outputs and effects of transportation management actions into a single monetary scale. Also, the method allows for subjective analysis in situations where an explanation is required for the observed behavior.

RECOMMENDATIONS

The application of the goals achievement function methodology to actual cases of TSM implementation is recommended as this will further increase program experience, provide valuable insights into transportation decision making and official accountability, and overcome existing obstacles and biases that sometimes inhibit program evaluation.

Also, with the proliferation of transportation system management actions in many cities in recent years and improvements in recordkeeping and data collection methods, there currently exists the data base for more comprehensive modeling. In this regard, it will be necessary to expand the goals achievement function model to include not only program costs but also growth patterns in economic and business activities and trends in social and other behavioral areas within the program environment. Two outcomes: a TSM production predictive model that includes a cost function or a TSM production model, or both, that can be used to evaluate performance of an improved transportation system supply relative to a predetermined cost, and socioeconomic impacts can be appropriate additions to the literature.

ACKNOWLEDGMENT

The research from which this paper was extracted was sponsored by the Joint Highway Research Advisory Council of the University of Connecticut and the Connecticut Department of Transportation, and was carried out in the Transportation Institute, Department of Civil Engineering of the University of Connecticut. The author is grateful to Professor Herbert S. Levinson, Dr. Christian F. Davis, Dr. Jack Stephens, and Dr. Hallas H. Ridgeway for their assistance and direction.

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Publication of this report sponsored by Committee on Transportation System Management.

Managing Traffic in Residential Areas

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ABSTRACT

This report presents traffic management concepts that were developed as part of a traffic plan for the city of Greenwood Village, a suburb of Denver. Greenwood Village includes established neighborhoods in addition to extensive commercial development in the Interstate 25 corridor. The community wishes to preserve its environmental quality while accommodating the traffic demands of commercial development and residential growth. Through travel demand modeling, it was demonstrated that substantial roadway improvements would be necessary to resolve the area's traffic problems. The magnitude of these improvements was environmentally unacceptable. As the forecasted demand exceeded the system capacity, a primary concern was the spillover effect of arterial traffic onto residential streets. This led to the development of a traffic management strategy, which considered the legal aspects of traffic diversion. The recommended plan attempts to manage systemwide traffic by encouraging traffic on selected streets and discouraging it on others. These objectives were accomplished by controlling roadway capacity through allocations of green time at signalized intersections, roadway design features, and travel time penalties. The plan does not totally satisfy the travel demand, but does provide reasonable travel routes for through traffic while minimizing the traffic impact on residential areas.

Greenwood Village is located in Arapahoe County in the southeastern section of the Denver metropolitan area. Initially incorporated in 1950, the community has placed great emphasis on maintaining a high environmental quality.

Greenwood Village also contains an area of extensive commercial development that includes both the Denver Technological Center (DTC) and Greenwood Plaza. Significant development has occurred, and the area is recognized as a primary activity center by the Denver Regional Council of Governments.

A current issue is the extent of future development, and the potential impact of this development on transportation systems and the environment. The DTC occupies approximately 3 million ft^2 of the approximately 11 million ft^2 of planned development authorized by Greenwood Village. Greenwood Plaza similarly occupies approximately 3 million ft^2 with a 7-million ft^2 potential.

TRAVEL DEMAND EVALUATION

Traffic impacts were assessed through the use of a computerized travel demand forecasting model. The first task in the development of a workable model for the study area was to define an acceptable population and employment data base that was compatible with regional growth estimates and local development plans. The data base was in the form of a regionwide trip table.

It was recognized early in the modeling efforts that extensive roadway improvements would be necessary to accommodate the full travel demand. The magnitude of these improvements was deemed to be environmentally unacceptable to the community. An effort was then made to develop a balanced system that would minimize the overall delay on the network.

After multiple tests and system refinements, a test network system began to emerge that would minimize the overall delay. Each successive network and its particular set of link changes resulted in a variation of the overall operating characteristics of the system. The overall efficiency of the system was evaluated in terms of three parameters: (a) free-flowing links, (b) links with conditions between free-flow and capacity, and (c) over-capacity links. The final test network resulted in the best combination of these parameters with an increase in free-flowing links together with a reduction in over-capacity links. In other words, more traffic was operating at or near desired speeds and more roads were experiencing at or below capacity conditions.

The final tests of this network showed that some problems remained. These could not be remedied through further system changes without degrading the environment. The issue became one of evaluating heavy travel demand within an environmentally sensitive area, and led to an investigation of traffic management strategies. Because the forecasted travel demand was greater than the roadway system capacity, a prime concern was the restraint of through traffic in residential neighborhoods.

METHODS FOR MANAGING TRAFFIC

Traffic problems in neighborhoods may frequently be attributed to the spillover effect of congestion on nearby arterials. In recent years this situation has led to the application of various methods, which are summarized later in this paper, of restricting nonlocal traffic. These restrictions take the form of passive or physical controls.

Passive controls include stop signs, speed limit signs, turn prohibition signs, one-way streets, and entry prohibition signs. Speed limit signs are effective when they represent reasonable speeds for certain road conditions. (This limit is generally considered to be the 85th percentile speed of motorists who use the road.)

Physical controls include speed bumps, speed undulations, median barriers, cul-de-sacs, and diagonal diverters. Each prohibits a specific action, and is used to reduce either the speed or volume of traffic flow. However, there are disadvantages associated with this type of control, such as impeded access for local residents and emergency vehicles (police, fire, and medical).

Speed bumps are usually no higher than 5 in., and less than 3 ft in length. They are typically used only on private drives because serious questions exist with regard to their impact on motorist safety. Speed undulations were perfected in England (1), and are a relatively new development. They offer a gradual roadway change, and are 4 in. in height at the midpoint of a 12-ft section. Studies show that undulations produce driver discomfort at speeds greater than 25 miles per hour (mph), and that properly spaced undulations are effective in controlling both speed and volume.

Recent studies by Clement (2) indicate that parabolic-shaped 3-in. high undulations at the midpoint of a 12-ft section are most effective in controlling speeds. The 3-in. high undulations should be spaced approximately 300 ft apart. This spacing will result in vehicle speeds of about 27 mph between undulations, and 23 to 25 mph at the undulations. Clement also pointed out that vehicles with a longer wheel base, such as fire trucks, would operate better if the undulation was at the midpoint of a 16- to 20-ft section.

Passive or physical controls are best applied as part of an areawide solution. Without the areawide plan, traffic problems may be shifted from one location to another. Strategies may be developed for perimeter control to prevent vehicles from entering a residential area, or for internal control at isolated locations.

The concept of environmental capacity, as developed by Marks (3), was applicable in determining the need for traffic management in Greenwood Village. Environmental capacity was defined as "the volume and character of traffic permissible on a particular street consistent with the maintenance of good environmental conditions." Environmental capacity (vehicles per hour) is a function of pedestrian delay, noise, fumes, vibration, and visual distraction. An examination of current traffic volumes reveals that the environmental capacity is currently exceeded on many streets in Greenwood Village. The recommended plan should minimize traffic impacts in residential areas to the maximum extent possible.

LEGAL CONSIDERATIONS

A study by Van Antwerp (4) showed that challenges to traffic diversion strategies may fall into four general groups:

1. The power of municipalities to manage traffic,
2. The reasonable exercise of such power,
3. Consequences of denial of access for through-traffic motorists and local residents, and
4. Compliance of diversion strategies with state or federal codes with regard to uniform traffic control devices.

The first and second issues have been addressed in several U.S. Supreme Court cases. The Court has

upheld zoning legislation, which has similar objectives to traffic diversion. In the zoning case of the Village of Euclid versus the Ambler Realty Company (272 U.S. 365), the Court cited that zoning will "tend to prevent street accidents . . . by reducing the traffic and resulting confusion in residential sections." The Court believed that the absence of zoning would lead to problems "until finally, the residential character of the neighborhood and its desirability as a place of detached residences are utterly destroyed."

Similar conclusions were reached in Village of Belle Terre versus Boraas (416 U.S. 1). The Court cited that

> a quiet place where yards are wide, people few, and motor vehicles restricted are legitimate guidelines in a land use project addressed to family needs . . . . The police power is . . . ample to lay out areas where family values, youth values, and the blessing of quiet seclusion and clear air make the area a sanctuary for people.

In a similar case, the County Board of Arlington County, Virginia versus Rudolph A. Richards (434 U.S. 5), the Court cited that

> A community may decide that restrictions on the flow of outside traffic into particular residential areas would enhance the quality of life thereby reducing noise, traffic hazards and litter . . . . The Constitution does not outlaw these social and environmental objectives . . . .

From a review of court cases, it appears that the exercise of police power, through land use zoning or traffic restriction, is valid if it has a substantial relation to public health, safety, and general public welfare, and is neither arbitrary nor unreasonable. Other legal considerations involve the rights of access of both through-traffic motorists and residents. Van Antwerp (4) cited that no compensable damage had been done unless residents were denied total access to their property. For through-traffic motorists, courts were similarly unwilling to give credence to complaints as long as alternate travel routes were available.

Some questions have arisen, however, with regard to the validity of diversion methodologies because some are not specified in the Uniform Manual of Traffic Control Devices (5) or in applicable state traffic codes. This issue was the basis for the case of Rumford versus the city of Berkeley [31 Cal. 3d 545, 645, p.2d. 183 Cal. Rptr. 73 (1982)], in which the legality of traffic diverters was questioned. The California courts held that the diverters were illegal because they did not conform to the specifications for official traffic control devices in the California Vehicle Code.

This ruling resulted in a new legislative act to redefine the meaning of "official traffic control devices," and excluded "islands, curbs, traffic barriers, or other roadway design features" from this category. This new legislative act also gave local governments the authority to adopt regulations that prohibit "entry to, or exit from, or both, from any street by means of islands, curbs, traffic barriers, or other roadway design features to implement the circulation element of a general plan. . . . ." The act further stated that "the regulations . . . shall be consistent with the responsibility of local government to provide for the health and safety of its citizens." The provisions of access for emergency vehicles was apparently a consideration in the "health and safety" clause.

On the basis of the review of legal issues and previous research, the following steps are recommended in developing a traffic management strategy:

1. Perform a comprehensive traffic study, and develop a full understanding of the problem.
2. Consider the inconvenience caused to both residents and through-traffic motorists. Viable alternative routes should be provided for through-traffic motorists.
3. Consider emergency vehicle (police, fire, ambulance) movement.
4. Consider the movement of trucks, and provide specific truck routes.
5. Involve both residents and local officials in the planning process.
6. Develop a traffic management plan as part of the areawide traffic circulation element of a general plan.
7. Gradually implement the traffic management plan to provide both residents and through-traffic motorists with an adequate adjustment period.
8. Monitor traffic flow at appropriate locations to assure that the plan objectives are accomplished.

TRAFFIC MANAGEMENT CONCEPTUAL PROGRAM

The recommended plan consists of a traffic management program and recommended improvements to both intersections and the road network. The plan attempts to "manage" systemwide traffic flow by encouraging traffic on selected streets and discouraging it on others. Figure 1 shows the traffic management program for a portion of Greenwood Village. Greenwood Village is located between Belleview Avenue and Orchard Road.

For the portion of Greenwood Village that is shown in Figure 1, residential areas are generally located west of Quebec Street and the commercial areas are located east of Quebec Street (Note: Many internal residential streets are not shown in Figure 1.)

The traffic management program was based on a thorough review of the travel demand, as well as the legal constraints to traffic direction. The provision of viable routes for through traffic was a major consideration. The following example illustrates this concept.

As shown in Figure 1, traffic flow is discouraged in the residential areas west of Quebec Street. These areas are impacted by two primary east-west routes, Orchard Road and Belleview Avenue. If both routes were upgraded to accommodate through traffic, the residential areas would be heavily affected. Conversely, if through traffic was restricted on both routes, Greenwood Village would be providing no viable east-west route to accommodate the travel demand. Based on legal considerations reviewed previously, serious questions could be raised about the reasonableness and validity of such an action by Greenwood Village. Thus, the plan encourages east-west movement on Belleview Avenue and generally discourages east-west movement on Orchard Road. This action attempts to balance the need for environmental protection against the need for through-traffic routes for east-west travel demand.

A list of the principal conceptual elements of this plan follows.

1. Traffic flow would be discouraged in the environmentally sensitive residential areas.

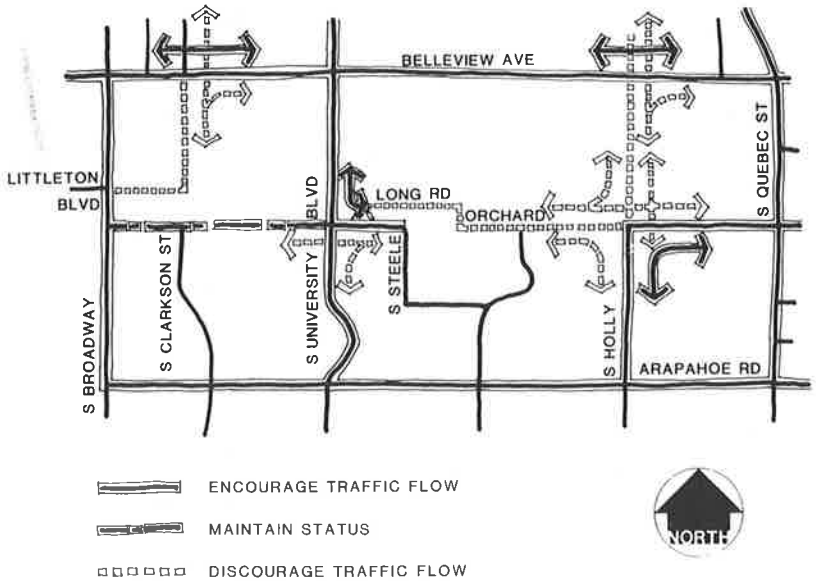

FIGURE 1 Conceptual plan for traffic management in Greenwood Village.

2. Traffic flow would be encouraged in the commercial zone that is located east of Quebec Street.

3. Through traffic peripheral east-west movement would be encouraged on that portion of Belleview Avenue that is adjacent to and west of the commercial area, and on Orchard Road east of Holly Street. East-west movement would be discouraged on Belleview Avenue east of the commercial area and on Orchard Road west of Holly Street.

4. For the portion of the plan shown in Figure 1, through traffic north-south movement would be encouraged on Broadway, University Boulevard, and Quebec Street. Through-traffic movement is discouraged on Littleton Boulevard-Clarkson Street and Holly Street north of Orchard Road.

IMPLEMENTATION OF TRAFFIC MANAGEMENT

Traffic management will be implemented in Greenwood Village by traffic signal timing and geometric improvements at intersections, the use of speed undulations, and roadway widths (number of lanes). A description of the various implementation measures follows.

1. Traffic signal timing and geometric control at intersections. Traffic signal timing is generally a function of traffic demand, with green time allocated to accommodate the traffic flow. However, in a management strategy, green time would be allocated to provide capacity for the desired movements, and to restrict capacity for unwanted movements. A key advantage of the traffic signal control system is that access is unrestricted for emergency vehicles (police, fire, ambulance). Signal timing control is recommended for the intersections shown in Figure 1, where specific traffic movements are encouraged or discouraged.

For example, a three-phase signal could be provided for the Holly Street-Orchard Road intersection shown in Figure 2. One phase could provide for south-east movement, the second phase for north-south movement, and the third phase for east-west movement. The initial signal timing would be set to generally accommodate the existing demand. More time would gradually be allocated to the desired south-east movement, with less time allocated for the other phases. The signal timing would be complemented by signs that prohibit right turns on red lights, and by the construction of additional turn lanes for the desired south-east movement. The additional lanes are shown in Figure 2.

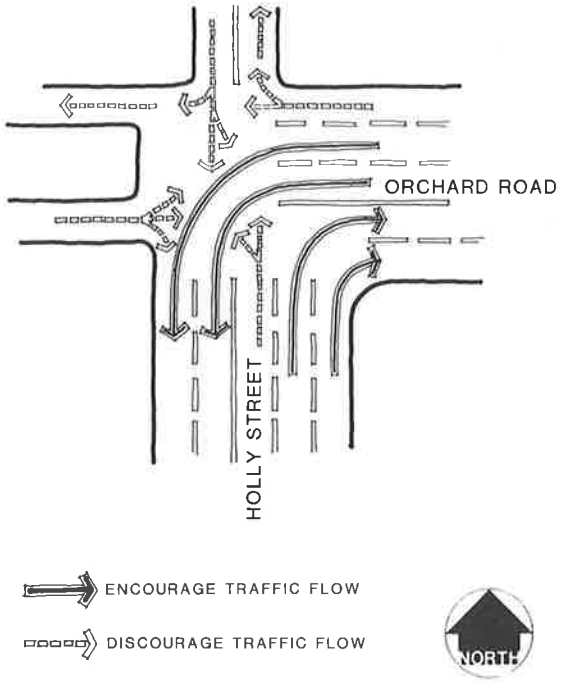

FIGURE 2 Management of traffic flow at an intersection.

2. Speed undulations. Speed undulations may be used to restrict vehicle speeds to 25 mph on selected roadways. Candidates for this geometric roadway treatment would include Orchard Road west of Holly Street, and Holly Street north of Orchard Road.

3. Posted speed limits. As the speed undulations are installed, the posted speed limits should be changed to reflect the goals of the traffic management conceptual program. Thus, the roads with undulations would be signed for lower speeds; conversely, the roads on which traffic flow was encouraged would be signed for higher speeds. Pre-

cise speed limits would depend on the spacing of the undulations (300 ft would reflect a 25 mph speed), and the 85th percentile speed on the other roadways.

4. Unsignalized intersections on arterial roadways. There are several unsignalized intersections on principal arterials that provide access to Greenwood Village residential areas. Residents have occasionally requested signals at these locations. Although the traffic volume does not satisfy signal requirements as specified in the Manual on Uniform Traffic Control Devices (5), motorists are forced to wait for openings in the traffic stream, and experience a poor level of traffic service. However, this poor level of service is also experienced by nonresidents who may wish to drive through the neighborhood. Traffic signals would facilitate turns by both residents and nonresidents.

The present practice of installing left-turn bays at these unsignalized intersections appears to be the appropriate solution. The left-turn bays allow for motorists on the arterials to safely turn; they also facilitate through traffic on these arterial roadways. Residents will experience delays on the unsignalized cross streets, but these delays also discourage nonresidential through traffic during the peak periods.

5. Roadway width (number of through lanes). The roadway plan for Greenwood Village proposes a recommended number of through lanes and complements the recommended traffic flow plan shown in Figure 1. Roadway widening was proposed for several routes, including Belleview Avenue and Quebec Street, on which traffic flow was encouraged. Travel access to the commercial development east of Quebec Street will be enhanced with the proposed roadway improvements to Belleview Avenue, Orchard Road, and Quebec Street. As mentioned previously, these recommended improvements will not totally accommodate the anticipated travel demand, and traffic management measures must be implemented to prevent through traffic from using residential streets.

ACKNOWLEDGMENT

This paper is based on work performed under contract to the city of Greenwood Village, Colorado. The authors wish to acknowledge the cooperation of the Greenwood Village Traffic and Transportation Committee and Steve Schroder, Greenwood Village Director of Community Development. Special appreciation is extended to Patty Haldorsen for editorial assistance, Barbara Binge and Barbara Hussey for manuscript preparation, and Bob Reish, David Bredahl, and Mike Hussey for technical consultation.

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Publication of this paper sponsored by Committee on Transportation System Management.