

Factors Affecting Selection of Lane Width and Shoulder Width on Urban Freeways

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Over the years a set of desirable design standards has evolved for lane width and shoulder width on freeways. These standards have been applied extensively, and a level of comfort has developed in which the use of full design standards results in roadways that are safe and operate satisfactorily. The use of these full standards is preferred and, all things equal, should form the basis for roadway design. However, especially in the upgrade and reconstruction of existing roadways—many of which were not originally built to full standards—a variety of competing factors begin to require attention. Some of the issues that justify consideration are (a) traffic operations, (b) traffic safety, (c) maintenance, (d) enforcement, (e) project cost, (f) public acceptance of the project, and (g) environmental issues. In effect a complicated trade-off analysis begins to take place. Although it is clearly desirable to construct a roadway that will be safe to operate and maintain, frequently other issues such as cost and environmental impacts can be greatly mitigated if something less than full design standards are used, at least at selected locations on a project. The effects of these various factors on the selection of lane width and shoulder width on urban freeways are assessed.

Over the years, a set of desirable design standards has evolved (1). These standards have been applied extensively, and a level of comfort has developed in which the use of full design standards results in roadways that are safe and operate satisfactorily. The use of these full standards is preferred and, all things equal, should form the basis for roadway design. This is particularly true when a proposed roadway improvement represents an “ultimate” plan for that particular facility.

However, especially in the upgrade and reconstruction of existing roadways—many of which were not originally built to full standards—a variety of competing factors begin to require attention. Some of the issues that justify consideration are (a) traffic operations, (b) traffic safety, (c) maintenance, (d) enforcement, (e) project cost, (f) public acceptance of the project, and (g) environmental issues. In effect a complicated trade-off analysis begins to take place. Although it is clearly desirable to construct a roadway that will be safe to operate and maintain, frequently other issues such as cost and environmental impacts can be greatly mitigated if something less than full design standards are used, at least at selected locations on a project. In fact, in addressing project feasibility, the choice may well be that, by using reduced standards, a meaningful project improvement, although perhaps not the perfect improvement, can be implemented. If strict adherence to all standards is mandated, it may be that no project improvement is feasible. Consideration needs to be given to the marginal benefits gained from marginal increases in expenditures. Nevertheless, in considering the use of reduced standards, it is important to be comfortable that, by so doing, traffic operations and safety will be acceptable.

Although only limited data exist concerning the use of reduced standards, the experience with reduced lane and shoulder widths has generally been good. Despite the record, there is continuing concern as to the appropriateness of reduced standards given the relatively small amount of relevant evaluation that has been performed. The NCHRP has under way a 27-month, \$300,000 study (Project 3-43) to help provide additional understanding of these complex issues.

Thus as a general approach it is suggested that full standards be used initially as the basis for highway design. On the basis of the conditions that occur at specific locations along a project, it may well be appropriate, with justification, to deviate from full standards at those locations to permit the project to move forward cost-effectively—if experience elsewhere leads to a reasonable assurance that the use of reduced standards will still result in a roadway project that is safe and operates acceptably. For this approach to work it requires that those in decision-making positions be receptive to the use of reduced standards when appropriate. Technical staff need to provide the necessary supporting justification. At least to an extent this is a statement of the obvious. Given the limited funds relative to the needs it has been suggested (2) that full compliance with AASHTO standards (1) is not always the most effective use of available space. One means of providing additional capacity quickly and inexpensively has been to reduce or eliminate shoulders and to narrow lanes. Even though the safety records of those projects that have been evaluated are generally good, there is continuing concern as to the appropriateness of shoulder removals given the limited amount of evaluation.

Many older multilane urban freeways were built without full left shoulders, right shoulders, or both, and continue to operate that way today. Examples include the Triboro Bridge approach in New York City, Lake Shore Drive in Chicago, Bayshore Freeway in San Francisco, and I-95 across the Bridgeport Harbor in Connecticut.

Most newer freeways provide full left and right shoulders when there are six or more lanes. The provision of these shoulders is consistent with AASHTO design guidelines and Interstate highway system criteria. However in the 1960s mounting congestion on freeways in the Los Angeles area caused the California Department of Transportation, known as Caltrans (then the Division of Highways), to look at ways of increasing freeway capacity within existing paved rights-of-way. This led to the provision of additional travel lanes by narrowing lanes to 11 ft in a few cases, 10.5 ft, and reducing shoulder widths. By 1989 there were 180 miles (one-way direction) of urban freeways with nonstandard shoulders and narrow lanes in Los Angeles (3).

Agencies in other urban areas and states followed California's initiative. Houston subsequently provided additional travel lanes by narrowing shoulders. By 1978 increased capacity through the

use of shoulders and narrow lanes had been implemented in Denver, Nashville, Pensacola, Boston, New York City, Providence (Rhode Island), and Portland (Oregon) as well as the Hartford area in Connecticut (4–12). Since then projects have been implemented in Chicago, Dallas, and Phoenix (7).

At most of the projects the anticipated traffic engineering benefits were realized. For example, the added lane increased the capacity of the section with a resultant decrease in total travel times, an improvement in the level of service and a reduced number of traffic conflicts. Some projects were designed to provide space for high-occupancy-vehicle (HOV) operations, whereas others were modified to provide emergency parking lanes.

ISSUES

Although safety is often the reason offered in opposition to the use of reduced standards, several issues are interrelated to safety and operations. In addition to safety, issues include lane positioning, frequency of stops, maintenance, enforcement, capacity, weaving, and sight distance. The following discussion will review the available information on these issues.

Safety

The accident experience initially reported by McCasland and Biggs (6) in 1980 and updated by Urbanik and Bonilla in 1987 (7) for 24 projects indicated that most of the sites experienced decreased accident rates after the projects were implemented. Houston and Los Angeles are prominent, with the largest number of documented cases; however, documentation varies substantially from one project to another.

McCasland and Biggs (6) noted that narrowing of the lanes to 11 feet (or occasionally 10.5 feet) while maintaining shoulders did not change accident rates. Projects in which one or both shoulders were eliminated during peak periods did not experience increases in accident severity, although it is important to note that unpaved emergency parking space existed beyond the right lane except at bridges. There were questions however about future effects and whether increasing volumes would bring back the level of congestion that existed before the improvements. Since the project to increase capacity also brought about an immediate improvement in the level of service on the freeway, it was believed that the congestion reduction benefits overshadowed the negative effects of reducing or eliminating shoulders.

A review of accident rates on the California projects (5–7) revealed that higher accident rates had not materialized several years after lanes were narrowed and left shoulders were removed. The projects represent long-term operational improvements because operations within the sections never returned to stop-and-go operation, even though the total volumes eventually approached or exceeded those before the improvements. The reason for the permanent nature of the improvement can be attributed to the metering effect of the upstream interchanges. The result is that the per lane volumes in the improved section remained at levels below the preproject level.

An important issue pointed out first by Urbanik and Bonilla (7) and later by Levine et al. (13) is the issue of accident migration. Urbanik and Bonilla demonstrated that accident migration is not a problem on well-designed projects. The conversion to re-

duced left shoulder widths and 11-ft lanes should be based on an analysis demonstrating that operational problems are not being relocated to another point in the highway system; traffic engineering studies are needed to ensure that proposed improvements do not create new problems.

Lane Positioning

The elimination of shoulders potentially has an impact on operations in a number of ways, including the lane positioning of vehicles. Urbanik and Bonilla (7) conducted a study on the Katy Freeway (I-10) in Houston to evaluate the impact of a concrete median barrier on lane placement. A comparison of vehicle placement on the lane relative to the left edge line was made on a section with a full shoulder and one with a 1-ft shoulder. The findings from the study indicated that driver performance relative to shoulder width could be measured and used as an indicator of minimum desirable shoulder widths. The initial study showed a “shy” distance of about 1 ft with a 1-ft shoulder. They suggested that the prevailing practice of desiring a 2-ft minimum shoulder width appears correct.

Urbanik (unpublished research, Texas Transportation Institute, College Station, August 1989) later evaluated vehicle placement within the left lane of a freeway at three locations along the southbound I-45 (Gulf Freeway) in Houston as it approaches I-610 South (South Loop Freeway) using means more sophisticated than those used in the initial study. Urbanik concluded that lane placement is affected by lane width, distance to barrier, darkness, and the volume in the adjacent lane. However, the data base was insufficient to make specific recommendations other than the apparent desirability of providing greater shoulder width than the existing width of less than 1 ft.

Characteristics of Stopped Vehicles on Urban Freeways

The existence of a shoulder provides an opportunity for vehicles to stop outside a traffic lane. These stops may be voluntary or involuntary; this distinction is important because voluntary stops may be deferred.

Vehicle Stop Rates

Hauer and Lovell (3) conducted a study on safety measures aimed at reducing accidents occasioned by vehicles stopped on freeway shoulders. They concluded that for every emergency (involuntary) stop by a passenger car there are seven to eight leisure (voluntary) stops, and for every emergency stop by a truck there are about five leisure stops. Trucks stop for emergencies almost three times more frequently than cars. It was cautioned that these data primarily represent daytime stops. Detailed data collected in Houston (14) suggested that one vehicle breakdown can be expected to occur about every 35,000 vehicle mi of travel.

Surveys of Drivers Stopped on Shoulders

Urbanik and Bonilla (7) conducted two data collection efforts. In both studies sections of roadways were periodically observed for

stopped vehicles and data were collected on the type of vehicle and purpose and length of the stop. In the first study main-lane stops appeared to be disproportionately represented in the section without any shoulders. Main-lane stops were observed at a rate of 1 in 167,196 vehicle mi overall, in comparison with a rate of 1 in 16,129 vehicle mi for the one section without any shoulders. In the second study they found that use of the left shoulder is infrequent even on sections with fully paved inside shoulders. The one observed main-lane stop was on a section with no left shoulder.

Urbanik and Bonilla (7) used a floating-car observer to survey stopped vehicles by either handing a questionnaire to the driver or placing the questionnaire on the windshield of the vehicle stopped on the left shoulder. The most significant finding was the higher rate of involuntary stops for those using the left shoulder. This result is consistent with the belief that drivers prefer to use the right shoulder when the option exists.

Data from Caltrans (15) for the Los Angeles Hollywood Freeway (State Route 101) indicate a rate of 1 stop per 9,800 vehicle mi on the basis of 337 observed stops. The disablement rate (stops longer than 8 min) was 1 per 25,000 vehicle mi. The data were collected by stationary observers.

Again, Texas data (14) suggest a disablement rate of about 1 per 35,000 vehicle mi of travel. This data base is extremely good since it measures only vehicle breakdowns and is based on extensive data collection. Of the breakdowns 35 percent were due to a flat tire, 18 percent ran out of gas, 15 percent had overheated engines, 12 percent had electrical or mechanical problems, and 20 percent broke down for other reasons.

Maintenance and Enforcement Issues

The reduction of shoulder width reduces the functional usefulness of shoulders for police enforcement operations, highway department operations and maintenance, incidence responses, and other emergency service activities. In 1986 the California Highway Patrol (CHP) and Caltrans (16) conducted surveys of

- CHP officers and supervisors responsible for patrolling urban freeway segments,
- Caltrans operations and maintenance supervisors responsible for the particular freeway segments,
- Relevant incident response team personnel,
- Fire suppression and rescue service teams, and
- Towing service operators.

A total of 122 questionnaires from field management and supervisory personnel formed the basis of the report. The findings indicate that provision of at least one shoulder is important.

CHP personnel indicated that the efficiency and effectiveness of enforcement operations are substantially affected when shoulders are not available. They also indicated that the safety of individuals involved in an enforcement-related activity is a major concern. Some officers are reluctant to initiate an enforcement action in areas without shoulders. Almost all the officers reported that they try to make motorists drive to a safe location, but frequently the violator does not understand or want to comply with the officer's direction. CHP recommended standard shoulder widths of 10 feet in open areas and 12 ft in areas bordered by barriers. CHP recommended that, when shoulder reduction must

occur, only median shoulders should be removed. When no shoulders can be provided, spacious turnouts should be provided.

Maintenance operations, which are commonly accomplished from a shoulder, usually require closing a freeway lane when there is no shoulder of adequate width to accommodate personnel and equipment. Closing a freeway lane can result in more congestion. More personnel, equipment, and time are required to provide motorists with advance warning. Although a highly accurate cost comparison between maintenance activities performed at locations with and without shoulders was not available, an increase of 50 to 250 percent in the cost was estimated by Caltrans. The increase was based on the following: (a) increase in personnel use, (b) increase in equipment use, (c) decrease in average daily production, (d) increase in labor cost when Saturday or Sunday work results in overtime pay, and (e) increase in the number and extent of damage to highway facilities. Eighty-five percent of the respondents indicated that elimination of the left shoulder, if a shoulder must be eliminated, would create fewer maintenance problems. This is particularly true when a median HOV facility can be used for maintenance during nonpeak periods. Forty-two percent of the maintenance personnel considered 10 feet to be the minimum shoulder width for maintenance activities, whereas 28 percent considered 8 feet as the minimum shoulder width for maintenance activities.

The report included several suggestions and recommendations on methods that could be used to mitigate problems for maintenance personnel when there is no freeway shoulder. Sample recommendations include (a) more input from maintenance personnel, (b) replace cable and metal median barrier with concrete barrier, (c) eliminate or replace high-maintenance glare screens on concrete barriers, (d) construct turnouts, (e) provide adequate structural strength for shoulders that are used as lanes, (f) relocate drainage inlets, and (g) plant low-maintenance landscaping.

Freeway shoulders are used by maintenance as well as other emergency equipment to reduce response time to the scene of incidents when lanes are congested or blocked by traffic. Because of the increase in response time when shoulders are reduced in width, motorists are exposed to hazardous conditions, traffic congestion, and delays for longer periods of time than if there were shoulders.

Tow-truck operators inside the city of Los Angeles were surveyed to determine the impact of shoulder availability on tow-truck operations. An average of 1,328 service calls per month were reported by operators for 9 of 18 police divisions in the city of Los Angeles. Although it does not directly relate to the issue of narrow shoulders, the extent of calls does indicate the need to provide at least one full shoulder.

Fire suppression and rescue personnel have indicated that urban freeway shoulders reduce their response times during periods of heavy traffic or when traffic is congested because of an incident. They responded to 1,930 freeway emergency situations during the 12-month period ending June 30, 1987. The shortest response times are on freeways with both left and right shoulders. The next shortest response times are on freeways with only a right shoulder; this is followed by the response times on freeways with only a median shoulder. Average response times on freeways with no shoulders are more than double those on freeways with both shoulders. Again the need to maintain at least one shoulder is important.

Urbanik and Bonilla (6) also demonstrated that, on the basis of typical vehicle breakdown rates, sections with no shoulders were

likely to cause as much delay because of incidents as they would see because of added capacity. Possible exceptions to this basic principle would be short sections (e.g., underpasses) and facilities with special mitigation, such as that sometimes provided at major bridges and tunnels.

Capacity and Weaving

The 1985 *Highway Capacity Manual* (17) provides reduction factors for computing capacity because of narrow lanes and narrow shoulders. A footnote to Table 3.2 of the manual indicates that adjustment factors for lateral clearance may not be appropriate with high types of barriers. Judgment is suggested in applying the factors. Newman (18) in 1985 concluded that 11-ft lanes have no effect on the level of service and safety and no measurable impact on capacity.

Urbanik et al. (19) presented freeway capacity data that included 12 high-volume flow rates observed in Texas. Only 2 of the 12 observations were greater than the 2,349 vehicles per hour per lane that were observed on a section with 11-ft lanes and full shoulders. It should also be noted that the high-volume section with 11-ft lanes is located just downstream from a weaving section with 11-ft lanes and no left shoulder. There is no indication of weaving problems associated with the high flow rates.

Weaving analysis in general has been the subject of numerous studies. The most recent and promising work was done by Cassidy et al. (20) in California. They concluded that existing methods do not have a strong predictive ability. The research of Cassidy et al. suggests that weaving capacity is a function of the number of lanes (i.e., no point on the freeway should have more than 2,200 passenger cars per hour per lane), geometric configuration (e.g., the use of optional lanes at multilane exits), and weaving section length. An 11-ft lane width is unlikely to have any more of an impact on capacity in weaving sections than it has on the capacity of basic freeway sections. However, weaving is more a question of the number of vehicles per unit length (density) than it is a question of lane positioning. That is to say, weaving problems occur when too many vehicles try to use the same lane at the same time or when a vehicle slows to look for a gap in an adjacent lane.

Sight Distance

The issue of horizontal sight distance is based on the basic idea of providing adequate stopping sight distance. Virtually no research has been done on the issue. Leisch (21) has made recommendations concerning horizontal sight distance that are based on making the most effective use of the available space. Because of the directionality of sight distance obstructions, the use of shifted alignments can sometimes reduce the sight obstruction.

A critical evaluation of the horizontal stopping sight distance model suggests that it may be conservative relative to typical freeway applications. The likelihood that a 6-in.-high object entering heavy traffic is not immediately hit, regardless of stopping sight distance, seems remote. Under light traffic conditions on a multilane freeway, lane changing is as reasonable an action as any.

The more likely hazard on a busy freeway is a vehicle stopped because of a breakdown or congestion. Congestion is a safety problem that can be amplified by inadequate sight distance (hor-

izontal or vertical). One could argue that maintaining stopping sight distance for stopped vehicles is a reasonable compromise when reconstructing an existing facility for which improving the horizontal alignment is not a practical alternative.

However, the issue of horizontal sight distance is complicated by other factors. The sight obstruction is typically a concrete median barrier or a bridge column. If the obstruction in the curve is a bridge column, it is likely that object height is irrelevant. With a bridge pier there is no advantage to a higher object for horizontal sight distance. With a median barrier object height is important because it may be possible to see over the barrier. However, seeing over the barrier is complicated. Superelevation and vertical curves further complicate sight lines.

AASHTO suggests that taillights 1.5 to 2.0 ft high, and a 1.5-ft taillight height is appropriate as a design value. Given a 32-in. concrete median barrier, visibility is marginal at best under ideal conditions for a 2.0-ft taillight height and would likely be obscured for a 1.5-ft object height. Some barriers may be higher because of differential elevations between roadways or glare screens. The high-mount brake light is of some help, but only when the brake lights are on. It would seem to be necessary to have roadway lighting to argue for an object height of more than 1.5 ft.

Research by Urbanik et al. (22) on two-lane highways indicated that the presence of vertical sight distance restrictions did not, by itself, cause a safety problem. The AASHTO stopping sight distance model alone is not a good indicator of accident rates on two-lane highways. Higher accident rates were found to exist at access points such as driveways and intersections. Extrapolating the findings for two-lane roadways to freeways would suggest that reduced sight distance would likely be a significant consideration only when stopped vehicles have a high probability of being present.

In summary being able to provide sight distance by seeing over a median barrier is a complex situation. Good lighting, the absence of columns or high barriers or glare screens, and no elevation distortions such as vertical curves or superelevation appear to be prerequisites for good sight distance. Sections exist in both Texas and California where horizontal sight distance is not adequate in sections with reduced design standards. Those sections have not been explicitly evaluated for accident experience. If problems are occurring, however, they have not been noted.

CONCLUSIONS

The studies by Urbanik and Bonilla (7), Urbanik (unpublished research), and McCasland (8,9) indicate that the use of narrow shoulders and narrow lanes can be safe and cost-effective. This conclusion includes observation of long-term effects. The research suggests that left shoulder removals are preferred to right shoulder removals, because drivers prefer to use right shoulders. It is important to maintain at least one shoulder. Maintenance and enforcement personnel also prefer the retention of the right shoulder if a shoulder must be eliminated.

Limitations in the existing accident data base include the fact that most of the data are from Sun Belt states (Texas and California). Additional consideration must be given to snow removal and storage requirements when interpreting the data.

The most serious limitations in the current understanding of the use of shoulders and narrow lanes involve the questions of how

narrow is too narrow and what are the compounding impacts of using several substandard design elements simultaneously? These issues apply to both lane width and shoulder width. For example, looking at left shoulder width it appears that, on the basis of experience, shoulders should be either 4 ft or less or 8 ft or more. Stated another way, shoulders wider than 4 ft and less than 8 ft give the appearance of being wide enough to park a car when in fact they are not. Although data have suggested two break points for left shoulders on the basis of empirical observation, minimum and desirable values for left shoulder widths have not clearly been demonstrated. Furthermore, the need to occasionally use minimum widths on the right shoulder for short distances (e.g., to avoid rebuilding or relocating bridge supports) requires careful consideration, because it is likely that the "shy" effect on the passenger side (right side) is greater than that on the driver side. That is to say, the data for clearances to the median barrier that have been provided should not be assumed to be valid for right side clearances.

Capacity and weaving do not appear to be adversely affected by reduced left shoulder width or by 11-ft lanes. There may be an impact of reduced left shoulder width on horizontal sight distance; however, the effects of this are unknown. Some existing facilities are known to possess sight distance deficiencies with no known documentation of problems.

Full left and right shoulders appear to be desirable features on all freeways. However, the removal of the left shoulder and the narrowing of lanes to 11 ft to increase capacity in a congested corridor may be an appropriate treatment when the only reasonable alternative is not to provide additional capacity. Traffic operations and traffic safety are improved on congested urban freeways when left shoulders are reduced and lanes are narrowed to 11 ft if the project is properly developed. Left shoulder removals are preferable to right shoulder removals because the right shoulder is usually selected by motorists when given a choice. The removal of both shoulders for any significant distance does not appear to be desirable from either an operational or safety viewpoint.

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