OPERATIONAL, SAFETY, AND LIABILITY ISSUES OF CONVERTING FREEWAY SHOULDERS TO TRAVEL LANES

by

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SUMMARY

Many urban areas across the United States experience congestion that not only reduces the effectiveness of the freeway system, but also reduces the capability of the public to effectively move people and goods. One answer to this problem is to reduce freeway mainlane widths and use the roadway shoulders to create additional lanes of travel. These extra lanes may either be used as an additional mixed-use travel lanes or as high-occupancy vehicle (HOV) lanes. The reduction of design standards in using freeway shoulders and narrow lanes is a change from the original freeway design concept. However, it has been observed that full compliance with AASHTO standards may not be the most effective method of using available space (1,2). Most of the projects that have used shoulders to increase capacity have been temporary modifications only to be used until other methods of providing necessary transportation services are available. While these other options are planned, one temporary solution is to modify existing geometry to provide additional capacity. The bottom line remains that when existing standards are reduced, there must be assurance that these exceptions provide the expected operational improvements while not increasing the likelihood of injury to the public.

The objectives of this paper were to:

1. Provide a historical review of previous attempts at shoulder conversion;
2. Provide a review of the operational and safety impacts of converting an existing shoulder to a travel lane;
3. Provide a discussion of the liability issues associated with converting shoulders to travel lanes;
4. Discuss cost and benefits of shoulder conversions;
5. Examine the design issues associated with shoulder conversion;
6. Make recommendations to be taken into consideration when implementing and narrow lane and shoulder-use project; and
7. Make recommendations to be considered in the advanced stages of facility planning to allow sufficient cross-section widths for future modifications.

An extensive research effort was undertaken to identify documentation of previous experience with shoulders used as travel lanes. The literature review was used to identify and quantify the operational and safety implications of shoulders used as travel lanes. Interviews were conducted with transportation professionals to gain knowledge of previous experience of shoulder conversions and to address concerns with implementing shoulder conversion projects. From the issues and concerns identified through the literature review and interviews, recommendations on the use of shoulders for travel lanes were formulated and are presented herein.

It was found that the conversion of freeway shoulders to travel lanes can be an extremely effective method of adding capacity to an existing facility. This additional capacity reduces congestion, having the direct effect of reducing accident experience. The costs of using the shoulders are considerably less than the costs of reconstruction. The costs of implementing a shoulder use project are remarkably small when compared with the option of reconstruction, typically on the order of 30 to 300 times less, depending of the extensiveness of the project.

Several recommendations are presented as a result of the information presented in the paper. When planning for new or reconstructed freeway facilities, it is recommended that forethought should be used in the consideration that shoulders may be used sometime in the future for additional capacity. This may include providing additional cross-section width in the new facility to accommodate for additional lateral clearance and adequate shoulder widths. It is noted that an additional 3 or 4 feet added initially to a cross-section allows for many more options that may be considered in future reconfigurations. It is recommended that a cost/benefit analysis be done to decide if this initial additional cross-section provides significant savings over any future modifications to provide additional capacity.

When retrofitting shoulders as travel lanes, there is not a specific set of guidelines that apply to every project. Every unique problem requires a unique solution. In general, every aspect of new facility design must be checked in a reconfiguration project. Even though many aspects of freeway design will be non-standard in the modification, these features must be checked to assure that they will not cause a greater potential for accidents on the facility. In addition to checking geometric considerations, emergency parking areas must be provided where possible. Where constricted segments exist, such as elevated or depressed freeway sections, strong consideration should be given to incorporating aggressive surveillance and incident management as a part of the modification plans.

These modifications of roadway geometry exposes liability issues for the engineers and agencies which implement these shoulder conversion projects. To alleviate these liability concerns, a key portion of a shoulder conversion project is the documentation of the project. Agencies should provide for the continuous upkeep of operational, safety, and maintenance records for modified sections. This allows for problem areas to be identified and rectified quickly. It should be stressed that shoulder conversions are temporary modifications, and when additional transportation services are provided in the areas where these modifications are used, these reconfigurations should be reversed.

From conversations with experienced transportation professionals and review of pertinent literature, the conclusion was made that reconfiguring freeway cross-sections to use the shoulder for additional capacity is an effective solution providing additional capacity on urban freeways. These projects are relatively inexpensive ways to increase capacity, reduce congestion, and improve public perceptions of the effectiveness of the freeway system.

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INTRODUCTION

Many urban areas across the United States experience congestion that not only reduces the effectiveness of the freeway system, but also reduces the capability to effectively move people and goods. There are options available to alleviate congestion. Some possible solutions that have been discussed include transit programs, congestion pricing, and demand management strategies. However, one of the more common solutions is to add more lanes of travel to increase freeway capacity.

In most cases, barriers exist to widening existing cross-sections to add more lanes. These barriers may include insufficient funding to widen freeway cross-section widths to increase number of mainlanes, legislated barriers imposed by the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) and Clean Air Act Amendments of 1990 (CAAA), environmental and neighborhood opposition to increased pollution and noise caused by construction and expansion, and spacial limitations incurred by adjoining development. One answer to this dilemma is to reduce mainlane widths and use the roadway shoulders to create one or more additional lanes of travel. These extra lanes may either be used as an additional mixed-use travel lane or as an high-occupancy vehicle (HOV) lane.

The reduction of design standards when converting freeway shoulders to operating lanes is a change from the original freeway design concept (1). However, it has been observed that full compliance with AASHTO standards may not be the most effective method of using available space (2,3). Most of the agencies that have used shoulders to increase capacity have justified the projects as temporary modifications only to be continued until other methods of providing necessary transportation services are available. While these other options are planned, one temporary solution is to modify existing geometry to provide additional capacity. The bottom line remains that when existing standards are reduced, there must be assurance that these exceptions provide the expected operational improvements while not increasing the likelihood of injury to the public.

The impacts of shoulder use projects are usually immediate, resulting in highly visible improvement to congested segments of urban freeway. The advantages of shoulder use projects include brief implementation periods with minimal interruption to operations, low costs, reduced delay and travel times, and extremely attractive benefit/cost ratios. There are, however, potential drawbacks. The reduction of the lane and shoulder widths may cause concern with respect to lateral clearances and adjacent lane encroachment. Other disadvantages may include fewer emergency parking areas, problems with entrance and exit ramp configurations, increased maintenance activity, and structural deterioration of the shoulder.

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6. Make recommendations to be taken into consideration when implementing and narrow lane and shoulder-use project; and
7. Make recommendations to be considered in the advanced stages of facility planning to allow sufficient cross-section widths for future modifications.

OPERATIONAL AND SAFETY ASPECTS OF SHOULDER CONVERSION PROJECTS

The use of existing freeway shoulders as travel lanes has been argued as both an effective use of existing cross section and as a potentially dangerous situation to the driving public. There have been several projects across the nation where shoulders have been used to increase capacity on freeways. Shoulders are considered for use as added travel lanes when reconstruction is not a foreseeable option and immediate congestion relief is required.

Potential Situations for Using Shoulder Conversions

Seven situations were identified that could be improved by the use of a shoulder in conjunction with narrow mainlanes. The first six were identified by McCasland and Biggs (1), the seventh by Roper (9).

1. To add an auxiliary lane between ramps;
2. To bypass a queue at an exit ramp;
3. To clear bottlenecks on mainlanes due to roadway geometrics;
4. To reduce merge conflicts;
5. To provide an high-occupancy vehicle (HOV) lane;
6. To use during maintenance or construction to increase capacity of the facility; and
7. To use as added, through capacity.

Add an auxiliary lane between ramps

Freeway segments which experience high traffic demand for the use of the right freeway lane can experience breakdowns on the entire upstream freeway section. An auxiliary lane between ramps can reduce the congestion caused by high entrance and exit ramp traffic demands. Figure 1 shows a situation where a shoulder is taken for use as an auxiliary lane. The entrance ramp configuration is altered to direct entering traffic to the shoulder, taking the merge point away from the inside-right lane at the terminal end of the ramp and placing it downstream on the shoulder.

Bypass An Excessive Queue at an Exit Ramp

Major freeway-to-freeway directional interchanges may experience congestion in peak flows. Queues may form upstream of the interchange, interfering with traffic movements to destinations not involving the congested movements. An additional lane may be added to the interchange approach to allow this traffic to bypass the interchange queue and continue traveling without delay. This situation is depicted in Figure 2. The off-ramp queue has extended into the mainlanes and has blocked the right exit. In this case, the shoulder has been striped for use by the traffic attempting to exit the non-queued exit ramp.

Clearing Bottlenecks on Mainlanes Due to Roadway Geometrics

In many instances congestion occurs when a freeway geometric feature causes constrictions detrimental to smooth operations. This type of situation may occur when roadway geometrics reduce capacity (geometric constrictions, bridges, etc.), traffic volumes increase over a period of time, or when recurring congestion reduces the effective capacity. The situation shown in Figure 3 might be typical of a geometric situation which might be relieved by the use of the shoulder as a travel lane. In this case, the increased volumes due to the upstream on-ramps coupled with the curvature of the freeway might cause a bottleneck due to driver difficulty with both the merge and the horizontal curve.

Reducing Merge Conflicts

If merge areas are being used at near capacity, congestion may cause long queues due to the complexity of merging into extremely high-volume traffic lanes. Upstream of the merge, one of the roadways can be relocated so, that at the merge point, the shoulder is used as an added lane so that the merge movement is eliminated. Figure 4 shows the situation where a merge conflict is reduced by using the shoulder as an additional lane. The double lane entrance ramp is relocated so the right lane of the entrance ramp uses the shoulder lane. The left lane of the entrance ramp is realigned to use the existing added lane instead of merging into the through lane upstream. The shoulder lane may then be terminated at the next exit ramp.

Providing an High-Occupancy Vehicle (HOV) Lane

When retrofitting an HOV lane into an existing freeway cross-section several methods may be used. First, an existing lane may be taken for HOV operations. There have been problems in using this method. This was attempted on the Santa Monica Freeway in Los Angeles, but was eliminated due to public perception of the "unused" lane (9). Second, a new lane is constructed in the median, barrier separated. Or third, the shoulder is used as a bypass lane for HOV operations during the peak periods. Figure 5 shows HOV use on the left shoulder in tandem with reduced lane widths on the mainlanes. The outside shoulder has been kept in this case for emergency use.

Maintenance or Construction

Major maintenance or construction projects may require that one or more lanes be taken for extended periods of time. Narrow lanes and use of shoulders should be given consideration to temporarily increase the capacity of the construction site. This can be achieved by aggressive traffic control and surveillance or for extended periods of time with barricading, restriping, and resigning the roadway section (1). Figure 6 shows an example of shoulder use for maintenance or construction activities. In this case the inside shoulder and the inside lane is taken for construction. The mainlane widths have been reduced and shifted to where the outside shoulder is used as a travel lane.

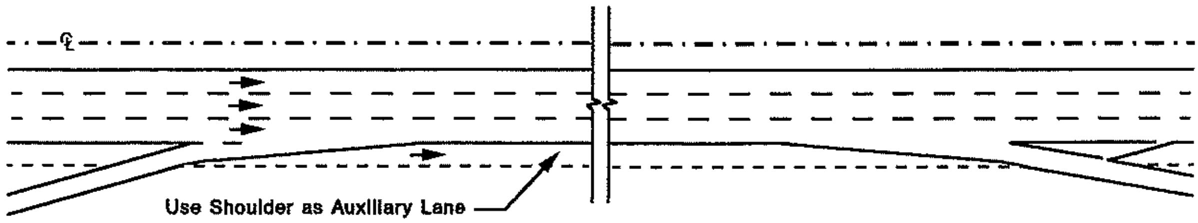

Figure 1. Auxiliary Lane Application of Shoulder Usage (1).

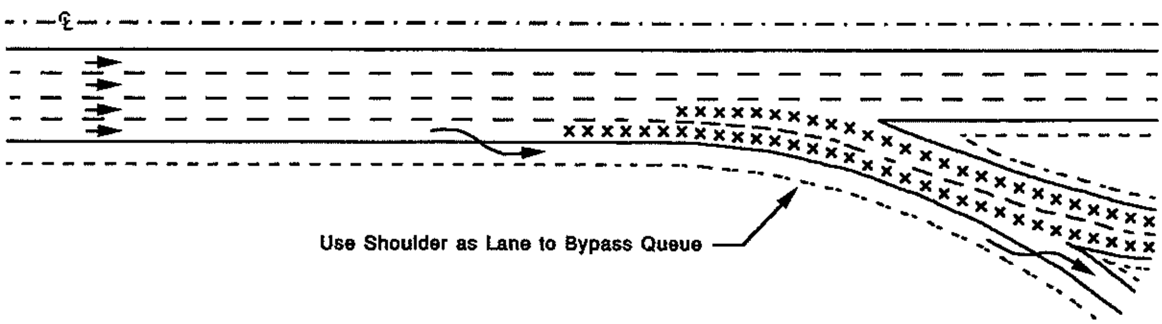

Figure 2. Queue Bypass Application of Shoulder Usage (1).

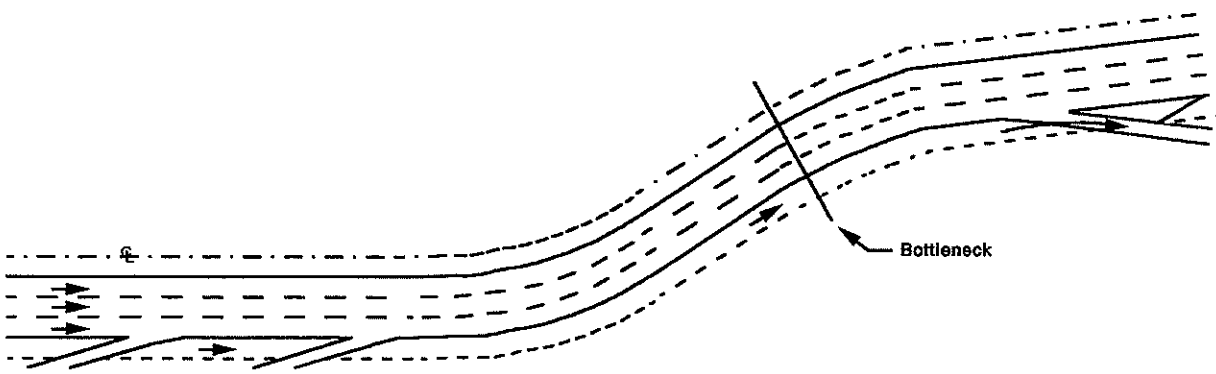

Figure 3. Freeway Bottleneck Application of Shoulder Usage (1).

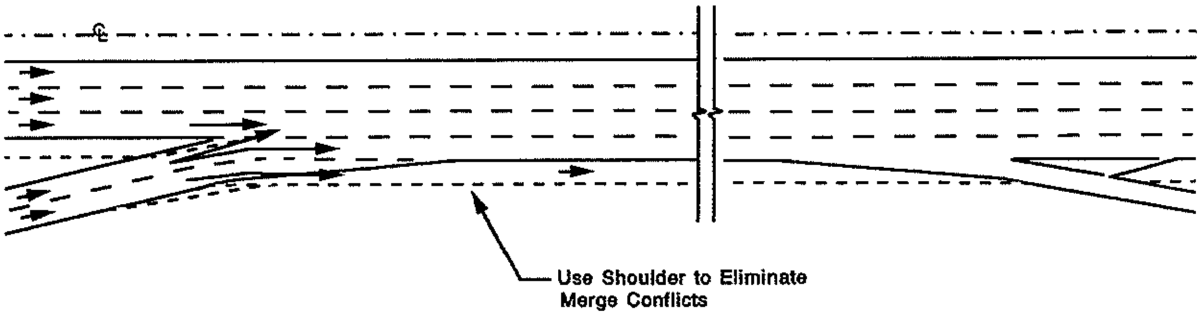

Figure 4. Merge Conflict Reduction Application of Shoulder Usage (1)

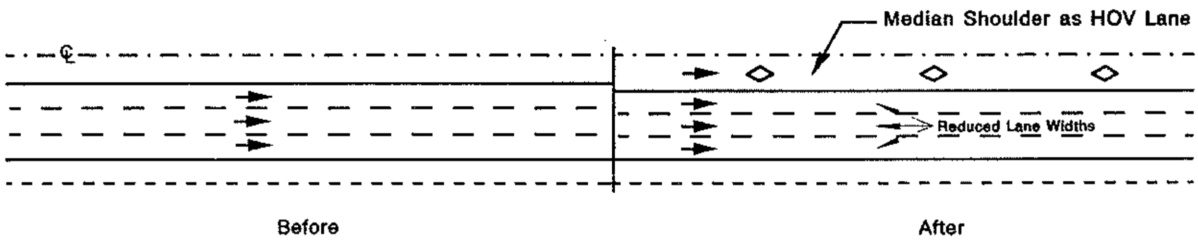

Figure 5. HOV Lane Application of Shoulder Usage (1)

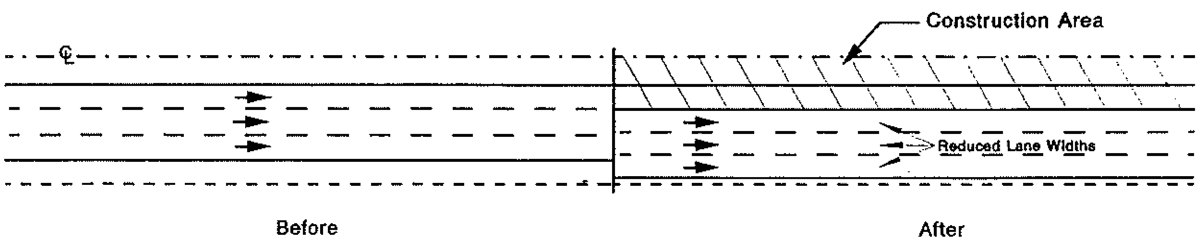

Figure 6. Maintenance or Construction Application of Shoulder Usage (1)

Added Through Capacity

When a facility is operating at or near capacity for extended periods of time, the shoulder may be used for added through capacity. Especially in cases where reconstruction is not possible or not feasible, additional capacity may be added by converting the shoulder to a full-time travel lane. This added lane to increase through capacity is usually longer than any other use and usually operates full-time. Figure 7 shows an example of this situation. The cross-section has been reconfigured to include the inside shoulder as a travel lane. It may or may not be necessary to reduce mainlane widths depending on the width of the total cross-section.

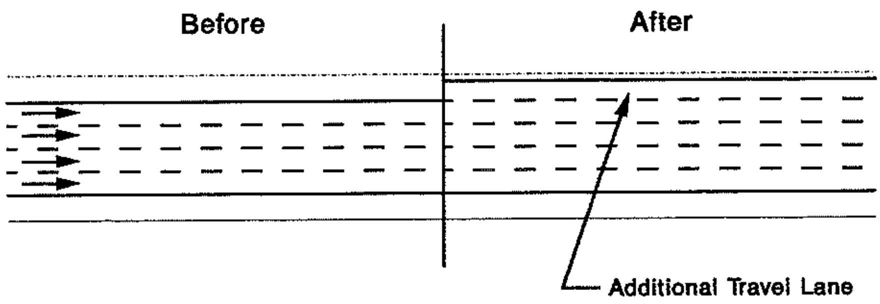

Figure 7. Use of Shoulders for Added Through Capacity

Each of the situations identified may improved by the reconfiguration of the freeway cross-section. The use of the freeway shoulders as travel lanes may be used to solve combinations of these problems as well. For example, the shoulder may be used to alleviate a freeway bottleneck caused by a difficult merge point.

Inside Shoulder Use for Travel Lanes

There are many instances where agencies have used an inside shoulder to provide increased capacity on congested freeways (1,3). Concerns of their use have been spurred by questions about the general safety with the absence of the left shoulder, and the impact of accident severity by their use. Use of the inside shoulder has been mainly on freeway segments either as HOV lanes or as added mixed-use lanes to increase mainlane capacity(3).

California Experience With Inside Shoulder Use

Urbanik and Bonilla reported in detail on the impacts of California's use of inside shoulders (3,6). They studied twelve freeway segments where inside shoulders were used as travel lanes. Before restriping, all of the segments had full inside shoulders and full outside shoulders except on the I-580 site. The outside shoulder on I-580 previously served as an auxiliary lane. The characteristics of the twelve freeway segments along with the reductions in lane and shoulder widths are given in Table 1.

Accident Rates on California Inside Shoulder Use Projects. There was only one significant increase in the accident rate at the California sites studied by Urbanik and Bonilla (6). However, this increase on I-405 NB is believed to be because of special circumstances. The increase in accidents on I-405 was believed to be due to the midlane weaving movements approaching the exit to the US-101 exit ramp. The US-101 ramp operated at over-capacity, which significantly increased the midlane rear-end accidents on the downstream segment. This caused the higher accident rate, but Urbanik did note that the partial inside shoulder was not believed to be the cause of the increase in accident frequency (6).

The I-580 site in Alameda County operated in a somewhat different manner than the rest of the California sites studied by Urbanik and Bonilla (6). Before restriping the segment operated with a full inside shoulder, 4-12-foot mainlanes, a 10-foot full-time auxiliary lane, and no right shoulder. After the restriping, the segment operated with no inside shoulder, four through lanes, a full-time auxiliary lane on the inside right, and a permissible auxiliary lane (4-6 p.m.) in place of the former full-time auxiliary lane. The restriping to provide the extra lane available for peak-hour weaving appeared to cause the reduction of weaving accidents (6).

Aside from the I-405 site, all of the study sites either experienced a non-significant change or a significant reduction in accident rates. Most of the sites experienced this reduction in conjunction with a fairly good reduction in the vehicles per lane in the peak hour. It has been noted that the reduction of congestion is a major influence of decreased accident rates.

Table 1. Characteristics of California Freeways Where Inside Shoulders Were Removed (6).

Freeway, County	Length (mi.)	Period	Cross Section			Vehicles per Lane[1]	Accident Rate (acc/MVM)
			Left Shldr.	Mainlanes	Right Shldr.		
I-5, SB Los Angeles	1.34	Before After	10' 3'	4-12' 5-11'	10' 10'	1700 1490	1.066 1.288
I-5, NB Los Angeles	0.69	Before After	10' 3'	4-12' 5-11'	10' 10'	1700 1490	1.178 0.784
CA-22, WB Orange	3.25	Before After	10' 2'	3-12' 3-11'[2]	8' 8'	2200 1890	0.829* 0.617
CA-60, EB Los Angeles	0.68	Before After	10' 3'	4-12' 5-11'	8' 8'	1770 1370	0.905 0.683
CA-22, NB Orange	0.67	Before After	8' 3'	4-12' 5-11'	10' 10'	2730 2460	0.789 0.685
I-405, NB Los Angeles	7.72	Before After	10' 3'	4-12' 5-11'	10' 10'	2020 2000	0.793* 1.058[4]
US-101, SB Marin	0.31	Before After	8' 2'	3-12' 4-11'	10' 8'	2150 1740	0.649 0.422
I-580, EB Alameda	0.61	Before After	8' 3'	4-12'[2] 5-11'[3]	0' 0'	1840 1580	1.964* 1.436[5]
I-680, SB Contra Costa	0.38	Before After	10' 2'	3-12' 4-11'	10' 10'	2690 2200	1.066 1.015
CA-94, EB San Diego	1.13	Before After	8' 3'	4-12' 5-11'	8' 3'	1580 1470	0.621 0.556

[1]Estimated (peak hour volume times 0.6 divided by number of directional lanes)
[2]Plus a full time auxiliary lane
[3]Plus a part time auxiliary lane
[4]See explanation for increase
[5]See description of project
*Significant difference at the 0.05 level

Accident Severity on California Inside Shoulder Use Projects. Accident severity on the inside shoulder removal projects was of increased concern, even if the actual number of incidents was reduced. Urbanik and Bonilla (6) examined the issue of accident severity on the same California roadway segments. They noted several interesting findings. First, fatal accident rates increased from 0.0031 accidents per million vehicle-miles (acc/mvm) before to 0.0052 acc/mvm after conversion. However, the low number of fatal accidents in the sample caused the comparison to be inconclusive. The injury accident rate remained statistically the same, at 0.31 acc/mvm before and 0.32 acc/mvm after restriping. There did not exist a statistically significant difference in the before and after accident rates after combining the injury and fatal accident rates and comparing them. However, for the non-injury accident category, accidents decreased at a 0.01 level of significance after the left shoulder removal. Therefore, Urbanik concluded that no indication existed that accident severity is heightened by the use of inside shoulders as operating lanes(6).

Upstream and Downstream Accident Comparisons on California Inside Shoulder Use Projects. Urbanik and Bonilla (6) also examined the potential for increased accidents upstream and downstream of segments which had been reconfigured to use shoulders. No segments were reported to have increased accident rates upstream. Only one site, CA-22, WB in Orange County had a significant decrease in accident rates downstream from the "shoulder-use" segment. Urbanik and Bonilla concluded that the restriping of the roadway segments studied had no detrimental effects on the safety beyond the boundaries of each project (6). Inside shoulder removal projects seem to either have a non-significant change or a statistically significant reduction in overall accident rates on the freeway segments studied in California. The explanation for this seems to lie in the fact that decreased congestion reduces the accident potential.

The use of the inside shoulder is advantageous where capacity problems exist and the outside shoulder is needed for ramp access or emergency parking. As can be seen from the California experience with inside shoulder use, safety and operations may be improved because of the additional capacity provided by the additional lane. Accident rates decreased in most instances, and accident severity was not heightened in the California shoulder conversion projects.

Outside Shoulder Use for Travel Lanes

The outside shoulder may also be used to provide additional capacity. The outside shoulder is typically used in shorter segments between ramps to provide auxiliary lanes or elimination of either bottlenecks or merge conflicts.

Outside Shoulder Use Experience in California

Urbanik and Bonilla (6) also examined the use of the outside shoulder in California. The sites they examined included three "permissive" (peak period) use lanes and four sections of "continuous" (full-time) use lanes. All of the segments were under one mile in length. The previous configuration of all of the segments included full outside shoulders and 12' mainlanes. Table 2 summarizes the characteristics of the California outside shoulder use sites cited by Urbanik and Bonilla (6).

Table 2. Characteristics of California Freeway Segments Where Outside Shoulders Were Adjusted (6).

Freeway, County	Length (mi.)	Period	Cross Section			Vehicles per Lane[1]	Accident Rate (acc/mvm)
			Left Shldr.	Mainlanes	Right Shldr.		
Part Time (Permissive Use) Removal							
I-5, NB Los Angeles	0.73	Before After	0' 0'	3-12' 3-11', 11' pl	8' 0'	2110 1560	0.700 0.677
I-5, NB Los Angeles	0.95	Before After	0' 0'	4-12' 1-12', 3-11', 11'	8' 0'	1930 1700	1.368 1.995
I-280, NB Santa Clara	0.74	Before After	2' + 2' +	3-12' 3-11', 10' pl	10' 0'	2050 1970	0.240 0.319
Full Time (Continuous Use) Removal							
I-5, NB Los Angeles	0.45	Before After	0' 0'	3-12' 4-11'	8' 0'	2200 1630	1.403 1.970
I-5, NB Los Angeles	0.75	Before After	0' 0'	4-12' 4-11', 1-12'	8' 0'	1930 1700	2.048 1.647
US-101, SB Los Angeles	0.89	Before After	10' 10'	4-12' 5-11'	8' 1'	2510 2110	1.044 1.318
I-580, EB Alameda	0.50	Before After	8' 8'	4-12' 5-11'	0' 0'	2110 1750	1.680 0.830**

**Significant at the 0.01 level

[1] Peak Hour Traffic multiplied by 0.6 and divided by number of lanes

Accident Rates on California Outside Shoulder Use Projects. There were very important conclusions drawn from the California data. On the four I-5 sections, some trends in the accident data were noticed. The accident rate overall on the four mile section on I-5 did increase significantly from 1.30 to 1.66 acc/mvm. Sideswipe accidents significantly increased from 0.29 to 0.48 acc/mvm, suggesting a weaving problem may have been evident. Rear-end accidents remained stable at 0.76 acc/mvm before and 0.81 acc/mvm after, and a.m. peak period accidents remained unchanged at 0.21 acc/mvm both before and after reconfiguration. As a result of an examination of accident rates on California shoulder use projects, Urbanik and Bonilla concluded that outside shoulders or parking areas are necessary for safe operations, however, other factors including speed differentials between lanes and weaving between lanes may cause other problems. Urbanik strongly suggested that removal of right-hand shoulders is extremely dangerous unless an emergency parking opportunity is provided. (6).

Accident Severity on California Outside Shoulder Use Projects. Accident severity on outside shoulder use in California was also examined by Urbanik and Bonilla. Because of limited accident data, the analysis results were somewhat suspect. The analysis did indicate a trend toward higher accident rates when using outside shoulders as travel lanes, however the statistical significance is limited by the small database. Urbanik did explain that the analysis supported the hypothesis that the right shoulder holds more importance for roadway safety than left shoulders(6).

Outside Shoulder Use in Houston, Texas

McCasland presented a study of the permissive shoulder lane used on northbound US-59 (Southwest Freeway) in Houston, Texas (5). The purpose of using the shoulder was to provide for higher volumes over the Santa Fe Railroad Crossing and to improve the traffic operation south of the Newcastle entrance ramp. The Texas Department of Transportation converted the right shoulder into a travel lane during the peak morning hours of 6:00-9:00 a.m. on weekdays. Figure 8 shows the configuration of the U.S. 59 site. The 0.9-mile section was located between the Newcastle exit ramp to the Edloe exit ramp. The Newcastle northbound entrance ramp was closed during this period by a railroad barrier gate. This ramp traffic was diverted on the frontage road to the entrance ramp past Edloe. The on-ramps were metered at higher rates during the peak period to permit higher volumes of traffic to enter the freeway with less delay. The identification of the right shoulder as a permissive travel lane was designated by the use of non-changeable roadside signs.

The purpose of including this case was to show that in many instances, narrow lane and shoulder use projects include coordination with other modifications to achieve the overall goal of increased level-of-service. In this case, coordination of a ramp closure, increased ramp metering rates, and use of the shoulder as a permissible travel lane all contributed to the elimination of a major freeway bottleneck.

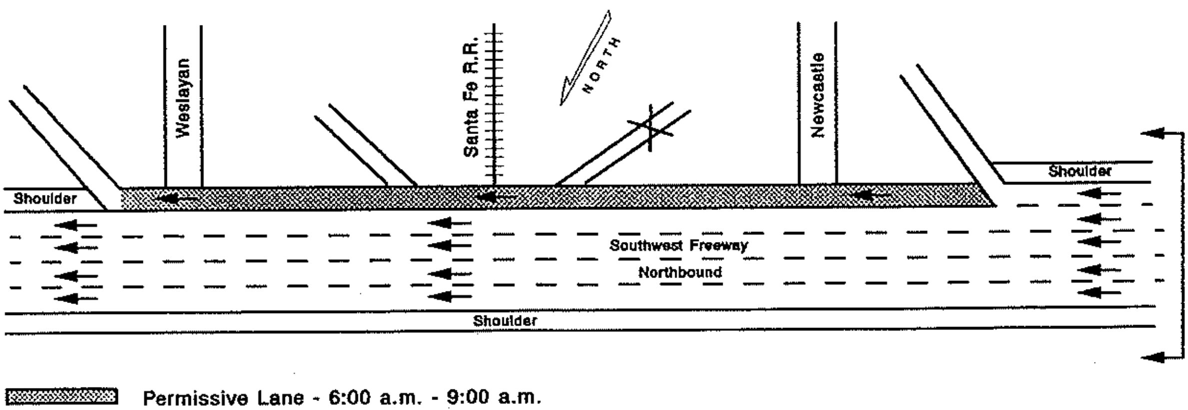

Figure 8. U.S. 59 -- Houston, Texas. Outside Shoulder Use Site.(5)

McCasland identified several factors as to why it was necessary to close the entrance ramp north of Newcastle during the peak period. They included:

1. The elimination of the ramp merging area on an upgrade approaching the bridge section;

2. The queue backup on the frontage road and Newcastle intersection from the metered Newcastle on-ramp is eliminated;
3. Over 500 vph are taken from the bottleneck existing at the Santa Fe Overpass and diverted to alternate routes;
4. Upstream demand replaces the diverted volumes, reducing upstream congestion and travel times; and
5. Elimination of the ramp merging area allowed for the permissive shoulder lane through the bottleneck without interference from oncoming traffic.

Operational Effects of the Houston Outside Shoulder Lane. The use of the outside shoulder permissive lane was found to increase traffic volumes on the overpass by 1300 veh/hr during the peak period while the traffic volumes on the frontage road were found to decrease. The decrease of volumes on the frontage road was indicative that the Newcastle entrance ramp volume was using alternative routes to enter the freeway. The use of the shoulder lane increased as the mainlane traffic demand increased and as the public gained familiarity with its operations. Within two years of the beginning of operation the shoulder lane was operating at 60 percent of capacity. Table 3 includes the results of volume counts at the Newcastle to Edloe exits. Table 3 also includes the number of violations in the hours directly preceding (5-6 A.M.) and following (9-10 A.M.) the permissive use period. The violations were not considered a problem and that no safety problems had been observed because of subsequent lane use violations (5).

Table 3. Characteristics of Permissive Shoulder Lane Use From Newcastle Exit to Edloe Exit. Northbound US-59 Southwest Freeway (5).

Location of Counts / Period	Vehicles using lane from 6-9 A.M.	Peak Hour Volume	Violations (5-6 and 9-10 A.M.)
Newcastle Exit to Weslayan Exit			
March 1981	1673 veh.	754 veh/hr.	13 veh.
March 1983	2525 veh.	1058 veh/hr.	116 veh.
Weslayan Exit to Edloe Exit			
March 1981	1792 veh.	733 veh/hr.	19 veh.
March 1983	1920 veh.	1022 veh/hr.	77 veh.

Travel times and delay in this section were also significantly reduced. Delay calculations indicated a daily reduction in delay of 385 vehicle-hours while providing additional throughput of 1646 vehicles during the two-hour peak period each weekday. Operations upstream of the I-610/US-59 interchange also improved as a result of the modifications with increased throughput and travel time reductions of 400 vehicle-hours per day (about 2.6 minutes per vehicle).

The estimated cost of implementing this permissive shoulder use lane was approximately $40,000. The estimated annual cost savings was about $2 million dollars. This estimate did not include non-delay related costs such as accident costs, vehicle operating costs, or maintenance costs.

Accident Experience on Outside Shoulder Lane in Houston. The accident frequency from the I-610 (West Loop) to Weslayan section (approx. 1.6 mi.) was found for the morning peak period of 6 to 9 a.m. while the shoulder was in use on weekdays. The analysis was for operations 2 years before shoulder use began and 2 years after the start of shoulder use. The results can be seen in Table 4. The results included a 50 percent decrease in the number of accidents and an accident rate reduction of 57 percent during the two years following the beginning of operations of the permissive shoulder lane. McCasland also analyzed the non-peak period accidents (9:00 a.m. to 6:00 a.m.) for seven days per week. The results showed that the frequency of all accidents fell only 2 percent and the accident rate fell by 5 percent.

Table 4. Accident Frequency and Accident Rates N.B. U.S.-59. I-610 to Wesleyan Interchange (5).

	Two Years Before (1979-80)		**Two Years After (1981-83)**		**Percent Change**	
	Peak	**Off-Peak**	**Peak**	**Off-Peak**	**Peak**	**Off-Peak**
Frequency (# Accidents)	58	307	29	301	-50	-2
Accident Rate (Acc/100 MVM)	441	314	189	299	-57	-5

Permissive Outside Shoulder Use

In some instances, shoulder lanes have been used as operating lanes where the structural section was not designed structurally adequate for continuous loading. To address capacity problems in these situations, some agencies have used the shoulders as travel lanes in a "permissive" manner, only during peak periods on weekdays. This shoulder is used as a regular shoulder the remainder of the week. This approach provides the additional capacity needed while demand is high while providing emergency use and stopping areas the majority of the time.

The advantage of using "permissive" shoulder lanes over the continuous shoulder lane is in the reduction of maintenance cost because of the limited use of the pavement (5). It is advisable, however that a strong pavement section be placed on the shoulder section, especially prior to use as a continuous (full-time) travel lane. The use of permissive shoulder lanes has been implemented on several projects where a trade-off was accommodated between the additional capacity needed and the maintenance costs associated with keeping the shoulder in good condition. However, most of these projects have been removed, either by making them full-time shoulder lanes or by reconstruction. The disadvantages of using permissive use shoulder lanes are that they only require additional signing, signals, and enforcement (7).

LIABILITY ASPECTS ASSOCIATED WITH SHOULDER CONVERSION PROJECTS

Kuhlman states:

> "The whole theory of negligence presupposes some uniform standard of behavior. The uniform standard, of course, is that of reasonable or ordinary care, and under this standard our law has defined negligence as a failure to do what the reasonable man would do under the same or similar circumstances. (12)"

The use of roadway geometrics which are of non-standard designs has the potential for being targeted in court as a result of accidents on modified sections. The transportation agency or professional does have a strong defense if they have documented the modification process and have shown a positive precedent that was used to support the modification. When defending the modifications, it must be pointed out that current authoritative publications, such as the AASHTO Green Book (2) and the Manual of Uniform Control Devices (MUTCD) are not the law, they reflect current *professional consensus*, publications do not create the consensus (12).

In general, long before they are published in AASHTO standards, many *potential* AASHTO standards are published in authoritative journals. Therefore, the most timely and state-of-the-art design practices are accepted among persons in the transportation profession before they are included in any AASHTO standard publication. Because of this, agencies can justify their decisions based on expert testimony and the prior experience of others in the field, even though these views may not yet have been officially adopted. Where states have adopted by statute the AASHTO standards and MUTCD, some attorneys have argued that deviation from these standards constituted negligence on the part of the government agency. However, a majority of courts have rejected this argument and have concluded that standards adopted by statute are evidence to determine if there has been a deviance from a standard of care. The court concludes that the standards do not in themselves establish a standard of care (13).

There have been several cases where courts have awarded the case to the plaintiff (the motorist involved in an accident) where it is concluded that in the design of a roadway segment, it was known by the designers that the shortcomings of the design might increase the possibility of the plaintiffs accident more foreseeable. It is important then, to be aware of the previous experience with narrow lane and shoulder use, and to be familiar with the operational and safety experience with these projects. There have been several cases where courts have ruled designs were negligent. One case involving shoulders was *Weddle v. State* (1972) in California where a motorist had stopped on a six-foot shoulder to change a tire and was hit and killed. The court ruled that the creation of that six-foot shoulder was not reasonable (12). An agency should be aware of previous litigation against it and other agencies to develop an extended knowledge of the potential pitfalls of shoulder conversion projects.

It is often too easy for engineers to get overburdened with numbers. However, the transportation engineering profession is inevitably linked to the duty to serve the public. Oliver states that "Tort liability law did not result from the notions of sympathy or charity towards those injured using the facilities created by the transportation engineer. It resulted from the notions of fair play and justice."(16) The effect that tort law should have on the practicing engineer is stated by David C. Oliver in his article *The Impact of Tort Liability on the Provision of Transportation Services*(16):

> " . . . if tort law makes you reconsider one action in the design, construction, and maintenance program under your command, if it provides you with an insight into new developments and standards, if it leads you to incorporate thinking about safety in your everyday operations, then tort law has done its job."

Oliver(16) also points out a four-point test that must be satisfied in establishing negligent conduct:

1. It must be shown that there was a duty to conform to a particular standard of conduct that would have protected the plaintiff from injury.
2. It must be shown that the defendant breached his duty. It has to be shown that something was done wrong or inadequately.
3. It must be shown a harm was caused to the plaintiff.
4. A connection must be made between the plaintiff's injury and the agency or personal conduct. This is referred to as proximate causation and is a concept that has undergone great "judicial liberalization" since the early nineteen-eighties (16).

David Roper of Roper and Associates, formerly of Caltrans, indicated that Caltrans had been taken to court over accidents on shoulder-use facilities. He indicated that in situations where Caltrans saw no hope of freeway reconstruction and widening due to community concerns, environmental concerns, and tight budgeting, Caltrans converted shoulders to mixed-use lanes using these concerns as a basis for their decision. Roper did indicate that Caltrans had been ruled both for and against in these cases. However, Roper indicated that when attempting a shoulder conversion project, close attention must be paid to documenting decisions and giving credence to the experience of other projects (9).

Fred Rooney of Caltrans (8) and William McCasland (7) of TTI both indicated that it may be necessary to receive approval from the Federal Highway Administration (FHWA) when changing the geometrics of a federally-funded project. FHWA prefers to have the assurance that a change in geometrics is only a temporary solution to a congestion problem, they have seen many of these types of projects operate for 10 or 20 years. Also from a liability standpoint, it is always advantageous for a state or local agency to have approval from a "higher-up" when implementing changes in roadway configuration which is not to recognized standards.

In conclusion to the liability aspects of geometric modifications to an existing roadway, there are a few very important tasks an agency must concentrate on achieving. First, maintenance and maintenance records of the roadway must be kept tenaciously, even more than normal when reconfiguration projects are implemented. In the eyes of the court, a well maintained roadway is "one maintained within accepted and understood criteria, under generally promulgated engineering standards (16)" Continuous inspection is necessary because negligence is "predicated on the knowledge or information of the existence of danger (16)" that on a portion of the roadway exists a dangerous condition and a failure to subsequently relieve the condition existed. The key is being aware of the condition of the roadway and documenting not only repair and maintenance activities, but operational and safety records as well.

DESIGN AND MAINTENANCE ISSUES ASSOCIATED WITH SHOULDER CONVERSION PROJECTS

There are several issues which must be addressed when converting shoulders to travel lanes. The reconfiguration of the freeway must be examined just as if the cross-section was new. The elements changed must be checked to ensure that they are either up to current standards or modified to that they are as close to accepted standards as possible. The following discussion focuses on the identification of design and maintenance issues associated with the reconfiguration of the roadway to accommodate the additional lane of travel on the shoulder.

Cross Section

The major concern in a shoulder use project, or for any project that modifies the geometric layout of a facility, is the cross-section. The cross-section consists of:

1. Available travel width,
2. Lateral clearance, and
3. Emergency parking/access.

Lane Widths

The accepted desirable standard width for a freeway lane is 12 feet. However, many facilities have operated successfully with lane widths less than 12 feet. There have been examples of facilities using lane widths of less than 10 feet (1). Many agencies, however, will use lane widths of 11 feet, while some agencies will use lane widths down to 10.5 feet where a small percentage of trucks use the facility. Where there is a significant amount of truck traffic, one lane is kept wider (say 12 feet) for larger vehicle use, while other lanes in the section are reduced in width. This approach has been used in cases where HOV lanes have been retrofitted into a facility and an attempt has been made to reduce lane widths to accommodate the mainlanes and HOV on the existing cross section (1).

Lateral Clearance

The Highway Capacity Manual (10) states that a reduction in capacity occurs when lateral clearances are six feet or less. However, it is recognized that a greater percentage of familiar drivers usually lessens the reductions in capacity. So the concern with lateral clearances is not so much a capacity concern, but one of safety. McCasland and Biggs (1) recommend that roadside appurtenances should be "relocated, removed, or protected" with guardrail or barrier when lateral clearances are reduced. Roadside features such as light standards and signposts should be relocated, while other features such as bridge piers may be further protected by barrier and crash cushions (1).

Emergency Parking/Access

The accepted standard width for shoulders on urban freeways with more than three lanes is 10 feet. When a shoulder-use project is attempted, it is desirable to have an emergency parking area on at least one side of the roadway (1). The width of these shoulders should be more than six feet (3,13). On at-grade sections, right-hand paved shoulders may be as little as 3 or 4 feet since the adjoining grass area may be used for emergency parking. Where no shoulders can be provided, many agencies provide emergency parking bays wherever the space allows.

On elevated or depressed freeway sections, having a shoulder on at least one side may not be possible. In these cases, additional treatments should be considered to ensure disabled vehicles do not cause operational problems. These might include increased motorist assistance patrols in the area and/or increased surveillance system capabilities. Since these sections are usually relatively short, surveillance has been increased in some segments by adding loop detectors at closer spacings and using video surveillance capabilities. Also, effective campaigns have been introduced to take advantage of the presence of cellular phones on the roadways. Cellular users have been used as an effective tool for incident detection and verification.

Other Features

Other features and functions of the roadway which are issues to be considered in a shoulder conversion to travel lane project include:

1. Pavement Surfaces
2. Weaving Sections
3. Entrance/Exit Ramps
4. Lane Lines/Delineation
5. Guide Signing
6. Sight Distance
7. Lane Termination
8. Law Enforcement/Emergency Access

Pavement Surfaces

There have been very few projects that have incorporated a total resurfacing with modifications for shoulder use lanes. On most freeways, the shoulders are structurally sound enough so vehicles can travel on them at freeway speeds. However, it has been of some concern that problems may arise if the texture, color, and contrast between the shoulder and mainlane pavements are greatly different. It has been found that if lane delineation is good, the differences in the pavements do not adversely affect the shoulder lane usage(1).

The main concern with the pavement surface of the shoulder lane is its deterioration after an extended period of time. If the shoulders were not either originally structurally adequate or subsequently improved before use, the joint between the mainlane pavement and the shoulder can enlarge. Agencies have approached these situations by allowing trucks to only use the original mainlane section of the freeway (14). This creates the need for some additional signing and enforcement but has great advantages in extending the life of the shoulder pavement.

The shoulder deterioration condition not only presents a maintenance problem, but a perception and safety problem as well. Drivers may not tend to use the shoulder lane if they perceive that using the lane may impair vehicle handling and safety. Another aspect to the modification is that when reducing lane widths, some longitudinal joints will be in the mainlanes and in some cases in the wheel paths. It has been stated that this situation has not caused problems and will normally have little effect on operations (1,15).

Weaving Sections

Care must be taken to insure that the modifications effects on weaving areas are minimized. This can be a large concern due to the potential for weaving area and mainlane capacity reduction. For example, if a lane is added downstream of an interchange and the new lane is to extend to a downstream exit ramp, the mainline traffic that will exit has to weave across one or more lanes. If this weaving distance is too short in length, the additional weaving movement can cause an increase in vehicle conflicts and a subsequent reduction in capacity (1).

Entrance/Exit Ramps

The conversion of right shoulders to travel lanes may change the angle of entry and acceleration lengths required for traffic entering the freeway. Both McCasland (1) and Roper (9) indicated that when converting right shoulders to travel lanes, ramps must be carefully analyzed to determine if ramp geometrics will need to be altered before the lane geometric modifications. Roper indicated that restriping of gore areas, acceleration and deceleration lanes, and checks of taper lengths and angles need to made because of the new ramp geometries caused by the ramp nose-area move. This has not been reported to cause operational or safety problems, but, in some cases, the reconfiguration is not in compliance to current standards.

Lane Lines

Removal of old pavement lines is another consideration in a shoulder/narrow lane-use project. There are several techniques which exist to remove old pavement markings. Buttons and thermoplastic lane markings may be removed with a grader and blade, and painted lines may be removed with either sandblasting, excess oxygen burning, and high pressure water. Many agencies believe that the water method is the most effective for removal of painted lines (1).

Guide Signing

Relocation of guide signing may be necessary due to the realignment of the roadway. Different messages may also be necessary to accurately reflect the new lane configuration.

Sight Distance

The combination of horizontal curvature with crest vertical curves can pose a significant reduction in sight distance when using inside shoulder lanes on freeways. J.P. Leisch (11) addressed the problem of inadequate sight distance on freeway curves, especially in situations with taller concrete barriers. While this article did not specifically address the use of the shoulder conversion, an insight could be gained from the recommendations of the paper. Some treatments Leisch included to alleviate the sight distance problems are to shift the barrier wall, or shift the lanes, if possible, to make adequate sight distance. Rooney of Caltrans gave the example of Route 280 in San Francisco where a curvilinear alignment did cause some problems with limited sight distance (8). Roper also indicated that Caltrans had removed glare screens in median shoulder removal projects to accommodate the need for additional sight distance (9).

Lane Termination

In most cases the right shoulder is dropped at an exit ramp. McCasland (1) added that whether or not a recovery area should be provided downstream of the lane drop should be a matter of local policy.

Law Enforcement/Emergency Access

Many law enforcement agencies use shoulder areas in enforcement activities. A great amount of speed limit enforcement occurs on the shoulder areas, and provides officials a relatively safer place to stop violators. Police, fire, and rescue also are concerned with the ability to reach an accident site in congested conditions. In many cases, the only space for these vehicles to pass is on the shoulder. It is recommend to involve these agencies in the planning process to learn of their concerns and problems with the proposed modifications.

Maintenance Requirements

The increased use of the shoulder increases the maintenance activity required to keep the mainlanes and adjoining areas in good condition. The issue of liability is an especially important factor in the motivation for aggressive maintenance on sections where the shoulder is modified for use as a travel lane.

Shoulder Maintenance

Shoulders usually lack the structural strength to support repeated loadings. The most common consequence of this is the separation of the joint with the mainlane pavement. The structural integrity of the shoulder is further lessened by any adjoining grass areas that have the tendency to rut and collect water. This contributes to drainage retention and further reduction of shoulder and base material strength.

Roadside Maintenance

If guardrails, barriers, light standards, sign posts, and delineators will be closer to the traveled roadway after modifications, increased in damage will probably result to these fixtures as a result of their proximity to the roadway mainlanes. As a result, maintenance activity will increase to repair damaged items. Also, some features actually in the pavement such as drainage inlets may suffer damage from increased traffic loading. Lane lines also tend to wear faster in narrow lane situations due to increased traffic wear (5).

Elimination of emergency parking areas also may effect the cost of maintenance activities. Many maintenance activities will require additional time, personnel, and equipment to set up work zones to complete more intensive jobs. The lack of working area may affect scheduling by having more activities at night or on the weekends. This also effects crew costs, since night and weekend work are typically overtime-pay situations. McCasland (3) states, however, that any increased costs of maintenance are more than offset by the reduced delay-related costs to drivers.

To alleviate the effects of maintenance on shoulder-use projects, permissive use shoulder lanes have been used. They have the advantage of reduced traffic loading and shoulder availability outside peak periods. Another solution is rebuilding the shoulder during the modifications. This may increase the initial costs, but will reduce maintenance costs over the life of the project. Roper indicated that in California, potential shoulder use sites were tested by defectometer to determine its loading capabilities. If tested, a better estimate of the shoulder's expected life can be found. In California, Caltrans used 6 or 7 years of expected service life as a rough guideline on whether or not to use the existing shoulder structure, or to upgrade the shoulder section before use (9).

COST COMPARISONS OF SHOULDER MODIFICATION OPTIONS

McCasland and Biggs report *Freeway Modifications to Increase Traffic Flow* (1) presented a very good comparative analysis of the various factors that can affect the cost of a reconfiguration project. The costs comparisons were made for a typical half section of an 8-lane freeway one mile in length.

Assumptions for Cost Comparisons

The assumptions for the segment of freeway used for comparison were:

1. The existing cross section consisted of 4 paved concrete lanes with 10' asphalt shoulders on each side.
2. All signs have a lateral clearance of 10 feet from the edge of the shoulder.
3. Illumination posts are mounted on the concrete median barrier.
4. Existing entrance and exit ramps with curb inlets on the right side on each ramp.
5. One diamond interchange with mainlane structure of crown width.
6. One overhead bridge sign structure.

Figure 9 shows the typical roadway used in the cost calculations.

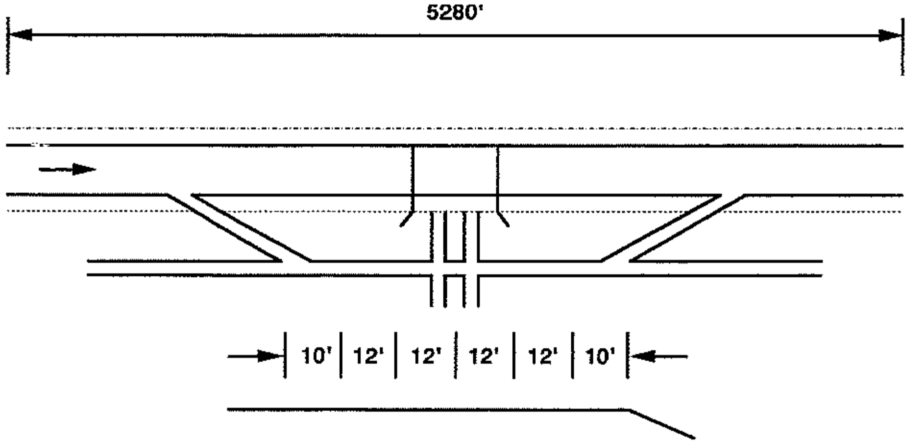

Figure 9. Typical Roadway Used for Comparison (1)

Configuration 0 -- Typical Roadway Section

The typical roadway section consists of 4-12 foot mainlanes and full 10-foot shoulders on both sides. Figure 10 shows the typical roadway section used in the comparison.

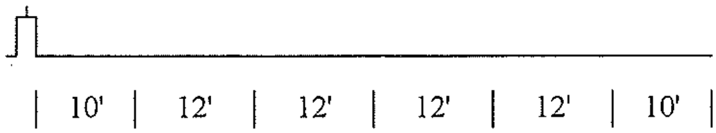

Figure 10. Configuration 0 -- Typical Roadway Section (1)

Configuration 1 -- Reconstruction

The reconstruction option would consist of a full cross-section of 5-12 foot mainlanes and 10 foot shoulders on both sides. This option is classified as major reconstruction taking 3 to 4 years from planning stages of the project to the end of construction. The additional lane is estimated to cost 3.80 million dollars. Figure 11 depicts the configuration resulting from a total reconstruction.

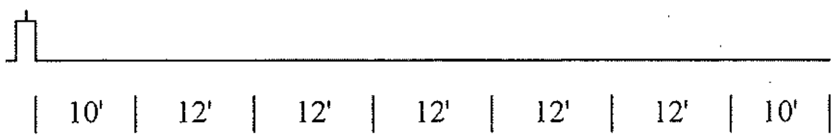

Figure 11. Configuration No. 1 -- Reconstruction Option (1)

Configuration 2 -- Restriping to Use the Right Shoulder as a Travel Lane

The cross-section consists of 5-10.5 foot mainlanes, 10 foot left shoulder, and a 5.5 foot right shoulder. This option might be used where the inside shoulder is insufficient in width or is raised. This configuration provides for a narrow shoulder to the right. Close attention must be paid to the entrance and exit ramp markings and geometry. Added costs are incurred using this option due to the deterioration of the shoulder pavement, maintenance, and reconstruction costs of the shoulder. Figure 12 shows the roadway configuration for restriping to use the right shoulder as a travel lane. The estimated cost is $105,000 to implement. See Table 5 for additional maintenance and reconstruction costs.

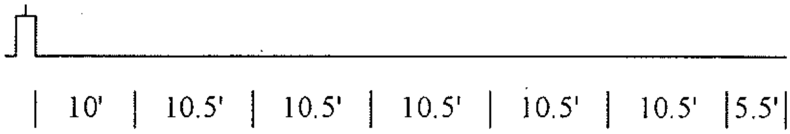

Figure 12. Configuration No. 2 -- Restriping to use the right shoulder as a travel lane (1).

Configuration 3 -- Restriping to Use the Left Shoulder as a Travel Lane.

This configuration provides a 3 foot left shoulder, 5-11 foot lanes and a full 10 foot right shoulder. In this configuration, entrance and exit ramps are not affected, but the introduction and elimination of the shoulder lane should be done carefully to insure lane continuity through the section. The estimated cost of this option is $36,000 plus additional maintenance and reconstruction costs. Figure 13 shows the configuration of the cross-section for this option.

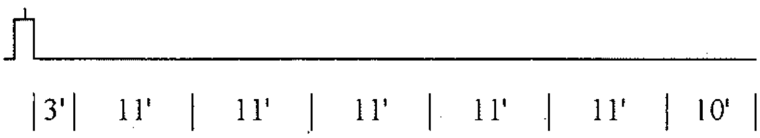

Figure 13. Configuration No. 3 -- Restriping to use the left shoulder as a travel lane (1).

Configuration 4 -- Restriping to Use Right Shoulder on a Lane During Peak Periods

This configuration provides for additional capacity when needed most, during the peak periods. This design reduces amounts of traffic using the shoulder, reducing maintenance costs. This configuration has the lowest implementation costs ($23,500) but additional costs will be incurred by enforcement agencies and transportation department programs to keep the lane clear during the peak periods. Figure 14 shows the configuration of using the right shoulder during peak periods.

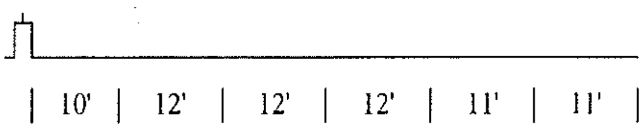

Figure 14. Configuration No. 4 -- Permissive Right Shoulder.

Table 5. Construction and Maintenance Costs for Example Configurations. Adapted from Reference (1).

Construction Items	Example Configuration			
	No. 1	No. 2	No. 3	No. 4
Construction Costs				
New Pavement	$2,917,000	$51,000	--	--
Bridge Widening	446,400	--	--	--
Pavement Markings	4,900	26,300	$26,300	$8,900
Signing	39,000	--	--	4,600
Miscellaneous Drainage Adjustments Seeding Guard fence Traffic control	62,300	18,100	6,500	5,000
Engineering & Contingencies	344,000	9,500	3,300	5,000
Total Construction	$3,774,600	$104,900	$36,100	$23,500
Maintenance & Reconstruction Costs				
Additional Maintenance ($/mile/year)	--	$7,000	$7,000	$7,000
Cost to Rebuild Shoulder ($/mile/year)	--	$37,900	$37,900	$22,800

As can be seen from the cost analysis of a typical section of freeway. The reconstruction option is by far the most expensive option. Even though this option is probably the most effective method to provide additional capacity, the high cost of reconstruction is not feasible in many instances. The three shoulder reconfiguration options are significantly cheaper than reconstruction. Depending on the reason for reconfiguration, it is advantageous to restripe the shoulder for use, until funding is available for the reconstruction of the freeway cross-section.

RECOMMENDATIONS

Planning For The Future

Considerations for Design

For new facilities, considerations should be made in the planning stage for the possibility of future use of the shoulders for travel lanes. Instead of shoulder conversions being afterthoughts to solve congestion problems, they should be forethoughts integrated into the design process of a new facility to anticipate the possibility of congestion problems.

Even though FHWA will not fund any more than 12-foot lanes and 10-foot shoulders, states should consider paying for additional cross-section width. Future mainlane additions should be considered when determining the initial cross-section widths. These considerations leave the agency with the flexibility to add additional lanes in the future with greater ease (17). Consider Figure 15, which shows typical new configurations as would currently be built under federal funding. Configurations of 3 mainlanes are presented for this example. The possibility of widening these cross-sections does not exist. This example assumes that there will be no expansion or rebuilding possible. It is interesting to note that only 1 to 3 feet are needed in several of the configurations to provide additional clearances and adequate shoulder widths.

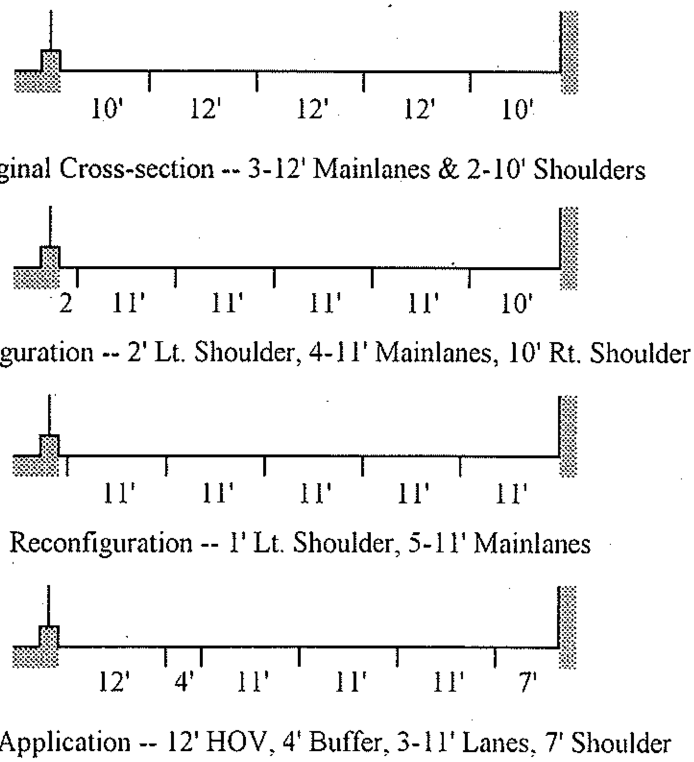

Figure 15. Alternate Cross-Section Configurations When Converting Shoulders to Travel Lanes.

Cost/Benefit Considerations

An analysis must also be done to determine if the addition of more cross-section will be cost-effective as compared to relocating a large retaining structure or building new bridge spans sometime in the future. Many urban freeway projects have full depth concrete shoulders. In these cases, there should be less concern about the structural integrity of the shoulder being used as a travel lane. However, if an agency typically initially incorporates lesser-quality shoulder structures (eg., less than full depth asphalt or concrete shoulders), consideration must be given to building shoulders on new facilities of full depth pavement similar to that on the mainlanes.

Another consideration is the location of other freeway features, for example, drainage structures. The type of drainage structures used may affect the ability of the shoulder to be used for not only as a travel lane, but as a temporary lane in incident situations or during maintenance (17). Other roadway features must be examined to ensure that their inclusion and placement will not prohibit future use of the shoulders for additional travel lanes.

Considerations in Relieving Congestion by Using Shoulders as Travel Lanes on Existing Facilities

Considerations for Retrofitting Travel Lanes on to Existing Shoulders

There is no set of guidelines or standards that encompass every application of shoulder use. It would be difficult to do so because of the uniqueness of each project. Each project has to identify the unique aspects of that project and address them with an individual solution. However there are several general concerns to acknowledge when attempting these modifications.

The main concern and trade-off involved in a shoulder use project is in the modification of the cross-section geometrics while maintaining adequate mainlane widths, lateral clearances, and emergency parking access. It has been shown in several studies that although the desirable mainlane width is 12 feet, lane widths less than twelve feet have been used effectively with very little effect on safety. Lane widths of 10.5 to 11 feet have been used in conjunction with full shoulders (10 feet on both inside and outside) without increasing accident rates (4). The most common lane width used in narrow lane/shoulder use applications has been 11 feet. There have been other projects which have used 10.5 foot lanes without negative results (5). However, most agencies prefer to limit the minimum lane width to 11 feet. In areas of heavier truck traffic, wider lanes have been used next to narrow lanes. Also, McCasland (1) stated that a narrow lane next to a paved shoulder may be just as effective for use by larger vehicles. It has also been observed that projects where one or both shoulders were used during peak periods have not shown increases in accident severity. There is concern, however, that by using shoulders to improve current congestion levels, future volume increases and resulting congestion levels could return the freeway to reduced levels-of-service and increased safety problems. However, the experience of long-term projects has indicated that accident rates have remained lower than previous accident rates after several years of operation (3).

The measure of effectiveness of a shoulder lane should be the actual usage of a section compared to the *potential* usage of the section (1), not to the calculated theoretical capacity of the section. In many instances the effectiveness of the additional lane is a function not only of total volumes, but of weaving volumes, ramp volumes, and the available length, in auxiliary lane use, for instance.

Of course it is better to have shoulders on both sides of the roadway. However, the nature of these projects usually require at least one of the shoulders to be used as a travel lane. In general, the inside shoulder should be taken first. The reason: there are usually more opportunities for disabled vehicles to escape the travel lanes on the right side. It is advisable to provide turnouts or turf areas to be used by these disabled vehicles. However, there are situations where it may be better to use the inside shoulder. In situations where both the inside and outside shoulders are non-existent, such as on elevated or depressed freeways, and there are no emergency parking areas, other approaches might be effective. These approaches include motorist assistance patrols and video and electronic detection systems. These approaches rely on the speed of services moving a vehicle blocking a lane, rather that the ability for that vehicle to remove itself from the travel lanes.

In general, the length of a modified section should only be as long as necessary to provide the anticipated benefits. The added lane should begin in advance of the problem area to allow traffic to use the lane before the target area, and should end at the next available terminus, usually the next convenient exit ramp (1). However, too short of a section will reduce the effective usage, that is, drivers will find it inconvenient to change lanes for such a short time to take advantage of the additional lane.

The project engineers must be aware of safety issues during the project. Sight distance, ramp geometrics, and the proximity of roadside features are all items which must be carefully dealt with and actions and decisions documented. The attempt to alleviate safety problems is a great concern as a liability issue. The ability to show conscious effort and a recognition of past experience is fundamental in liability cases.

Looking at the overall picture, these modifications are temporary measures to increase capacity over a problem section of roadway. If the project is expected to be in use for a period of several years, then consideration must be given to bettering the quality of the ride in a trade-off with the use of narrow lanes by using pavement overlays and better delineation of lanes. Monitoring of operations and safety data is a key, especially in an extended use situation. It must be remembered that in many of these projects, higher accident rates are a function of congestion. After improvements, accident rates should decrease because of this relationship. However, as volumes increase to use the additional capacity, accident rates may increase, and if insufficient emergency areas are provided, accident rates and severity may increase from before the modification. For this reason, it is stressed that these modifications are temporary solutions to larger capacity problems.

CONCLUSIONS

In speaking with several professionals with experience with modifying surface geometrics, a general theme seemed to emerge: cross-section reconfiguration projects work. These types of projects are effective in increasing capacity and safety on congested roadways. It is an inexpensive and a relatively quickly implemented solution which is popular not only with transportation professionals, but motorists as well. It is also stressed that these are to be classified as temporary solutions. These modifications should not interfere with planning and design of major reconstruction projects that many facilities will ultimately face.

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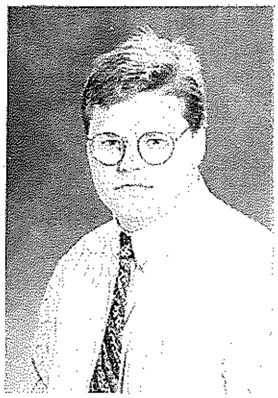

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