Traffic Management from Theory to Practice: Past, Present, Future

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It is proposed that traffic management will be most successful when theory and theoreticians work closely with practice and professionals. The past, present, and future are discussed because observing the path of traffic management to its current position provides insights into future possibilities. The scope is limited to the major urban road system. After a brief overview of traffic management fundamentals and the recognition of the important contributions of TRB, emphasis is given to important topics related to freeways and freeway systems, including capacity analysis, speed-flow relationships, simulation models, and traffic management strategies. Final observations are presented in the context of "bridges between."

It is indeed an honor to have been selected to give this third annual TRB Distinguished Lecture. It is of particular pleasure to me because over the years I have held TRB in such high esteem. Many individuals and organizations have guided me throughout my career, but my association with many of you through various TRB activities during the past 40 years has been most important to me.

My contact with the Highway Research Board began in the early 1950s when the annual meetings were held at the National Academy of Sciences building on Constitution Avenue and Roy Crum was the Executive Director. HRB (now, of course, TRB) has been fortunate over the years to have the fine leadership of Fred Burggraf, Grant Mickle, Bill Carey, and Tom Deen. I would also like to acknowledge the excellent support and encouragement that those of us in traffic and operations have received from TRB staff engineers, including K. B. Johns, Dave Witheford, Bob Spicher, Dan Rosen, and Richard Cunard.

During this period my involvement with TRB has increased from committee member to committee chairman to Group Council to Executive Committee, and each new opportunity has been a rewarding experience. For those of you who have over the years participated within the TRB family, I am sure that your experiences have been equally rewarding. For those of you who are just beginning your association with TRB, I encourage you to become more involved, for TRB needs your participation and your professional and academic contributions—the more you become involved, the more you will be rewarded with an enriched experience.

The title of my presentation is *Traffic Management from Theory to Practice: Past, Present, Future*. The selection of the topic for me was easy. I deeply believe that one of the most important areas in transportation—particularly today—is managing traffic operations on the system. Further, I believe that traffic management will be most successful when theory and theoreticians work closely with practice and professionals. I have added "past, present, future" because, as it is for the surveyor, observing the path to the current position provides insights into future possibilities.

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Preparing the contents of the presentation, however, was very difficult, for traffic management is a very broad topic and there are many subjects that could be covered. After considerable thought, it was decided to limit the presentation to the major urban road system; after a brief introduction to suggested fundamentals, emphasis will be given to freeways and freeway corridors. If I have not included subjects that you feel are equally important, their omission is not because they are not recognized as being important, but because time was limited.

The outline of the presentation is now covered. After introducing an overview and some fundamental concepts of traffic management, a historical perspective of a TRB committee involved in a particular aspect of traffic management will be presented. Then attention will be focused on freeways and freeway corridors, with particular emphasis given to capacity and speed-flow relationships, simulation models, and traffic management strategies. The presentation will conclude with some final observations.

TRAFFIC MANAGEMENT OVERVIEW

This overview of traffic management of the major urban road system will be presented in three parts. First, it will be suggested that the urban road system be structured as consisting of traffic operating environments that can be studied individually or in combinations to represent more complex traffic operating environments. Then a generalized analytical framework will be presented that is applicable to the various traffic operating environments. Finally, a demand-supply relationship is proposed that can be used to identify traffic operation problems and possible sets of potential solutions.

Traffic Operating Environments

It is proposed that the major urban road system be considered to consist of individual traffic operating environments or of a combination of such environments. Figure 1 identifies these individual environments and their various combinations leading to more comprehensive traffic operating environments. The urban area, for example, is made up of the arterial network and the freeway system. The arterial network consists of arterials that in turn are connected to individual unsignalized and signalized intersections. The freeway system consists of individual freeways, which in turn are connected straight-pipe sections, ramp junctions, and weaving sections. A unique traffic operating environment receiving much attention today is the freeway corridor, which integrates the arterial network with the freeway. The freeway corridor will serve as an example of traffic management theory and practice in this paper, and each topic will provide a historical perspective of development to date and anticipation for the future.

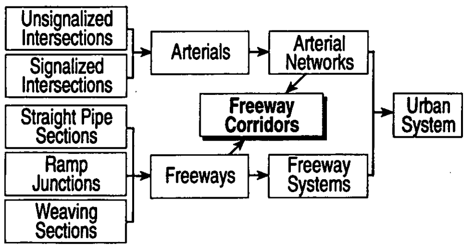

FIGURE 1 Traffic operating environments for major urban road system.

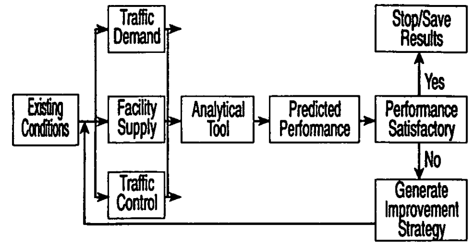

FIGURE 2 Generalized analytical framework for major urban road system.

The traffic operating environment concept for the major urban road system is suggested for several reasons. Experience has shown that larger systems cannot be managed without a full understanding of the individual components and their interactions. Therefore, it is imperative that the traffic phenomena in the smaller elements be understood completely, and then the traffic interactions between the smaller elements that make up the larger traffic operating environments, before the traffic management of the larger traffic operating environment can be addressed.

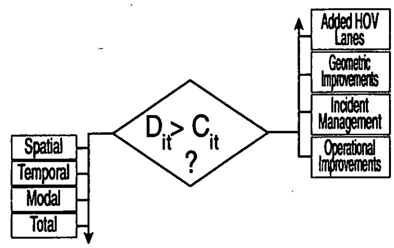

FIGURE 3 Problem identification and potential solutions for major urban road system.

Analytical Framework

An analytical framework is proposed for the traffic operating environments identified previously. An attempt has been made to generalize the analytical framework so that it applies to all of the traffic operating environments. The proposed generalized analytical framework is shown in Figure 2.

The analytical framework begins with assembling traffic demand, facility supply, and traffic control for the existing or base conditions in the traffic operating environment being investigated. This information provides the input to the analytical process, which in turn provides an output in terms of predicted performance. If the performance is satisfactory, the analysis can terminate and the results be saved as a base for future analysis. If the performance is unsatisfactory, an improvement strategy is generated that results in the modification of the initial demand, supply, or control (or all three), and the analytical process is repeated until performance is deemed satisfactory.

More details of this analytical process will be presented later in the paper as the freeway corridor is addressed as an example of a traffic operating environment.

Problem Identification and Potential Solutions

There is commonality between traffic operating environments in terms of approaches to identifying problems and potential solutions. Although operational problems may occur when undersaturated conditions exist, such as at unsignalized and signalized intersections, the most severe operational problems in all traffic environments are those associated with oversaturation. Figure 3 suggests a way of identifying the oversaturated condition and alternative potential solution approaches.

Consider a time-space matrix in which an estimate is made of the demand and capacity in each cell of the matrix. The term D_{it} represents the demand in space domain i and time domain t. Correspondingly, the term C_{it} represents the capacity in space domain i and time domain t. The demand and capacity values are compared in each cell, and the problem is identified—that is, oversaturated condition, when demand exceeds its corresponding capacity. When this occurs the performance of the system deteriorates greatly, with inferior traffic performance, inefficient use of the road system, and harmful effects to the environment in terms of air pollution, energy consumption, and vehicle noise.

What are the alternative solutions? There are three possible approaches: increase capacity, reduce demand, or combine the two. There are a number of ways to increase the capacity and reduce the demand. Capacities can be increased in several ways: operational improvements, incident management, geometric improvements, and added high-occupancy vehicle (HOV) lanes. Operational improvements might range from intersection control improvements to capacity increases by maintaining smooth, steady flow. Incident management attempts to reduce the duration and magnitude of capacity reductions due to incidents. Geometric improvements vary from providing special turn lanes at intersections to adding auxiliary lanes along the freeway. Introducing HOV lanes on arterials and freeways is another way to increase the capacity side of the equation.

There are a number of ways that demand can be reduced on critical portions of a traffic operating environment. The intent of these demand management strategies is to reduce demand on critical sections through spatial response, temporal response, modal response, and total response. Traffic diversion to parallel underused alternative routes is an example of spatial response. Spreading the demand to pre- and post-peak congested periods is an example of temporal response. Encouraging increases in vehicle occupancy and use of public transit are examples of modal response. Finally, reducing the vehicle miles traveled is what is meant by total response; examples include combining trips, changing the destination of trips, or simply no longer making trips.

HISTORICAL PERSPECTIVE OF A TRB COMMITTEE

Early Committee Activities

My involvement in TRB activities dates to the early 1950s, with attending Annual Meetings, presenting technical papers, and participating in committee meetings. Those of you who have had similar long-term association with TRB are aware of the significant efforts of individuals who volunteer their time to the work of TRB committees and the effect that these committees have had on pushing forth the frontiers of knowledge. Those of you who have more recently become involved in TRB activities might not have seen the significant long-term positive impacts of a TRB committee. Perhaps tracing the history of one TRB committee's activities and contributions will, when integrated over the several hundred TRB committees, give an appreciation of the important role that TRB has played over the years.

The TRB Committee on Highway Capacity was established in the mid-1940s. The first major accomplishment of the committee was the publication of the 1950 *Highway Capacity Manual* (HCM), which became the principal guide for capacity analysis not only in the United States but throughout the world. O. K. Normann and William Walker of what was then the Bureau of Public Roads served as chairman and secretary, respectively, of the 18-member committee.

Recognizing almost immediately the need to continuously update and expand the HCM, the committee began work on assembling new material for the revision. A comprehensive nationwide intersection study program was initiated in 1954. By 1957, the committee began detailed planning for a new edition. Progress was gradual until 1963, when a five-man task group was assigned by the Bureau of Public Roads to work with the committee on writing the new HCM. The second HCM was published in 1965. One of the major contributions of the 1965 HCM was the introduction of the concept of "level of service." O. K. Normann continued to serve as committee chairman until his death in 1964. Carl Saal served as chairman during the final publication stages of the 1965 HCM, and Art Carter served as committee secretary and played a major role in the completion of the manual. More than 30,000 copies of the 1965 HCM were printed, and it has been translated into 27 languages.

After a few years, efforts began again toward developing the third HCM. Bob Blumenthal, Jim Kell, and Carlton Robinson led the committee during this period. In the spirit of transforming the Highway Research Board to the Transportation Research Board, the committee expanded the scope of the HCM to give greater emphasis to transit capacity and to include capacity analysis of pedestrian and bicycle ways. Added attention was also given to a systems approach both for freeways and arterials. The third HCM was published in 1985.

Current Committee Activities

The committee took on new leadership in the late 1980s; its specific goals included the development of a research program in highway capacity and the revisions of several key chapters. In addition, the committee gave greater attention to the international community by involving a number of world experts on capacity and by holding midyear meetings in Germany in 1991 and Australia in 1994.

Seven of the 14 chapters of the 1985 HCM have been revised; they were published in 1994. These chapters for the most part were undertaken by the various subcommittees of the Capacity Committee; they were prepared by committee members working almost completely on a voluntary basis. The revision of each chapter was the responsibility of a subcommittee, which presented it to the total committee for approval. Subcommittee chairpersons played a very important part in this effort and should be recognized: Stan Teply, Roger Roess, Ron Pfefer, Ken Courage, Mike Kyte, and Dan Fambro. Their efforts have included field studies, analyses, and the preparation of individual chapters.

A program of research in highway capacity was developed and published as *Transportation Research Circular 371* in June 1991. The program recommended the conduct of 21 research studies as a means to address deficiencies in the present HCM and to upgrade future editions. The total cost of the research program was estimated to be $3.55 million over the next 6 years. The research program with the support of research sponsoring agencies has been very successful in that 12 of the 21 studies are either under way or were expected to begin in 1994.

Future Committee Activities

Efforts will continue to ensure that all research studies needed for updates and expansions will be undertaken and completed. The target is to complete the new HCM in the year 2000. In the Matson Award paper presented by the Institute of Transportation Engineers in 1992, I attempted to indicate what the year 2000 manual might look like. Five key phases were identified to describe the direction for the next HCM: multimodal, systems, oversaturation, computerization, and user interface. The paper concluded with this summary:

> In summary the year 2000 capacity manual may have an entirely different look than previous capacity manuals. It may not be printed on paper but be part of the computer software. It will most likely include multimodal analysis on a systems basis and handling the oversaturated condition. The user interface with the computer program will be much improved with extensive diagnosis to aid the user by providing information as analysis is undertaken and warning the user when difficulties can be foreseen.

FREEWAY CAPACITY AND SPEED-FLOW RELATIONSHIPS

Speed-flow relationships are fundamental to understanding traffic flow phenomena on freeways. These relationships have been studied for more than 60 years, and it is important to note the significant changes that have taken place over this period with anticipation of what these relationships will look like in the years ahead.

Early Speed-Flow Relationships

In the 1930s Greenshields studied traffic flow relationships and proposed that speed was a linear function of density that results in parabola-shaped relationships between flow and density as well as between speed and flow. These stream flow relationships are shown in Figure 4.

The speed-density relationship is shown in the upper left-hand corner of the illustration, with speed shown as a linear function of density. Although this relationship is of greater interest to the theorist than the practitioner, it defines the other two relationships as shown in the illustration.

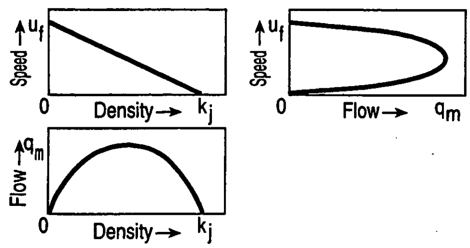

FIGURE 4 Basic stream flow diagrams.

The flow-density relationship is shown in the lower left-hand corner of the illustration, with flow being shown as a function of density. Theorists and practitioners who are engaged in freeway control often base their control algorithms on this relationship. Density (or occupancy) is used as the control variable and flow as the measure of productivity. It is important to note that maximum flow (or capacity) is obtained at a midrange value of density: density values lower than this midrange are indicative of free-flow conditions and higher levels of service; density values higher than this midrange are indicative of congested or oversaturated conditions. The portion of this illustration under high-density conditions reveals that this flow regime is characterized by both poorer level of service and lower productivity.

The speed-flow relationship is shown in the upper right-hand corner of the illustration, with speed as a function of flow. This relationship is most important to the practitioner whether involved in planning, design, or operations. Like the flow-density relationship, there are two portions of the curve (free flow and congested flow), but in this case they are separated on the basis of a midrange speed value. This relationship is used in three ways. The upper portion of the curve is used to estimate level of service for the users under free-flow conditions, the right maximum values are used to estimate capacity, and the bottom portion of the curve is used to calculate resulting upstream congestion patterns through shockwave analysis.

1950 HCM Speed-Flow Relationships and Predicted Capacities

A major accomplishment in speed-flow relationships occurred in 1950 with the publication of the first HCM. This HCM contained procedures for calculating capacity (then called possible capacity) and what was then called practical capacity [occurring at an approximate volume/capacity ratio (*v/c*) of 0.75]. Although some speed-flow relationships were included, the methodology was directed at the calculation of possible and practical capacity. It is interesting to note that the capacity under ideal conditions was proposed to be 2,000 passenger cars per hour per lane (pcphpl) and that this value was changed only in the 1990s with the revised HCM chapters. The highest maximum observed hourly volumes were reported for such facilities as US-1 near the Newark (New Jersey) International Airport [2,275 vehicles per hour per lane (vphpl)], Grand Central Parkway in New York (2,194 vphpl), and the Outer Drive in Chicago (1,958 vphpl).

1965 HCM Speed-Flow Relationships and Predicted Capacities

One of the key advancements with the 1965 HCM was the introduction of level of service based on the *v/c* integrated with the determination of capacity. The proposed speed-flow relationships in the 1965 HCM are shown in Figure 5. Note that the horizontal scale has been normalized and is shown as the *v/c*. The procedure was to calculate the capacity, then calculate *v/c*, and determine the operating speed from this illustration. The value for the capacity under ideal conditions continued to be 2,000 pcphpl. More than 10 sites were reported to have hourly lane flows of more than 2,000 vphpl, and the highest maximum observed hourly volumes were reported for such facilities as Lake Shore Drive in Chicago (2,236 vphpl), US-99 in Seattle (2,189 vphpl), and Hollywood Freeway in Los Angeles (2,190 vphpl).

1985 HCM Speed-Flow Relationships and Predicted Capacities

The 1985 HCM continued the level-of-service concept integrated with the determination of capacity. Greater emphasis was given to density, and it was used as the traffic parameter on which level of service was determined. The proposed speed-flow relationships in the 1985 HCM are shown in Figure 6. The value for capacity under ideal conditions continued to be 2,000 pcphpl. The shape of the upper portion of the speed-flow curve continued to be parabolic, and capacity was expected to occur at speeds of about 35 mph. Many sites were reported to have hourly lane flows of more than 2,000 vphpl.

Multiregime Speed-Flow Relationships

During the period between the publication of the 1965 and the 1985 HCMs, several researchers proposed and developed multiregime

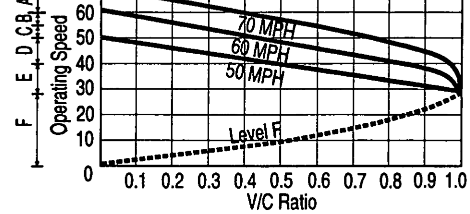

FIGURE 5 1965 HCM speed-flow relationships.

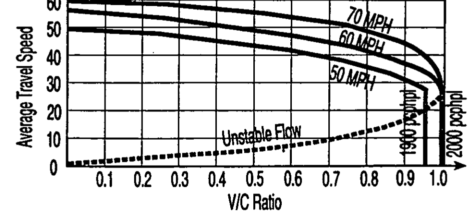

FIGURE 6 1985 HCM speed-flow relationships.

speed-flow relationships. An example of such a relationship is given in Figure 7. The concept was that there was a discontinuity between free-flow conditions and congested-flow conditions, and models that could be used to represent one condition were not necessarily the best for the other.

1994 HCM Speed-Flow Relationships and Predicted Capacities

The chapter on freeway capacity and level of service has been revised and was published in 1994 with the other updated chapters. The level-of-service concept is continued, with emphasis on density, but two significant changes have occurred. First, the capacity under ideal conditions has been increased by 10 percent, from 2,000 to 2,200 pcphpl. Improvements in the vehicle fleet and driver capabilities are thought to be the reason for the increase. The other significant change is the shape of the upper portion of the speed-flow relationship as well as the beginning recognition of a multiregime relationship. The proposed speed-flow relationships in the revised freeway chapter are shown in Figure 8. It was common to find sites with hourly flows of more than 2,000 vphpl, and a number of sites were reported to have hourly flows of more than 2,200 vphpl.

Current NCHRP Project 3-45 on Speed-Flow Relationships and Capacity Predictions

A new research project specifically directed at developing speed-flow relationships and estimating freeway capacity for the anticipated year 2000 HCM is under way as part of NCHRP Project 3-45. The hypothesis to be tested is that the speed-flow relationship is a multiregime relationship consisting of three regimes, or segments, as shown in Figure 9. This hypothesis is based of the work

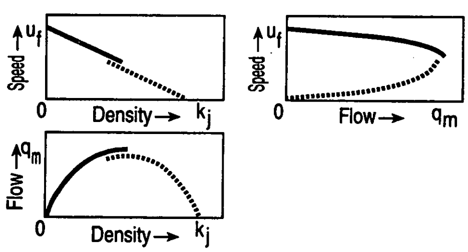

FIGURE 7 Multiregime speed-flow relationships.

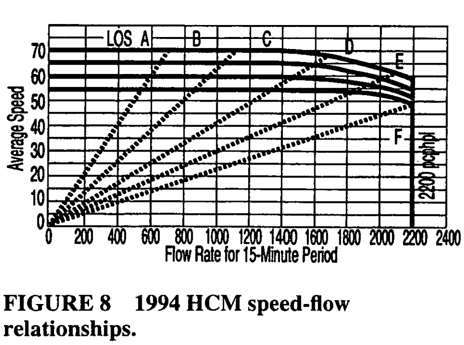

FIGURE 8 1994 HCM speed-flow relationships.

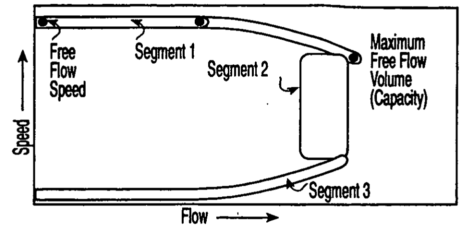

FIGURE 9 NCHRP Project 3-45 hypothesized speed-flow relationships.

of many individuals, including Hall, Banks, Roess, Reilly, and Urbanik.

The upper portion of the speed-flow relationship is assumed to be essentially horizontal up to a flow of about 1,400 vphpl and then to continue to capacity with only a slight decrease in speed on the order of 5 to 10 mph. Capacities would be observed at bottlenecks just before upstream congestion commences. Because of the small decrease in speeds over this complete range, the use of density (percentage occupancy) and *v/c* for identifying levels of service becomes more apparent.

The second flow regime would be represented by an almost vertical line in which near-capacity flows would be recorded but with speeds ranging from approximately 50 to 30 mph. Density would increase in the range from approximately 45 to 70 vehicles per mile per lane. There is some evidence that the capacity is slightly higher—on the order of 2 to 5 percent—before congestion occurs just upstream of the bottleneck. This would mean that if free-flow conditions could be maintained and the bottleneck capacity fully used, a slightly higher capacity could be obtained.

The third flow regime is represented by the lower portion of the speed-flow relationship, which occurs under congested flow conditions. Less is known about this flow regime, yet it strongly affects the degree of upstream congestion. If, for example, the speed at a flow of 1,000 vphpl was 10 mph instead of the indicated 8 mph, the resulting density would be 100 instead of 125 vehicles per mile per lane. Thus, the travel time rate within the congested portion of the freeway would be decreased by 1.5 min/mi of travel, but the length of the congested portion would be 20 percent more.

Future Speed-Flow Relationships and Capacity Predictions

In the short term, as the vehicle fleet and drivers' capabilities continue to improve and as in-vehicle driver aids increase, it would not be surprising if the capacity value under ideal conditions were to grow to 2,400 pcphpl by the time the year 2000 HCM is published. The shape of the upper portion of the speed-flow curve should remain unchanged, with the curve extending to the right to the higher capacity value. Additional and more precisely measured traffic flow characteristics will probably show that capacity flow prior to congestion will be about 5 percent higher than when congestion forms. The bottom portion of the speed-flow relationship will be much better defined for use in predicting shock-wave phenomena and resulting congestion patterns.

A possible speed-flow relationship by the year 2000 is superimposed on typical speed-flow relationships as contained in the 1965, 1985, and 1994 HCMs (Figure 10). Over time, the upper portions

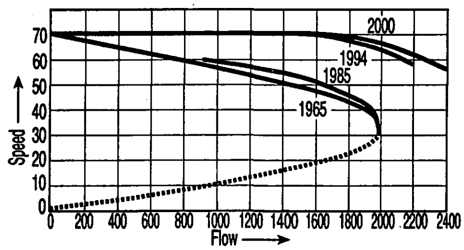

FIGURE 10 Past-present-future speed-flow relationships.

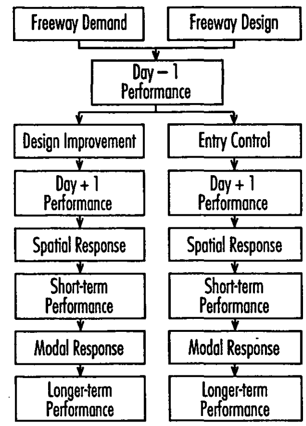

FIGURE 11 Freeway simulation model.

of the relationships have continuously moved upward in the diagram and extended farther to the right.

It is more difficult to predict speed-flow relationships beyond the year 2000. With fully automated vehicle control systems, higher speed-flow relationships could be expected along with the corresponding higher capacity values. The limitations will be determined by the fail-safe system. Capacities in excess of 2,400 vphpl (average time headways of 1.5 sec/veh) will be required to exceed anticipated freeway capacities without fully automated vehicle control systems.

FREEWAY SIMULATION MODELS

Professional engineers and researchers are accepting and recognizing more readily the important role that simulation models can have in assessing problem areas, generating potential solution approaches, and evaluating the traffic and environmental impacts of implementing advanced traffic management systems (ATMS) and advanced traffic information systems (ATIS). The applications of simulation models have expanded because of the development of improved and more comprehensive models, models that can better represent real-life situations, with user-friendly input and output interfaces and much improved computer capabilities. A new frontier in the use of simulation models is in the area of on-line surveillance, control, and information systems, which will be given attention later in this paper when freeway entry control systems are described.

Three classes of simulation models for freeway corridor-type traffic operating environments will be described: the FREQ model, the INTEGRATION model, and a newly developed traffic-planning model.

FREQ Simulation Model

The FREQ model is a deterministic macroscopic model that includes simulation and optimization submodels and permits a time-stream evaluation of freeway corridor performance under design or control traffic management strategies. An illustration of this time-stream evaluation is shown in Figure 11. Its development and enhancements have evolved over the past 20 years, and the current versions are referred to as FREQ10 and FREQ11. It operates on a personal computer, and one of its strengths is its input and output user interface with diagnostics when problems are encountered. FREQ on-hands computer laboratory workshops have been held in a number of states, most recently California, Texas, and Washington.

As shown in Figure 11, the inputs to the model are the time slice traffic counts and facility design features. A synthetic origin-destination (O-D) procedure is incorporated into the model that converts the traffic counts into time slice O-D tables. The user provides subsection capacities based on the facility design features. The simulation model is employed to predict traffic performance in the freeway corridor for the time before implementation of a traffic management strategy (Day − 1). Design improvements such as added HOV lanes and mixed-flow lanes can be incorporated into the model, and the simulation model will predict the effect of these improvements without traveler responses (Day + 1). Optimized entry control strategies can be generated either with or without the design improvements, and the simulation model will predict the effect of these improvements without traveler responses (Day + 1).

The FREQ model also includes spatial and modal response submodels that predict and reassign users to alternative routes or multi-occupancy vehicles. The simulation model can be used to predict the short- and long-term traffic performance of implementing the design/control improvement with spatial or modal responses.

INTEGRATION Simulation Model

The INTEGRATION model was developed in the 1980s and has been enhanced and expanded since then. The original work was done at Waterloo University; work has been done more recently at Queens University by Van Aerde. This development has been sponsored in part by the Ontario Ministry of Transportation, and its chief applications have been to the Trav-Tek Project in Orlando, Florida, and to the SMART corridor in Los Angeles. It is currently being used by the intelligent vehicle-highway system (IVHS) architecture contractors in assessing IVHS strategies.

The model is a deterministic macroscopic model explicitly developed for IVHS applications in freeway corridors; it has the following features:

- Models freeways and arterials simultaneously,
- Uses individual vehicles with self-assignment capabilities,
- Includes five vehicle types with varying levels of information,
- Optimizes traffic signals, and
- Simulates multiple incident and construction scenarios.

An auxiliary program is available called QUEENSOD that will generate time slice traffic demand O-D tables based on traffic counts. The O-D tables, physical network, and intersection and ramp signal control serve as inputs to the model. The traffic assignment routines and the traffic performance predicted by the simulation model operate concurrently to load the traffic onto the network and thus predict the traffic performance in the freeway corridor.

ATMS strategies such as on-freeway HOV lanes, incident management, entry control, and intersection signal control can be investigated. ATIS strategies such as highway advisory radio (HAR), changeable message signs (CMSs), and in-vehicle information systems can be simulated. Up to five vehicle types can be simulated with varying levels of information. Various vehicle types can obtain current travel time information either precisely or with noise at every node in the corridor, at HAR/CMS locations, or not at all.

The output to the model is very comprehensive and includes off-line geographic maps of the entire corridor or subparts with superimposed input/output data and with the option of on-line vehicle animation on the computer screen for any portion of the freeway corridor. Vehicles can be color-coded to represent various situations: their existence in free- or congested-flow conditions, or perhaps their status as HOV vehicles or vehicles receiving updated traffic travel time information.

Traffic-Planning Simulation Model

The traffic-planning simulation model integrates a regional planning model with traffic simulation models (FREQ and TRANSYT) in order to predict traffic and environmental impacts. The use of the regional planning model provides a broad view of travel in the region for current and future scenarios. The use of the traffic simulation models predicts freeway and arterial traffic performance in specific freeway corridors on the basis of the regional planning model's prediction of demand.

This new type of simulation model was developed by JHK & Associates for the Transportation Systems Center and the California Department of Transportation. It is being tested and evaluated on the I-880 freeway corridor in the San Francisco Bay Area.

A simplified flow chart of the traffic-planning model is shown in Figure 12. The planning submodel portion is shown in the five boxes in the upper-left portion of the figure, and the traffic submodel portion is shown in the five boxes in the upper-right portion of the figure. The outputs of the model are shown in the two boxes at the bottom of the figure and the box on the far right of the figure.

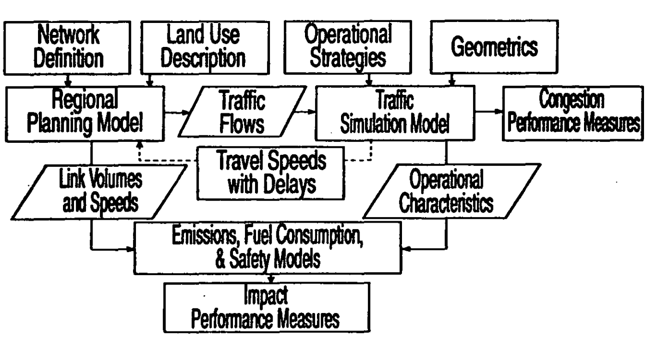

FIGURE 12 Traffic-planning model integration.

The input to the regional planning model is the network definition and the land use description. The regional planning model estimates the traffic flows on each link of the freeway corridor. The traffic simulation model uses these traffic flow estimates with operational strategies and geometrics to predict travel speeds with delays. The travel speeds with delays from the traffic simulation model are compared with similar measures from the regional planning model, and if they are found to be significantly different, the regional planning model is rerun using adjusted travel speeds and new predicted traffic flows. This process is continued until equilibrium is reached between the two models. Once this occurs, the traffic congestion performance measures and the environmental impact performance measures can be predicted.

FREEWAY ENTRY CONTROL

Freeway entry control is one of the major strategies within the ATMS program. Referring to Figure 3, which identifies possible solution approaches when demand exceeds capacity, freeway entry control is one strategy that incorporates almost all of the possible solution approaches. On the capacity side,

- HOV bypass lanes can be provided for the on-ramps,
- Geometric improvements can be made a part of the entry control strategy,
- The entry control system can be designed for recurring congestion as well as for incident congestion, and
- If free-flow conditions can be maintained, slight increases in freeway capacity can be expected.

On the demand side, freeway entry control can result in a variety of traveler responses. Excess demand may be

- Diverted to underused parallel facilities,
- Spread to pre- and post-congested time periods,
- Shifted to carpools, vanpools, and buses due to priority treatment of higher-occupancy vehicles, and
- Reduced by trip consolidation, altered destinations, and trip reductions.

Although implemented freeway entry control systems have been successful in many locations in North America and abroad, some such systems have not been as successful. Lessons have been learned over the years, and key features for the more successful projects have been identified:

- Recognize the corridor solution approach,
- Institute partnerships with government agencies,
- Enhance entry control systems of ATMS/ATIS,
- Implement comprehensive surveillance systems first,
- Consider spot improvements on freeway and arterials,
- Select the most promising implementation,
- Take advantage of public information and marketing,
- Monitor implementation closely, and
- Fund operations and maintenance adequately.

Earlier Periods of Freeway Entry Control

Freeway and tunnel entry control began in the early 1960s with tunnel entry control systems in some of the New York tunnels and with manual police officer control on the Red Feather Expressway in St. Louis. Soon thereafter, surveillance and control projects were initiated in Chicago and Detroit, and the first automatic entry control system was implemented in Chicago in 1963.

Freeway entry control systems grew in terms of both number of geographic areas and number of ramps controlled in the geographic areas. Two types of freeway control systems were implemented: local traffic responsive control and multiramp time-of-day control based on historical traffic information.

TRB's Committee on Freeway Operations was started as a task force in the late 1950s and has continued to serve as a national central point for discussions and publications related to freeway operations. One of its continuing activities is to provide a freeway operations project summary periodically. The most recent summary was published in 1991 and indicated that more than 2,000 ramps were being metered in more than 30 geographic locations.

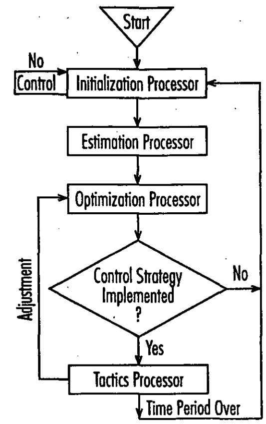

FIGURE 13 Overview of systemwide traffic responsive control.

Working Toward Coordinated Traffic Responsive Entry Control

There has been a continuous improvement in freeway entry control systems in terms of educational programs, enforcement procedures, priority entry control, use of detectors, and control strategies. One of the more technically challenging efforts has been to work toward coordinated traffic responsive entry control.

When an individual controlled ramp reaches its minimum metering rate or its maximum permitted queue length, it cannot further restrict entry onto the freeway. Without some form of coordinated traffic responsive control, freeway congestion will occur but further restriction to entry to the freeway from upstream ramps will not occur until sometime later, when the queues extend through the next upstream ramp.

The purpose of coordinated traffic responsive entry control is to reduce the metering rates at upstream ramps as soon as any ramp reaches either its minimum metering rate or its maximum permitted queue length. In this way action is taken immediately and the entry control strategy begins to take on a systems approach. Very recently, several researchers have proposed a more systemwide traffic responsive freeway entry control strategy approach. "Helper" ramp implementations include those in Chicago, Denver, Minneapolis-St. Paul, Seattle, and Europe; examples of on-line simulation models include the Cornerstone, European, and Minneapolis-St. Paul approaches.

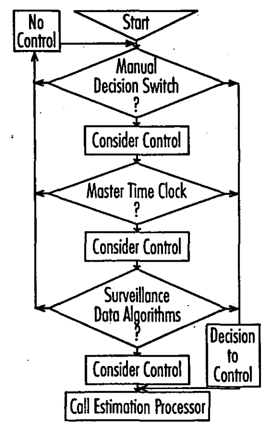

FIGURE 14 Initialization processor.

Systemwide Traffic Responsive Freeway Entry Control

One approach to systemwide traffic responsive freeway entry control is to integrate a freeway optimization and simulation model into the on-line entry control system. The approach presented in this paper incorporates four processors that will be described in the following; their interrelationships are shown in Figure 13.

The control strategy begins with the first processor, which is called the initialization processor; a flow chart of this processor is shown in Figure 14. One of three decisions is made: the choices are to (a) not control and therefore not call the next processor, (b) consider control if a feasible control strategy can be generated, or (c) require an implementation of control. The selection is based on the system manager's instructions, the system time clock, and traffic performance.

If the decision is made to consider control or to implement control, the second processor, referred to as the estimation processor, is called; its flow chart is shown in Figure 15. The purpose of this processor is to assemble the necessary input data for the freeway optimization and simulation model. The input data consist of an array of subsection capacities along the freeway and a freeway traffic demand O-D table for the next period. The nonincident capacity of each freeway subsection is stored in the computer memory but

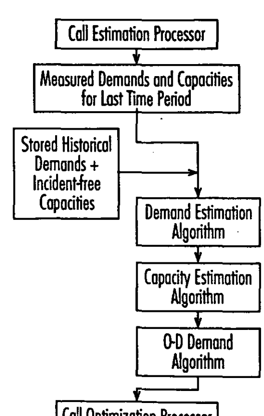

FIGURE 15 Estimation processor.

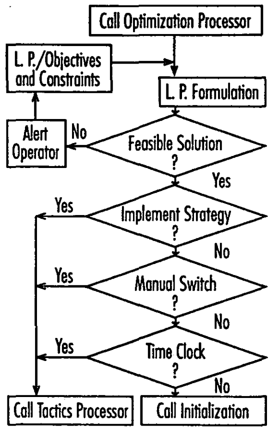

FIGURE 16 Optimization processor.

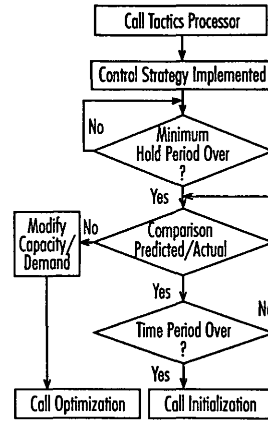

FIGURE 17 Tactics processor.

would be replaced by on-line estimates of capacity if they were found to be lower. The traffic demand O-D table would be obtained on the basis of entry and exit flow measurements obtained during the previous time period and historical data. Demand predictions would be made for the next time period and the O-D demand table developed through synthetic O-D techniques. The demands and capacities would be transferred to the next processor.

The next processor is called the optimization processor, which determines the systemwide traffic responsive control strategy based on the O-D demand table and the subsection capacity array. A flow chart of the optimization processor is shown in Figure 16. A linear program would be employed in which the objective function would have been preselected and the constraints would include queue limits, minimum and maximum permitted metering rates, and desired maximum v/c's. The operator would be informed of the resulting control plan and either could modify the objectives and constraints or could modify any specific element of the control plan.

The fourth and final processor is referred to as the tactics processor, which is called once the control plan for the next period is implemented. A flow chart of the tactics processor is given in Figure 17. A short-term new set of demands, capacities, and system performance is measured and compared with predicted values. If there are no significant differences, the control plan is maintained, and another short-term new set of demands, capacities, and system performance is measured and compared, and the process is repeated. If there is a significant difference between any of the new measurements and predicted values, the optimization processor is recalled, a new control plan is developed, and the tactics processor is called again. This process is continued until the end of the period, at which time the initialization processor is recalled and the four-processor procedure is repeated.

Placing the traffic optimization and simulation model on-line using predicted demands and capacities has many advantages. First, the entry control strategy is determined on the basis of *anticipated*—not historical or previous—traffic measurements and is optimized on a system basis. Second, anticipated travel time and ramp delay information is available for ATIS-types of information systems. Third, unusual traffic conditions are identified early on in terms of modifying traffic signal systems and alerting traffic incident management activities. As traffic conditions change, the traffic management strategy is reassessed and a more appropriate one is selected.

SOME FINAL OBSERVATIONS: "BRIDGES BETWEEN"

This presentation has attempted to propose certain fundamentals of traffic management that have been learned from research and practice. Then the freeway and freeway corridor traffic operating environments were selected as an example with special emphasis given to TRB committee contributions, capacity and speed-flow relationships, simulation models, and traffic management strategies.

The discussion closes with some final observations that are presented in the context of "bridges between." Traffic management is a complicated issue and requires many bridges between people, organizations, disciplines, and approaches. No one person, organization, discipline, or approach can solve the problem, but by working together we can make a difference and give the traveling public the very best use of the urban road system. Let me close with a few examples.

Educators and engineering professionals need to work together to encourage the very best candidates to enter the transportation educational process. Educational programs must be designed carefully to provide the fundamental education for those who wish to enter professional service. Education is a continuing process and requires continuing interaction between the educational communities and the profession through seminars, workshops, short courses, and more formal educational opportunities.

Bridges are needed between theory and practice, research and on-road realities, and analytical tools and real-life applications. One without the other falls short of the needs.

System components and their integration into total systems must be well understood if traffic management is to be successful.

Traffic management requires the expert contributions of individuals from many disciplines: from marketing and planning to computer software and hardware, from sociology and economics to operations research and engineering. All are needed, and many more, if traffic management is to be successful.

There must be a balance between capacity improvement and demand management. Only by working together will these approaches lead to better traffic management.

Traffic management of the major urban road system is not just a city or county or state or federal responsibility. A partnership is required if traffic management is going to work. It is not just *my* system—it is *our* system working together.

The final bridge is from the past to the future. The past has given us the major urban road system that we have. In the recent past, and today, attention has turned toward managing it. The operational problems that were easier to solve have been addressed and many lessons have been learned. The more difficult problems have been left to the future, with increased constraints being placed on the solutions. Traffic management in the future will not be easy, and there will be many unforeseen difficulties. The challenge is there; working together, we can meet it.