaluations. This paper will highlight the development and application of these analytical models for freeway corridors, arterial networks, dense networks, and rural highways. It is based on earlier work (1).

OVERALL RESEARCH DIRECTION

The overall research direction for the development of a system of operational planning models for evaluating TSM projects is shown in Figure 1. As shown, the overall research direction consists of four activities that integrate operational and planning techniques: demand-supply modeling, strategy selection, impact assessment, and traveler responses. These four activities and their interactions will now be described.

The research plan calls for the development of a set of demand-supply models for four operating environments--freeway corridors, arterial networks, dense networks, and rural highways. Such models are now operational, but research continues in attempting to improve and extend them. The input to each model consists of supply-related design features, origin and destination (O-D) demand patterns, and the initial control state. The simulation submodel predicts impacts for the existing state, that is, the day before the traffic management strategy will be implemented. The optimization submodel searches for an improved or optimum strategy and then calls the simulation submodel, which predicts impacts for the improved or optimum state, that is, the day after the traffic management strategy has been implemented.

Differential impacts are assessed to evaluate the first day of operation and to provide input data for the forecasting of traveler responses. The impacts assessed include user impacts (travel time, fuel, emissions, noise, and safety) and system impacts (facility and fleet costs).

Travelers may respond to impact changes. For example, individual travelers may change their routing (spatial response), their mode of travel (modal response), and/or their time of travel (temporal response). Strategies implemented further may affect the total demand level over a longer period of time by eliminating nonessential trips, modifying O-D pairs, changing employment and/or residential locations, modifying normal demand growth, etc. Finally, strategy implementation may not be publicly acceptable and such schemes may be terminated.

If traveler response changes the traffic demand, model input demands are modified and the simulation submodel predicts longer-term impacts. These activities are interactive in such a way that a time stream of states can be predicted (impacts and traveler responses) that starts the day before implementation and continues for several points in time for a period of two to five years.

FREEWAY CORRIDORS

Demand-supply modeling efforts for freeway-corridor operating environments were initiated at Berkeley in 1968 when a California Department of Transportation (Caltrans) research project required the evaluation of alternatives for improving 140 miles of the existing San Francisco Bay Area Freeway System. The system was too extensive and the alternative improvements were too numerous for manual analysis to be considered. This first model, called FREQ (2) (now referred to as FREQ1), was developed; it was the forerunner of the system of models displayed in Figure 2. The three freeway-corridor models (FREQ6PL, FREQ6PE, and FREQ6T) that have been most extensively developed and are currently operational will each be described briefly. Before this is

Figure 1. Overall research direction.

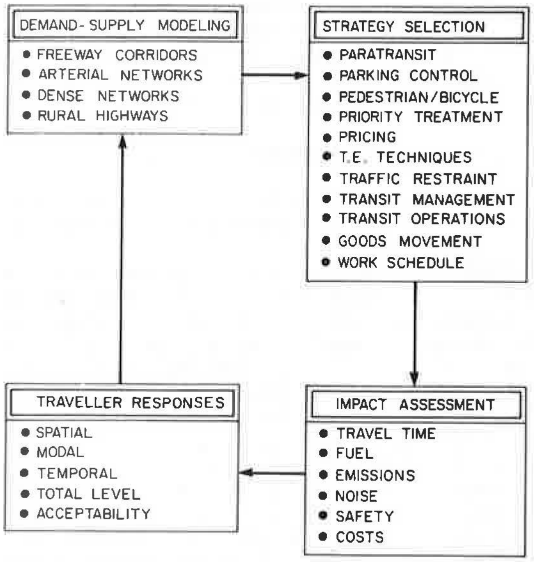
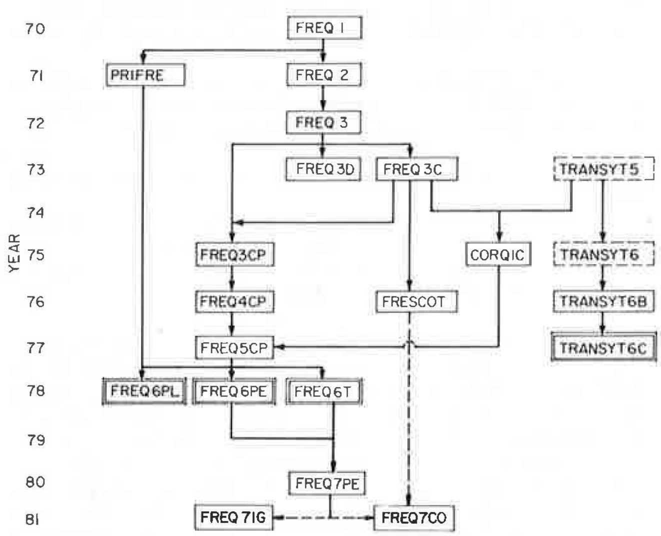


Figure 2. Freeway corridor and arterial network models.



done, some highlights of this systematic model development will be discussed.

The FREQ2 and FREQ3 models were extensions and refinements of the earlier model in which particular attention was directed to shock-wave analysis, computer efficiency, and output format (3,4). The PRIFRE model was developed for the evaluation of priority lanes on freeways (5).

By the early 1970s, the need for decision models (those that incorporated simulation and optimization submodels) was recognized. Three models in this family (FREQ3CP, FREQ3D, and FREQ3C) were developed and incorporated priority-entry control, design improvement, and normal entry-control optimization submodels, respectively (6-8). An on-line version of the FREQ3C model was developed and designated the FRESCOT model (9). One of the significant results of this work was the development of a technique for generating synthetic O-D tables from on-ramp and off-ramp counts. As the modeling effort continued, attention was given to the surrounding street system, (CORQ1C) (10), impact assessment (FREQ4CP) (11), and traveler-demand responses (FREQ5CP) (12).

FREQ6PL Model

FREQ6PL (13) is a macroscopic model of a freeway corridor and is used primarily for the evaluation of reserving a lane or lanes on freeways for carpools and/or buses. The model can also be used for evaluating design improvements with or without priority-lane operations. It incorporates many features from the earlier-developed PRIFRE and FREQ5CP. The user selects the priority lane or lanes, design configuration, priority-cutoff level, and time duration of priority operations. Then the model automatically modifies the demand and supply sides and predicts a time stream of impacts and traveler responses.

The impact assessment includes travel time, fuel, emissions, and facility costs, and the model combines these impacts into one performance index. The demand forecasting includes spatial and modal traveler responses in increments during the first year of operation. The model has been applied to the Santa Monica Freeway in Los Angeles and, through sensitivity analysis, initial policy guidelines have been proposed.

Highlights of these initial policy guidelines are listed below [before implementation, the report by Cilliers, May, and Cooper (13) should be consulted for a description of the study and limitation of research].

1. A with-flow median lane used exclusively by priority vehicles on a congested freeway is expected to compare unfavorably with the previous situation in both the short-term and the long-term situations that follow, considering total travel time, fuel consumption, and vehicle emissions;
2. A with-flow median lane used exclusively by priority vehicles on an uncongested freeway is expected to perform equally well or slightly worse than in the previous situation in both the short-term and the long-term situations that follow, considering total travel time, fuel consumption, and vehicle emissions; and
3. There may be some operating environments significantly different from the Santa Monica Freeway environment in terms of occupancy distribution, level of bus service, mode-shift propensity, and parallel arterials (if a with-flow median lane used exclusively by priority vehicles is being considered in such an environment, it is recommended that an in-depth analysis be undertaken before it is decided to implement it).

The FREQ6PL model is written in FORTRAN IV, currently operational on Control Data Corporation (CDC) and International Business Machines (IBM) computer systems, and the program and user's guide are available for distribution from the Institute of Transportation Studies, University of California at Berkeley.

FREQ6PE Model

FREQ6PE (14) is a macroscopic decision model of a freeway corridor and is used primarily for the evaluation of priority-entry and normal-entry control on a directional freeway. The model can also be used for evaluating design improvements with or without freeway-entry control. The user selects the type of entry control combined with any desired design analysis and the objective function and operational constraints, and the model selects the ramp-control plan through a linear programming optimization process. The model predicts a time stream of impacts and traveler responses due to the intersection between ramp-control strategy and traveler responses.

The impact assessment includes travel time, fuel, emissions, and noise, whereas the demand forecasting includes spatial and modal traveler responses in increments during the first year of operation. The model has been applied extensively to the Eastshore Freeway in the San Francisco Bay Area and to the Santa Monica Freeway in Los Angeles, and initial policy guidelines have been proposed as a result of sensitivity analysis.

Highlights of these initial policy guidelines are listed below [before implementation, the report by Jovanis, May, and Yip (14) should be consulted for a description of the study and limitation of research]:

1. Normal-entry freeway control on a previously congested freeway is expected to result in (a) reduced passenger hours of travel, carbon monoxide emissions, and hydrocarbon emissions; (b) little effect on fuel consumption and noise emissions; and (c) increased nitrogen oxide emissions;
2. Priority-entry freeway control on a previously congested freeway is expected to result in slightly improved impacts as compared with normal-entry freeway control; the degree of improvement depends on passenger occupancy distribution and level of service;
3. Extensive freeway congestion and the availability of underutilized alternate routes were positive factors in assessing levels of freeway-corridor improvements; if entry control is being considered in environments where such conditions do not exist, it is recommended that an in-depth analysis be undertaken before a decision is made to implement it.

The FREQ6PE model is written in FORTRAN IV, currently operational on CDC and IBM computer systems, and the program and user's manual are available for distribution from the Institute of Transportation Studies.

FREQ6T Model

FREQ6T (14) is a simulation model of a directional freeway used primarily for the evaluation of temporal traveler-demand responses that result from on-freeway and off-freeway strategies. The model can also be used for evaluating design improvements and longer-term traveler-demand responses.

The research effort for off-freeway strategy investigations was primarily directed toward the evaluation of the influence of flex-time work scheduling on freeway-corridor operations. A series of working papers (15-18) and a final report (19) were prepared. Highlights of these initial policy guidelines are listed below [before implementation, the working papers just mentioned (15-18) should be consulted for the description of the study and limitation of the research]:

1. In situations where intense congestion is encountered for an extended time, congestion improvement or degradation is possible; detailed site-specific studies with the model are recommended;
2. In situations where congestion is encountered for a brief time, there is a strong likelihood of travel-time savings;
3. In situations where little or no congestion is encountered, only a slight traffic impact is expected; congestion may be shifted to earlier time periods.

The research effort for on-freeway strategy investigations was primarily directed toward temporal demand responses due to freeway-entry control. A working paper (20) and a final report (21) have been prepared. The new model, FREQ7PE (19), which incorporated many features from the FREQ6T and FREQ6PE models (14), was developed and applied in this study. A description of current research on the FREQ7PE model is included in the next section.

Current Freeway-Corridor Research

Four freeway-corridor research activities are currently under way. A brief description of each is given below.

The FREQ7PE model (19) is now being used in a research mode, but before being distributed as an operational-planning tool, the model will be thoroughly tested and applied to a wide variety of freeway-corridor environments. FREQ7PE is a revised and extended version of FREQ6PE. The model structure has been reorganized for improved efficiency and flexibility. Many new operations are available to increase the program's power and usefulness in practical traffic-engineering problems. Improvements to simulation include input and output flexibility, fuel and emissions options, and mainline-delay calculations. Improvements to optimization include user-supplied metering plans, queue-length limits, congestion optimization, and overcontrol protection. Improvements to traveler response include temporal response and user-sequenced and/or simultaneous spatial, modal, and temporal response options.

Current research is under way on the subject of on-line traffic-responsive freeway-entry control. The major research objectives are as follows:

1. The modification of a large-scale freeway model,
2. The evaluation of existing and proposed control strategies by using the freeway model, and
3. The evaluation of selected control strategies by their implementation in the field.

Current research is also under way that is concerned with deriving O-D information from routinely collected traffic counts. The first working paper (22) contained a review of current research and applications. Current efforts are being directed along three lines: development of a single-path network model and a multipath network model and data-base acquisition for evaluating models. The freeway-corridor model requires freeway O-D data and it is anticipated that the developed single-path network model will have direct application.

Exploration continues with regard to an interactive-computer-graphics version of the freeway-corridor model. Such a model (FREGRAF) has been developed by the University of Washington (23) and there are plans to expand it. This scheme will permit the user to interact with the intermediate computer results and give direction for further analysis.

ARTERIAL NETWORKS

Demand-supply modeling efforts for arterial corridors and networks were initiated in 1973 when a very extensive freeway-corridor model (CORQ1C) (10) was being developed. The intent was to integrate the previously developed FREQ3C model (8) with a new arterial-network model and to develop the coordination routines for freeway-arterial interactions. Fortunately, a literature review revealed the existence of the TRANSYT model, which was compatible with the concept of the freeway-corridor model and performed the same tasks for arterials that the FREQ series was performing for freeways. The TRANSYT5

(24) and TRANSYT6 (25) models were extended (Figure 2). THe TRANSYT6B (26) model was an extension of the TRANSYT6 model that had impact assessments added. The TRANSYT6C (27) model is an extension of the TRANSYT6B model and not only includes impact assessments but a comprehensive performance-index objective function and traveler-demand responses.

TRANSYT6C Model

TRANSYT6C (27) is a macroscopic decision model of an arterial corridor or arterial network used primarily for the evaluation of traffic-signal settings. The model can also be used for evaluating design improvements combined with the search for improved traffic-signal settings. Further, the model can be used to evaluate priority lanes. A branch-and-bound optimization technique is employed that searches for an improved traffic-signal setting by means of minimizing a performance index. The model predicts a time stream of impacts and traveler responses due to the interaction between signal settings (with or without priority treatment) and traveler responses.

The impact assessment includes travel time, fuel, and emissions, and these impacts are combined into one performance index that includes nine terms; the user can select coefficients or weights for each term. The demand forecasting includes spatial and modal traveler responses. The model has been applied to the Wilshire Boulevard corridor in Los Angeles and the San Pablo Avenue corridor in the San Francisco Bay Area. From these applications and sensitivity analyses, some initial policy guidelines have been proposed (27).

Highlights of these initial policy guidelines are listed below [before implementation, the report by Jovanis and May (27) should be consulted for description of the study and limitations of research]:

1. Signal timing optimized to minimize vehicle delay is expected to result in reduction in delay, fuel consumption, and vehicle emissions; only marginal benefit to buses; and improved arterial productivity.
2. Signal timing optimized to minimize passenger delay is expected to result in moderate reduction in delay, fuel consumption, and vehicle emissions; moderate savings in bus time and bus fuel consumption; and improved arterial productivity.
3. Exclusive bus lanes that have shared stop lines are expected to result in negative short-term impacts; savings in bus time and bus fuel consumption; possible slight mode shift to buses; return to their existing conditions of time spent and environmental impacts in the long term; and little improved arterial productivity.
4. Operating environments significantly different from those studied in terms of level of bus service, degree of saturation, and availability of alternate routes may be encountered; in such cases, it is recommended that an in-depth analysis be undertaken before it is decided to implement such strategies.

The TRANSYT6C model is written in FORTRAN IV, currently operational on CDC and IBM computer systems, and the program and user's guide are available for distribution from the Institute of Transportation Studies.

Current Arterial-Network Research

No sponsored research is currently under way on arterial-network modeling. Efforts continue to extend and refine the initially developed policy guidelines (28). Extensive sensitivity analysis is currently under way to investigate the effect of route characteristics, traffic-flow levels, cycle lengths, and objective functions on various measures of effectiveness.

DENSE NETWORKS

Demand-supply modeling efforts for dense networks were initiated in 1978. Dense networks are distinguishable from arterial networks in three ways: smaller spacing between parallel routes, stronger traffic-resistant actions, and greater concern for environmental impacts. Residential areas, central business districts (CBDs), shopping centers, and sports centers exemplify the dense networks being considered.

The four major tasks were to prepare a state-of-the-art report of existing experience and models, to evaluate and select the most appropriate existing dense-network model or models, to apply them to a residential area and a CBD to assess TSM-type strategies, and to refine and reapply the model in order to work toward initial guidelines for traffic management policy.

A state-of-the-art working paper (29) of existing experience and demand-supply models for traffic management in dense urban networks was prepared. Attention was directed toward identification of problems encountered in dense networks, various types of traffic management strategies implemented, measures of effectiveness considered, foreign and U.S. case studies, and availability of existing demand-supply models.

It was found that existing models fell into five major categories: planning, optimization, equilibrium, simulation, and operational models. More than 30 models were identified within these categories. A general evaluation of model categories was accomplished and this indicated that the category of operational models best met the evaluation criteria established for the purpose of this project. The six operational models (Figure 3) were studied in greater detail, authors were contacted for further information, and copies of computer programs were obtained when possible. Finally, two models [micro-assignment (30) and CONTRAM (31)] were selected for initial application on this project.

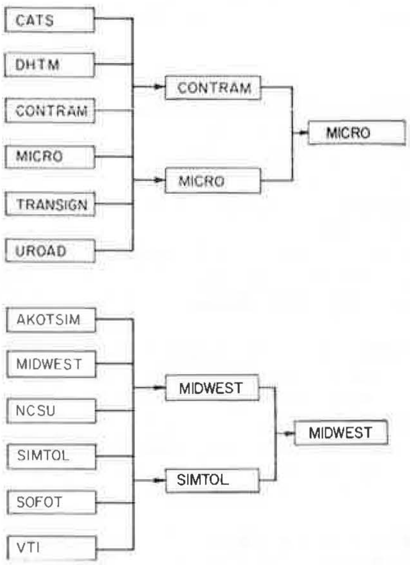
City officials in California were contacted to determine their interest in cooperating, to locate appropriate residential and CBD sites, and to assess available traffic demand and supply data. The major constraint in selecting sites was the availability of adequate traffic demand and supply data, particularly O-D data. Agreements were reached with the cities of Palo Alto and San Jose; the selected residential site was in Palo Alto, and the selected CBD site was in San Jose. The selection of the two models for initial application and the selection of study sites are described in the second working paper (32).

The micro-assignment and CONTRAM models were made operational and applied to the Palo Alto study site. The micro-assignment model was selected as the one to be used in the final phases of this project. This work is described in the third working paper (33).

Micro-Assignment Model

In the final phase of the project, the micro-assignment model was refined to include fuel consumption as a measure of performance and to provide a clearer output and a more-flexible process of input. The refined model was then applied to the residential and CBD study sites and several TSM control plans were evaluated and preliminary guidelines pre-

Figure 3. Dense network and rural highway models.



sented. This phase of the project as well as earlier phases are described in the two-volume final report (34,35).

Highlights of these initial policy guidelines for residential dense networks are listed below [before implementation, the final report (34,35) should be consulted for the description of the study and limitation of research]:

1. Providing a good environment for residents while maintaining reasonable neighborhood accessibility and through-traffic mobility are proposed as specific goals.
2. Reduced traffic on neighborhood streets, residential connectivity, and travel time on adjacent arterials are proposed as measures of effectiveness.
3. TSM strategies to be considered within the residential dense network include pedestrian/bicycle treatment, traffic-restraint measures, and intersection geometries; TSM strategies to be considered on adjacent arterials include parking control, bus routing and stops, truck routing and loading and unloading zones, and traditional traffic-engineering techniques.
4. Involvement of citizens, providers of neighborhood services, and bus and truck management are essential for successful implementation.

Current Dense-Network Research

One of the major obstacles to dense-network analysis is the required O-D data for input. As mentioned in the discussion of freeway corridors, current research is under way that is concerned with deriving O-D information from routinely collected traffic counts. The multipath-network-model development portion of the project will be applicable to dense networks (22).

It is anticipated that work in the dense-network operating environment will continue. Emphasis will most likely be directed to further model refinement, development of an interactive version, screening techniques for selecting strategies for evaluation, application of the model to other dense networks, experimentation with synthetic O-D input, and improving traffic-management guidelines.

RURAL HIGHWAYS

Demand-supply modeling efforts for two-lane, two-way rural highways were initiated in 1975. Primary attention was given to capacity and levels of service under the condition of trucks and grades. This led to the development of the SIMTOL model, which will be described below.

In 1978, Caltrans became interested in sponsoring research on the development of a decision-making framework for the evaluation of climbing lanes. This research activity led to the refinement of the MIDWEST model and the formulation of climbing-lane guidelines. This work will be described later.

SIMTOL Model

SIMTOL (36) is a microscopic simulation for two-lane, two-way rural highways. The model is primarily intended to predict the traffic performance as a function of facility design (design speed and vertical alignment) and traffic loads (quantity and composition). Special attention is given to the performance of trucks on grades and to driver behavior (following cars and passing maneuvers). Only travel-time impacts are assessed, and no demand forecasting is undertaken. The model has been applied to several situations in California. Some sensitivity analysis has been undertaken to predict levels of service and capacities.

MIDWEST Model

In 1978, work began on this development of a decision-making framework for the evaluation of climbing lanes (37-39). The four major tasks were to prepare a state-of-the-art report of existing experience and models, to evaluate and select the most appropriate existing model for this project, to modify the model as required and perform field validations, and through model application and sensitivity analysis to develop policy guidelines for climbing lanes.

A state-of-the-art working paper of existing experience and models was prepared (38). Attention was directed to two-lane rural highway research studies, availability of existing two-lane highway models, and vehicle-driver performance. Six candidate models were identified and included (Figure 3): (a) Akonteh's model from Stanford University (AKOTSIM), (b) St. John's model from Midwest Research Institute (MIDWEST), (c) Heimbach's model from North Carolina State University (NCSU), (d) Stock's model from the University of California (SIMTOL), (e) Kaesehagen's model from Australia (SOFOT), and (f) Gynnerstedt's model from Sweden (VTI). Authors were contacted for further information and computer programs were obtained when possible. The characteristics of the six models were evaluated by using a 19-point list of criteria, and the MIDWEST model was selected for the purposes of this project (39,40).

The MIDWEST model had several deficiencies for use on this project and required some modifications. These included adding a climbing-lane option, adding additional measures of effectiveness such as safety and operating costs, and improving input/output features. The next step was validation of the modified model with particular emphasis on the climbing-lane option. Field studies were conducted in northern California, and the model was refined to represent actual traffic conditions.

In early 1980 the modified MIDWEST model was employed to develop cost-effectiveness curves for a wide variety of traffic (volume and composition) and climbing-lane (percentage of grade, length of grade, length of climbing lane, and position of climbing lane) situations. By using the extensive set of cost-effectiveness curves, initial policy guidelines were formulated with regard to climbing lanes on grades and a final report was prepared (41).

Highlights of these initial policy guidelines are listed below [before implementation, the paper by Botha (41) should be consulted for a description of the study and limitation of research]:

1. The optimum location for construction of a climbing lane is at the midpoint of the upgrade (symmetrical).

2. The optimum length of a climbing lane is 1500 ft; shorter climbing lanes were not considered, since safety implications may restrict the use of shorter climbing lanes.

3. It is more efficient to construct one 1500-ft climbing lane on several upgrades than to have more than one 1500-ft climbing lane on one upgrade.

4. The benefit (travel time) that can be obtained from the construction of a climbing lane is most sensitive to the gradient.

Current Rural Highway Research

A new project, "Further Investigation of Traffic Operations on Two-Lane Two-Way Rural Highways," is currently under way. The two parallel efforts on this project are the further refinement and enhancement of the modified MIDWEST model and the development of a macroscopic-modeling approach for the evaluation of the performance of design elements of a highway.

ACKNOWLEDGMENT

This work resulted from the efforts of many individuals and the support of several organizations. The California Department of Transportation, the Federal Highway Administration, the Office of University Research of the U.S. Department of Transportation, and the National Science Foundation not only provided a large portion of the financial budget but gave excellent guidance and advice on a continuous basis. The Transport and Road Research Laboratory provided copies of TRANSYT5, TRANSYT6, and CONTRAM models and provided advice during periods of model refinement and application. This activity received the continual support of the Institute of Transportation Studies, and many Institute staff members are due a special word of thanks.

Finally, I would like to acknowledge the many individuals who directly participated in the development of these operational planning models. This effort would not have been possible without their enthusiastic involvement. It was a pleasure working with this fine group of researchers.

REFERENCES

1. A.D. May. Impact Assessment and Traveller Responses to Traffic Management Strategies. Institute of Transportation Studies, Univ. of California, Berkeley, Rept. UCB-ITS-RR-79-10, June 1979, 26 pp.
2. Y. Makigami, L. Woodie, and A.D. May. Bay Area Freeway Operations Study--Final Report, Part I: The Freeway Model. Institute of Transportation and Traffic Engineering, Univ. of California, Berkeley, Aug. 1970.
3. R.C. Blankenhorn and A.D. May. Freeway Operations Study--Phase III: FREQ2, A Revision of the "FREEQ" Freeway Model. Institute of Transportation and Traffic Engineering, Univ. of California, Berkeley, Interim Rept. 4-1, June 1972.
4. W.A. Stock, R.C. Blankenhorn, and A.D. May. Freeway Operations Study--Part III: The FREQ3 Freeway Model. Univ. of California, Berkeley, Rept. 73-1, June 1973.
5. R.D. Minister, L.P. Lew, K. Ovaici, and A.D. May. Computer Simulation Model for Evaluating Priority Operations on Freeways. HRB, Highway Research Record 461, 1973, pp. 35-44.
6. K. Ovaici, A.D. May, R.F. Teal, and J.K. Ray. Simulation of Freeway Priorities Strategies (FREQ3CP)--Final Report. Federal Highway Administration, U.S. Department of Transportation, June 1975, 471 pp.
7. M. Eldor and A.D. May. Freeway Operations Study--Phase III: Cost-Effectiveness Evaluation of Freeway Design Alternatives. Univ. of California, Berkeley, Institute of Transportation and Traffic Engineering, Rept. 73-1, June 1973.
8. J.J. Wang and A.D. May. Computer Model for Optimal Freeway On-Ramp Control. HRB, Highway Research Record 469, 1974, pp. 16-25.
9. M. Eldor and A.D. May. Integrated Freeway On-Ramp Control Strategies Under Normal and Incident Conditions. U.S. Department of Transportation, Interim Rept., March 1975, 100 pp.
10. M. Orthlieb and A.D. May. Freeway Operations Study--Phase IV: Freeway Corridor Control Strategies. Institute of Transportation and Traffic Engineering, Univ. of California, Berkeley, Rept. 74-5, Aug. 1975.
11. A.J. Kruger and A.D. May. The Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Freeways. U.S. Department of Transportation, Oct. 1976, 116 pp.
12. A.J. Kruger and A.D. May. Further Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Freeways. U.S. Department of Transportation, Oct. 1977, 47 pp.
13. M.P. Cilliers, A.D. May, and R. Cooper. Development and Application of a Freeway Priority-Lane Model. California Department of Transportation, Sacramento, Final Rept., Sept. 1978, 516 pp.
14. P.P. Jovanis, A.D. May, and W. Yip. FREQ6PE--A Freeway Priority Entry Control Simulation Model. California Department of Transportation, Sacramento, Final Rept., Sept. 1978, 516 pp.
15. P.P. Jovanis and A.D. May. Flex-Time Travel Choice: A Literature Review and Framework for Analysis. Institute of Transportation Studies, Univ. of California, Berkeley, Rept. UCB-ITS-WP-79-1, Jan. 1979, 56 pp.
16. P.P. Jovanis and A.D. May. Flex-Time Travel: Research Framework and Preliminary Findings. Institute of Transportation Studies, Univ. of California, Berkeley, Rept. UCB-ITS-WP-79-8, Aug. 1979, 97 pp.
17. F. Harrison, D. Jones, and P.P. Jovanis. Flex-Time and Commuting Behavior in San Francisco: Some Preliminary Findings--Summary Report. Institute of Transportation Studies, Univ. of California, Berkeley, Rept. UCB-ITS-RR-79-12, Aug. 1979, 19 pp.
18. D.W. Jones, Jr., F.D. Harrison, and P.P. Jovanis. Work Rescheduling and Traffic Relief: The Potential of Flex-Time. Institute of Governmental Studies, Univ. of California, Berkeley, Public Affairs Report, Volume 21, Feb. 1980, 10 pp.
19. P.P. Jovanis. Analysis and Prediction of Travel Responses to Flexible Work Hours: A Socioeconomic Workplace and Transportation System Perspective. Univ. of California, Berkeley, Ph.D. dissertation, Dec. 1979, 368 pp.

20. D.B. Roden. The Temporal Demand Aspects of Traveler Response to On-Freeway Entry Control Strategies. Institute of Transportation Studies, Univ. of California, Berkeley, Rept. UCB-ITS-WP-79-17, Nov. 1979, 154 pp.
21. D.B. Roden, W. Okitsu, and A.D. May. FREQ7PE--A Freeway Corridor Simulation Model. Institute of Transportation Studies, Univ. of California, Berkeley, Res. Rept. UCB-ITS-RR-80-4, June 1980, 348 pp.
22. V.C. Chan, R.G. Dowling, and A.E. Willis. Deriving Origin-Destination Information from Routinely Collected Traffic Counts--Phase I: Review of Current Research and Applications. Institute of Transportation Studies, Univ. of California, Berkeley, Rept. UCB-ITS-WP-80-1, Jan. 1980, 92 pp.
23. J.B. Schneider, C.L. Jette, and B.T. Lewis. FREGRAF: A Computer Graphics Aid to the Operation and Interpretation of FREQ6PE, A Freeway Simulation Model. Univ. of Washington, Pullman, Sept. 1979.
24. D.I. Robertson. TRANSYT: Traffic Network Study Tool. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, LR 253, 1964, 37 pp.
25. D.I. Robertson and P. Gower. User Guide to TRANSYT Version 6. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, SR 255, 1977, 107 pp.
26. T.J. Clausen and A.D. May. The Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Surface Streets. U.S. Department of Transportation, Oct. 1976, 119 pp.
27. P.P. Jovanis and A.D. May. Further Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Surface Streets. U.S. Department of Transportation, Oct. 1977, 258 pp.
28. P.P. Jovanis and A.D. May. Alternative Objectives in Arterial-Traffic Management. TRB, Transportation Research Record 682, 1978, pp. 1-8.
29. S.M. Easa, A.E. Willis, and A.D. May. Traffic Management of Dense Networks--Existing Experience and Analytical Techniques. Institute of Transportation Studies, Univ. of California, Berkeley, Working Paper UCB-ITS-WP-78-11, Dec. 1978, 111 pp.
30. Micro Assignment--Final Report. Creighton-Hamburg, Inc.; Bureau of Public Roads, 1969.
31. D.R. Leonard, J.B. Tough, and P.C. Bagulez. CONTRAM: A Traffic Assignment Model for Predicting Flows and Queues During Peak Periods. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, TRRL Laboratory Rept. 841, 1978.
32. A.E. Willis, S.M. Easa, and A.D. May. Traffic Management of Dense Networks--Model Evaluation and Site Selection. Institute of Transportation Studies, Univ. of California, Berkeley, Working Paper UCB-ITS-WP-79-5, July 1979, 60 pp.
33. S.M. Easa, A.E. Willis, and A.D. May. Traffic Management of Dense Networks--Application and Evaluation of Two Network Traffic Models. Institute of Transportation Studies, Univ. of California, Berkeley, Working Paper UCB-ITS-WP-79-14, Oct. 1979, 111 pp.
34. S.M. Easa, T-L. A.Yeh, and A.D. May. Traffic Management of Dense Networks--Volume 1: Analysis of Traffic Operations in Residential and Downtown Areas. Institute of Transportation Studies, Univ. of California, Berkeley, June 1980, 223 pp.
35. S.M. Easa, T-L. A. Yeh, and A.D. May. Traffic Management of Dense Networks--Volume 2: User's Guide of the Refined Micro-Assignment Model. Institute of Transportation Studies, Univ. of California, Berkeley, June 1980, 176 pp.
36. W.A. Stock and A.D. May. Capacity Evaluation of Two-Lane, Two-Way Highways by Simulation Modeling. TRB, Transportation Research Record 615, 1976, pp. 20-27.
37. A.D. St. John and D.R. Kobett. Grade Effects on Traffic Flow Stability and Capacity. NCHRP, Rept. 185, 1978, 110 pp.
38. J.L. Botha and A.D. May. A Decision-Making Framework for the Evaluation of Climbing Lanes on Two-Lane, Two-Way Rural Roads--Literature Search. Institute of Transportation Studies, Univ. of California, Berkeley, Working Paper UCB-ITS-WP-78-5, Sept. 1978, 37 pp.
39. J.L. Botha and A.D. May. A Decision-Making Framework for the Evaluation of Climbing Lanes on Two-Lane, Two-Way Rural Roads--Preliminary Evaluation of Candidate Models for Use in the Project. Institute of Transportation Studies, Univ. of California, Berkeley, Working Paper UCB-ITS-WP-78-12, Dec. 1978, 28 pp.
40. J.L. Botha and A.D. May. A Decision-Making Framework for the Evaluation of Climbing Lanes on Two-Lane, Two-Way Rural Roads--Final Model Selection, Simulation Methodology, and Proposed Data Collection. Institute of Transportation Studies, Univ. of California, Berkeley, Rept. UCB-WP-79-12, Oct. 1979, 93 pp.
41. J.L. Botha. A Decision-Making Framework for the Evaluation of Climbing Lanes on Two-Lane, Two-Way Rural Roads. Univ. of California, Berkeley, Ph.D. dissertation, May 1980, 454 pp.

Publication of this paper sponsored by Committee on Passenger Travel Demand Forecasting.