SAFETY-RELATED CHARACTERISTICS OF ARTERIAL HIGH-OCCUPANCY VEHICLE (HOV) ROADWAY AND LANE TREATMENTS

by

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SUMMARY

The growth of traffic congestion in the United States has been dramatic over the last three to four decades. This fact, combined with a heightened interest in the environment and increased constraints on transportation funding has forced a new approach to be used in the provision of transportation services in the United States.

In general, the method used to provide transportation services in the 1990s has been to improve the efficiency of the existing system rather than building more roadways. These type of transportation improvements have less impact on the environment and allow a more effective use of funds. Overall, the efficiency of existing roadways can be improved by two methods: transportation system management (TSM), and/or transportation demand management (TDM).

One specific technique which improves the efficiency of a roadway by encouraging people to carpool, vanpool, or ride the bus is the implementation of high-occupancy vehicle (HOV) lanes. A large number of these facilities currently exist within the freeway environment. However, these type of corridors (i.e., freeways) represent only a small amount of the current roadway mileage in a typical metropolitan area, and normally do not serve the suburb-to-suburb work trip very efficiently. It is for these reasons, among others, that the application of HOV lanes on arterials is gaining in popularity.

The safety of arterial and freeway HOV roadway and lane treatments is very important. Unfortunately, the research on this subject has been focused on freeway HOV lanes, and the results of these studies have only a limited applicability to the safety of HOV priority treatments on arterial roadways. The arterial roadway environment has a number of characteristics, such as signalized intersections and pedestrians, which do not exist on freeways.

The focus of the research documented in this paper was the safety-related characteristics of the following four arterial HOV roadway and lane treatments: bus streets, concurrent flow lanes, contraflow lanes, and queue “jumper” lanes. The characteristics of these HOV facilities were identified through an extensive literature review and the completion of telephone interviews with the users and/or operators of existing arterial HOV treatments.

Overall, it was found that there are some HOV priority treatment characteristics related to safety which should be considered in the planning, design, and operation of all (i.e., arterial or freeway) HOV facilities. Some examples of these type of characteristics include: meeting acceptable geometric and traffic control standards, “adding” or “taking” the HOV lane, and the proper lighting and maintenance of a HOV facility. These generic characteristics should be considered for safety reasons along all HOV facilities.

It was also found that there are some safety-related characteristics which only need to be considered in the planning, design, and operation of specific arterial HOV roadway and lane treatments. Some examples of these type of characteristics, which must be considered in the arterial environment and do not exist along freeways, include turning movements and parked vehicles.
The telephone interviews which were done as part of this research generally verified the information and characteristics which have been documented in the literature. The majority of the case studies evaluated were believed to operate safely by their users and/or operators. This fact supports the idea that all arterial HOV roadway and lane treatments can be operated safely and efficiently if they are planned and designed correctly. One example of a safety-related characteristic which was identified in the telephone interviews, but not in the literature, is the allowance of bicycles on bus streets.

Four checklists of safety-related characteristics and a set of guidelines prepared by the author as a result of the findings reported herein are presented at the end of this report. The four checklists were compiled from the information gathered in an extensive literature review and several telephone interviews. The guidelines are intended to ensure the proper consideration of the characteristics identified in these checklists. The use of both these tools is recommended in the planning, design, and operation of the four arterial HOV roadway and lane treatments considered in this study.
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INTRODUCTION

The amount of traffic congestion in the United States has increased dramatically over the past three to four decades. It affects millions of people each day, and is considered a serious problem in hundreds of suburbs throughout the country (1). The major reason for the increase in congestion is that more people are traveling alone in their automobiles to more dispersed suburban locations. Unfortunately, many of these locations do not have the transportation infrastructure necessary to serve this additional vehicular demand, and congestion results (2).

In general, traffic congestion is caused by a spatial and/or temporal mismatch of supply and demand. The capacity (i.e., supply) of roadway lanes, at many locations and times, is not large enough to serve the travel demands that currently exist (especially at current vehicular occupancy levels). There are generally two approaches that can be used to alleviate traffic congestion: 1) increase the number and/or improve the efficiency of the existing supply of roadway lanes, or 2) manage, and possibly reduce, the demand for travel on the existing transportation system. These two approaches are referred to as transportation system management (TSM) and transportation demand management (TDM), respectively.

In the 1990s, the focus of most transportation system improvements is on the maximization of existing efficiency and some modest capacity (i.e., supply) improvements (3). This approach is due, in the most part, to the financial constraints being experienced by governmental agencies, and an increase in environmental awareness. One technique that meets the requirements placed on transportation improvements in the 1990s is the implementation of high-occupancy vehicle (HOV) priority treatments.

One of the objectives of HOV priority treatments is to increase the efficiency of an existing roadway by maximizing its person throughput through a redistribution of the travel modes currently used. Preferential treatment is given to HOVs (i.e., buses, carpools, and vanpools) in terms of economy, convenience, space, and time (4). The focus of this report is on arterial HOV roadway and lane treatments. These type of preferential treatments encourage the use of HOVs by offering them more reliable and reduced travel times (3).

There are a number of reasons HOV-oriented projects, in particular lane treatments, have become more popular in the past several years. One of the main reasons is the strong support shown for these type of projects in two pieces of recently passed legislation. The 1990 Clean Air Act Amendments (CAAA), for example, require some metropolitan areas within the United States to implement transportation control measures (TCMs). One of the TCMs designated by the federal government is the preferential treatment of HOVs. In addition, one of the primary funding sources for the implementation of projects which improve air quality (i.e., TCMs) is the Congestion Mitigation Air Quality (CMAQ) program established in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. The funds in this program cannot be used for the addition of roadway capacity unless the lanes are intended to serve HOVs (5).

Traffic congestion in the United States is no longer an issue limited to the commercial business districts (CBDs) of large metropolitan cities. It has become a regional problem, and requires a regional solution. For this reason it is imperative that the implementation of HOV
roadway and lane treatments not be limited to freeway (i.e., limited access roadways) corridors. Limited access roadways represent only three percent of the total urban highway mileage, and are often only oriented to effectively serve those trips between the CBD and the suburbs (2). Unfortunately, it has been shown that this travel pattern is longer the highest orientation for work trips (6). Therefore, to truly be a regional solution to congestion, HOV roadway and lane treatments must be implemented along arterial roadway corridors in both the CBD and the suburbs. Fortunately, HOV systems “. . .to cover an entire urban area are now emerging (7).”

The functional and operational environment within which an arterial HOV roadway or lane treatment is implemented has a number of characteristics that do not exist along freeways. For example, in the arterial environment factors such as signalized intersections, marginal (i.e., roadside) access, and pedestrians must be considered. Thus, the planning, design, and operational guidelines produced for freeway HOV priority treatments are very limited in their transferability.

One area of interest in the planning, design, and operation of HOV priority treatments, along both freeways and arterials, is their safety. However, this issue is a particular concern for arterial HOV roadway and lane treatments because of the more diverse and less-controllable environment within which they must be implemented (8).

Purpose and Scope

The purpose of the research documented in this report was to identify the safety-related characteristics of four arterial HOV roadway and lane treatments, and to develop a tool which would ensure their consideration in the planning, design, and operation of these facilities. The four HOV priority treatments which were considered include bus streets, concurrent flow lanes, contraflow lanes, and queue “jumper” lanes. The safety-related characteristics of these HOV facilities have been identified from the literature, and verified, validated, and/or supplemented by the results of telephone interviews conducted as part of this research. All of this information was then combined and condensed to produce four checklists of safety-related characteristics, and a set of guidelines for their proper consideration. The use of these tools is recommended in the planning, design, and operation of the four arterial HOV priority treatments considered in this project.

Organization of Report

The body of this report consists of five sections. The first section is the introduction. It contains a discussion of the traffic congestion problem in the United States, and why its effects should be partially alleviated through the use of arterial HOV roadway and lane treatments. The second section of this report describes the four arterial HOV priority treatments of interest in this project: bus streets, concurrent flow lanes, contraflow lanes, and queue “jumper” lanes. Typical geometric, operational, and environmental characteristics of each treatment are discussed. The third section of this report discusses the safety-related characteristics identified in the literature for each of the four arterial HOV priority treatments previously identified. The fourth section summarizes the results of the telephone interviews done to collect information on the safety concerns, if any, related to the operation of several arterial HOV priority treatment case studies. Finally, the last section of this report contains the conclusions reached due to this research, and a presentation of the four checklists and set of guidelines developed by the author.
ARTERIAL HOV ROADWAY AND LANE TREATMENTS

The following geometric, operational, and environmental characteristics can be used to describe an arterial HOV roadway or lane treatment (9, 10):

- Exclusive or shared right-of-way;
- Direction of travel (concurrent, contraflow, or reversible);
- Roadway location (median or curb lane);
- Eligible users (buses only or buses and carpools/vanpools);
- Hours of operation (24 hours or peak period); and
- Roadway environment (CBD or non-CBD).

The identification of these characteristics for a specific arterial HOV facility can also help define some of its potential safety-related problems.

As the list above indicates, there is a larger number of characteristic combinations which can be applied to a specific HOV project being considered for implementation. Fortunately, certain combinations make more sense, and are more typically used. These typical combinations are described in the following paragraphs for arterial bus streets, concurrent flow lanes, contraflow lanes, and queue “jumper” lanes.

**Bus Streets**

Exclusive arterial right-of-way HOV facilities are commonly referred to as bus streets or “transitways” because of their usual restriction to bus use only (8, 11). Normally, this restriction to bus use is applied on a 24-hour basis, but in special cases non-HOVs may also be allowed to use the facility for short discontinuous segments in order to access land uses such as parking garages. In addition, taxis and delivery vehicles may also be allowed to use the bus street in off-peak hours (12).

Bus streets are generally located in CBDs which are highly-oriented toward the use of public transit. Their purpose is to improve the collection, distribution, and transfer of the significant transit passenger volumes in these areas (2). In addition, they may also be used to improve the operation of the surrounding street system by serving bus routes which would normally operate on these mixed-traffic facilities.

Bus streets are normally two-lane undivided roadways. However, they may also increase in width or have bus stop pullouts to facilitate through flow along the facility (8, 12). Bus streets may also be more than one lane in each direction, but this is less typical. Figure 1 shows two typical bus street designs for different volumes of bus traffic.

Some examples of bus streets which are currently operating include 5th and 6th Streets in Portland, Oregon, Nicollet Mall in Minneapolis, Minnesota, and State Street in Chicago, Illinois (4, 12). In general, safety is not considered to be a significant problem on arterial bus streets (8, 13).
Figure 1. Typical Bus Street Designs (12).
Concurrent Flow Lanes

Concurrent flow lanes are the most commonly used arterial HOV lane treatment (12). They typically consist of one or more non-barrier separated lanes which operate in the same direction of travel as the adjacent mixed-traffic lanes (11). Specifically, the HOV lane may be located next to the curb or the median, be limited to buses or allow other HOVs (i.e., buses, carpools, and vanpools), and operate on a 24-hour or more commonly a peak-period basis. The specific geometric and operational characteristics of a concurrent flow HOV lane are usually dependent upon where it is located on the roadway and in the metropolitan area.

Concurrent flow HOV lanes which are located adjacent to the median or the curb may be implemented within a CBD or a non-CBD area. Within the CBD these type of HOV lanes are usually restricted to buses, and implemented to improve transit circulation, travel times, and/or the general flow of traffic (8). A concurrent flow HOV curb lane, whether located in the CBD or not, normally serves buses on local routes which have frequent stops (8, 14). The location of these HOV lanes next to the curb also produces a situation where these buses conflict with right-turning, parked, and/or stopped vehicles (14). Concurrent flow HOV lanes in the median, on the other hand, are normally implemented to provide a travel time savings, and generally serve both express buses and other HOVs. This characteristic eliminates any operational or safety problems associated with the loading or unloading of bus passengers in the middle of the road. Median concurrent flow HOV lanes are also more likely to appear in non-CBD areas, be longer in length, allow HOVs other than buses, and operate at higher speeds. The users of this type of concurrent flow HOV lane conflict with left-turning vehicles.

The safety and efficiency of concurrent flow HOV lanes located next to the median or curb can be impaired if conflicting turn movements are not restricted (11). However, in many areas the complete prohibition of turning movements may not be physically or politically possible. There are two basic designs for curbside concurrent flow HOV lanes when turning movements cannot be completely prohibited. The first design permits right-turning vehicles to merge into the HOV lane an appropriate distance in advance of the access point or intersection (see Figure 2). The other design involves the implementation of a right-turn only lane which allows HOVs continuous through flow. The design and operation of this type of concurrent flow HOV lane is almost identical to the facility shown in Figure 2.

There are also two typical designs for a median concurrent flow HOV lane located on a roadway where left-turns cannot be completely prohibited. The first design allows left-turning vehicles to merge into the HOV lane in advance of the intersection, and then enter a left-turn bay to the left of the HOV lane (see Figure 3). The second design involves the introduction of a signal phase which stops the traffic in the HOV lane so that vehicles in the left-turn bay can safely perform the intended crossing maneuver. In this case, the left-turn bay is on the right side of the HOV lane (see Figure 4).

In one of the most comprehensive studies of HOV priority treatments, Batz identified 95 concurrent flow HOV facilities (4). Of the 95 facilities identified, 22 had been suspended, but only two were terminated for safety problems. Both of these facilities were median HOV lane treatments (4, 12, 15). In addition, the contention that concurrent flow HOV lanes had a potential for additional
Figure 2. Continuous Curbside Concurrent Flow HOV Lane (16).
Figure 3. Median Concurrent Flow HOV Lane with Left-Turn Bay (16).
Figure 4. Median Concurrent Flow HOV Lane with Left-Turn Phasing (16).
accidents was not supported by the data collected in the study. Fully, 7 out of 10 concurrent flow HOV facilities for which data were available showed no increase in accidents (4).

Contraflow Lanes

Arterial contraflow HOV facilities consist of at least one lane which operates against the flow of travel in the adjacent mixed-traffic lanes. In most cases, the HOV lane is “borrowed” from the mixed-traffic lanes in the off-peak direction (11). These “borrowed” lanes can be located on the right side of a one-way street, or on the off-peak direction side of a two-way roadway with or without a raised median. The typical designs for contraflow HOV lanes implemented on one-way and two-way undivided roadways are shown in Figure 5. These lanes may be separated from oncoming traffic by a yellow line(s), pylons, cones, and raised or painted medians. Head-on collisions have never really materialized as a significant safety problem on these facilities.

Arterial contraflow HOV lanes can be applied in CBD and non-CBD areas. The contraflow HOV lanes located in CBDs are often implemented to continue bus service on streets which have been changed to one-way operation. There are two reasons that the use of these facilities is normally limited to buses (typically local routes): 1) they are usually used by a large number of bus routes, and 2) there are some safety concerns related to their operation (2). However, other non-HOVs (e.g., taxis, delivery vehicles) may also be allowed to use the facility in the off-peak periods and/or at specific locations. Contraflow HOV lanes in the CBD normally operate on a 24-hour basis because of the amount of infrastructure necessary for their implementation and operation.

The typical characteristics of a contraflow HOV lane in a non-CBD area are somewhat different than those located in the CBD. Outside of a CBD contraflow HOV lanes are more likely to be longer in length, allow HOVs other than buses, and because they are normally “borrowed” from the off-peak direction of traffic they are usually of a non-permanent nature (i.e., peak-period only). In addition, because contraflow HOV lanes are more likely to be located next to the median in non-CBD locations (due to a general lack of one-way streets in the suburbs) they are usually associated with express service (i.e., HOVs must travel the entire length of the facility without turning or stopping). Left turns across the HOV lane by traffic traveling in the same direction as the HOVs (and possibly in the opposite direction) are usually prohibited (see Figure 5).

There are several examples of contraflow lanes that operate safely. Some of these include the Kalanianaole Highway in Honolulu, Hawaii, Marquette and 2nd Avenues in Minneapolis, Minnesota, and Ponce de Leon and Fernandez Avenues in San Juan, Puerto Rico (4, 8). In his study of HOV priority treatments, Batz identified 26 contraflow HOV facilities (4). Safety was the reason given for three of the eight facilities which had suspended operation. In addition, the future suspension of two contraflow HOV lanes in Chicago was also documented. Since the time of Batz’s study, the operation of these two contraflow HOV lanes in Chicago has been terminated for safety reasons (17). Pedestrian safety and awareness are significant concerns in the operation of contraflow HOV lanes.
Figure 5. Median and Curbside Contraflow HOV Lanes (8, 12, 18).
Queue “Jumper” Lanes

Queue “jumper” or bypass HOV lanes are typically short concurrent flow spot treatments intended to give HOVs preferential treatment around an area of restricted capacity. In fact, they are usually only a few hundred feet long, and provide only one to three minutes of travel time savings (19). These type of treatments are most commonly located on metered freeway entrance ramps, but they can also be applied at similar locations along arterial roadways.

Queue “jumper” HOV lanes can be implemented along arterials at capacity bottlenecks such as congested signalized intersections and approaches to bridges or tunnels. When applied at signalized intersections these facilities may be combined with a separate signal head and lead green phase that provides the HOVs with a “jump” on the mixed-traffic lanes. A merge lane for the HOVs is usually provided downstream of the intersection (16).

The design of a queue “jumper” HOV lane is unique to the location at which it is constructed. However, one general requirement of these facilities is that the “jumper” lane be long enough to allow the HOVs to bypass the entire queue in almost every instance. Queue “jumper” HOV lanes can be implemented on the left side of the roadway to bypass queues of left-turning vehicles, or on the right side of the roadway to bypass queues of through traffic. Figure 6 provides a typical design of a queue “jumper” HOV lane on the right side of a roadway. Normally, the construction of a queue “jumper” HOV lane consists of extending what used to be a right-turn only lane in both directions (i.e., upstream and downstream of the intersection).
Figure 6. Typical Queue “Jumper” HOV Lane (16).
SAFETY-RELATED CHARACTERISTICS

There have been several studies done on the safety aspects of the various freeway HOV lane designs (e.g. barrier separated, or painted buffer) currently in operation (20, 21, 22). The general conclusion of these studies has been that the implementation of HOV lanes do not decrease the safety of a roadway. In fact, although some of the designs studied (i.e., physically separated HOV lanes) appeared to operate more safely than others, it has not been shown that the implementation of a non-separated, contiguous HOV lane results in a degradation of safety (20, 21, 22). Unfortunately, the separation design aspect considered in the majority of these studies is only one of many safety-related characteristics which must be considered in the planning, design, and operation of an arterial HOV roadway or lane treatment. Therefore, although the conclusions reached by these studies are useful, they have a very limited applicability to arterial HOV facilities.

There are a number of characteristics which affect the safe operation of an arterial HOV roadway or lane treatment. Fortunately, these characteristics have been the subject of several reports published in the United States and Great Britain (8, 13, 15, 23, 24, 25). The subject material of these reports is often limited to the safety-related aspects of a specific arterial HOV roadway or lane treatment (e.g., contraflow lanes), but at least two of those referenced take a more comprehensive approach. In particular, a report prepared for the Federal Highway Administration (FHWA) in 1979 considered the safety aspects of 22 HOV facilities on 16 different roadways (five of which were arterials) (8). This study, and a similar one from Great Britain, are considered the state-of-the-art in research on the safety issues of arterial HOV roadway and lane treatments (8, 25). The safety-related recommendations of these two studies form the basis of the following discussion.

General Characteristics

There are a number of safety-related characteristics which should be considered in the development of all (arterial- or freeway-based) HOV roadway or lane treatments (8). Those safety-related characteristics connected with the planning, design, and operation of these facilities are listed in Table 1 and discussed in the following paragraphs.

Planning

The safety-related characteristics associated with the planning of a HOV facility are of an information gathering and dissemination nature. For instance, government agencies (including enforcement) and the general public should be involved in the planning of HOV facilities (8). This involvement allows specific governmental agencies to identify their particular safety concerns, and provides the public with a better understanding of the advantages, disadvantages, and safety concerns related to the operation of a HOV priority treatment (8). Public involvement in the planning stage of a HOV facility limits the possibility of misunderstandings later in the development process.
Table 1. General Safety-Related Characteristics of HOV Facilities (8).

<table>
<thead>
<tr>
<th>HOV Facility Development Stage</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>• Government Agency and Public Involvement</td>
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<tr>
<td>Design</td>
<td>• Geometric Design and Traffic Control Standards</td>
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<tr>
<td></td>
<td>• “Add” or “Take” a Lane</td>
</tr>
<tr>
<td>Operation</td>
<td>• Lighting and Maintenance</td>
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<tr>
<td></td>
<td>• Bus/HOV Conspicuity</td>
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<tr>
<td></td>
<td>• HOV Volumes/Headways</td>
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<tr>
<td></td>
<td>• Bus/HOV Driver Training</td>
</tr>
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<td></td>
<td>• Incident Detection/Mitigation</td>
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</table>

**Design**

There are several designed-related characteristics that generally affect the safety of all HOV facilities (see Table 1). First, all HOV facilities should at least meet the minimum commonly accepted geometric and traffic control standards necessary for their safe operation. In general, a HOV facility should not be implemented if it increases the safety or operational effects of an existing geometric deficiency in the roadway.

A second safety-related design aspect of HOV facilities is whether the lane should be “added” or “taken” (8). Overall, it has been recommended that all HOV lanes be “added”, if possible, rather than “taken” from the off-peak direction of traffic. Presumably, this recommendation is based on the fact that the congestion added by “taking” a lane from the off-peak traffic would decrease the overall safety of the roadway, and that a new lane might be built to better geometric (i.e., safer) standards.

**Operation**

Finally, there are also five safety-related characteristics which pertain to the operation of HOV facilities (8). First, all HOV facilities, as with any other roadway, should be well lighted and maintained. Second, a safer HOV environment can be created in areas where buses must weave across several lanes of traffic by the addition of more conspicuous turn signals and/or overhead signing. In addition, non-bus HOVs must also be conspicuous. Third, people must be aware of the HOV facility. Therefore, the headways between the buses and other HOVs on the facility must be short enough to avoid the unsafe assumption by non-HOV drivers and pedestrians that the HOV lane is “empty” (8). Finally, all bus drivers should be specially trained and HOV drivers educated in the operation of the HOV facility, and any incidents on the facility should be detected and mitigated as quickly as possible.

In general, there are a number of safety-related characteristics which should be considered in the planning, design, and operation all HOV facilities. However, there are also those characteristics which only need to be considered in the planning, design, and operation of arterial
HOV roadway and lane treatments (i.e., bus streets, concurrent flow, contraflow, and queue “jumper” lanes). These safety-related characteristics are specific to the arterial environment, and are discussed in the following paragraphs.

Specific Characteristics

There are a number of arterial HOV roadway and lane characteristics which are specifically related to safety. In general, these characteristics are connected to the conflicts experienced between the users (e.g., buses) and non-users (e.g., non-HOVs) of an arterial HOV facility. Typically, non-HOVs in an arterial environment are vehicular (e.g., single-occupant vehicles or bicycles) or pedestrian in nature.

The safety-related characteristics of bus streets, concurrent flow lanes, contraflow lanes, and queue “jumper” lanes are shown in Table 2. These characteristics were derived from the discussions and recommendations reviewed in the literature. Their significance in the planning, design, and operation of bus street, concurrent flow lanes, concurrent flow lanes, and queue “jumper” lanes are discussed in the following paragraphs.

Bus Streets

The safety aspects of bus streets, or exclusive right-of-way facilities, have not been studied extensively because their operating environment (i.e., bus use only and very restricted access) is considered to be the safest of all arterial HOV roadway and lane treatments. However, there are still some characteristics (see Table 2) which may potentially affect their safety, and should be considered in their planning, design, and operation.

The typical design of a bus street minimizes the number of conflicts between buses and mixed- or cross-traffic. In fact, the only points of conflict between these two traffic flows on a bus street are at its terminal points and at-grade intersections. Therefore, the terminal points of these facilities must be located and designed such that the entering and exiting bus traffic is safely separated and merged with the mixed-traffic flow (8). In addition, the number and operation of the intersections along a bus street must be considered because a Transport and Road Research Laboratory (TRRL) study found that 65% of the bus street accidents identified (on the four facilities evaluated) occurred within 20 meters (66 feet) of a roadway junction (25).

Bus streets are often associated with pedestrian malls and the amenities and increased concentration of transit service connected with these facilities can actually increase the possibility of conflict between buses and pedestrians. Therefore, pedestrian mall design must also be considered for bus street safety. The addition of trees, kiosks, and street furniture for atmosphere along pedestrian malls can sometimes limit the sight distance of bus drivers.

Pedestrian volumes and crossing behavior, although difficult to control, must also be considered. In fact, a TRRL study showed that only 15 of the 49 bus street pedestrian accidents they had identified were actually near a pedestrian crossing (excluding those at signalized intersections) (25). One possible explanation for this finding is the distracting nature of the pedestrian mall atmosphere. Pedestrians in this aesthetic atmosphere may fail to consider when and where they cross a bus street.
Table 2. Safety-Related Characteristics of Arterial Roadway and Lane Treatments.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Bus Streets</th>
<th>Concurrent Flow Lanes</th>
<th>Contraflow Lanes</th>
<th>Queue “Jumper” Lanes</th>
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<tbody>
<tr>
<td><strong>Vehicular-Related</strong></td>
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<tr>
<td>Number of Access Points and/or Intersections</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Operation of Cross Streets</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Right- and/or Left-Turn Volumes and Restrictions</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Facility Terminal Point Layout</td>
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<tr>
<td>Facility User Eligibility</td>
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<td>X</td>
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<tr>
<td>Enforcement of Stopping/Parking/Loading Restrictions</td>
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<td>X</td>
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<tr>
<td>Median and Access Point Design</td>
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<tr>
<td>Weaving and Speed Differential</td>
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<td></td>
<td>X</td>
</tr>
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Concurrent Flow Lanes

Concurrent flow HOV lanes on arterials may be located next to the median or curb, and their safety concerns and characteristics are similar (see Table 2). However, the specifics of the safety-related characteristics identified for each design are typically defined by the location of the lane on the roadway. For example, the vehicular movements that conflict with the HOVs in a curbside concurrent flow lane include not only left-turning (like median concurrent flow HOV lanes), but also right-turning vehicles. Weaving is also a safety-related concern of median and curbside concurrent flow HOV lanes, but in the case of the curbside lane this maneuver is between the “high speed” HOV lane and the right (or slow) mixed-traffic lane rather than the left (or “high speed”) mixed-traffic lane (8, 23). The differences in the safety-related characteristics of concurrent flow HOV lanes in different roadway positions are supported in the literature (8, 24).

One FHWA study reviewed the accident experiences of three median concurrent flow HOV lanes, and several curbside lanes in the Washington, D.C. CBD. The safety-related characteristics that were identified for median concurrent flow HOV lanes included: 1) the “taking” or “adding” of the HOV lane, 2) left-turning vehicles, and 3) the combination of weaving maneuvers and speed differential between the mixed-traffic and HOVs (8). In addition, it was speculated that the wide variation in the accidents found along the median HOV facilities was related to their traffic volumes, and the number of conflicting movements (i.e., crossing or left-turning) allowed. Overall, it was concluded that crossing and left-turning movements should be restricted, and that HOV traffic volumes must be high enough for non-HOV drivers and pedestrians to be aware of the HOV facility operation (8).

There has also been at least one study which specifically considered the safety of curbside concurrent flow HOV lanes, and verified the relationship identified above between the safety of these facilities and the number of conflicting or merging movements allowed (24). The study was limited to the evaluation of accidents along two roadways with HOV lanes. It found that HOV lanes implemented along roadways with long sections of “C” (i.e., raised) median or no driveway access produced no apparent increase in total accidents (24). The number of accidents experienced along HOV facilities on roadways with a large number of access points and median two-way-left-turn-lanes (i.e., unlimited access), on the other hand, is significantly different. For example, the one HOV facility of this type which was evaluated in this study had over four times as many accidents as a comparable right shoulder lane (24). In addition, almost all the accidents on this facility were related to vehicles turning left across or merging into the HOV lane (24).

The results of the study described above appear to support the conclusion that the safety of concurrent flow HOV lanes are directly related to the number of conflicting movements, and/or the number of access points along a roadway. In addition, the conspicuity of the HOVs using the facility (especially non-bus HOVs) is also important.

In conclusion, curbside concurrent flow HOV lanes (particularly those in CBD areas) also have two safety-related characteristics which are unique to their location on the roadway. First, HOVs using these lanes must bypass illegally parked or stopped vehicles. This maneuver forces the HOVs to merge with mixed-traffic and then quickly reenter the HOV lane (possibly several times in short succession). Second, there is a distinct possibility of an errant pedestrian stepping off of the
curb. This is a significant safety concern for curbside concurrent flow HOV lanes because there is relatively little avoidance reaction time for the HOV driver, and many pedestrians do not cross roadways (i.e., HOV lanes) at designated locations (25). These two characteristics should be considered along with others in the planning, design, and operation of curbside concurrent flow HOV lanes.

**Contraflow Lanes**

“Contraflow lanes have a varied accident history (12).” On the one hand, it has been shown that they can be, and are, operated safely and effectively. But, on the other hand, they have a number of characteristics (see Table 2) which consistently cause serious safety concerns.

Many of the safety-related characteristics of contraflow HOV lanes are similar to those already described for bus streets and/or concurrent flow HOV lanes (see Table 2). However, the safety concerns related to these characteristics are often greater in magnitude because the HOVs on contraflow facilities operate in the opposite direction of the adjacent mixed-traffic.

In general, the safety concerns generated by contraflow HOV lanes are due to their violation of pedestrian and non-HOV driver expectancies (8). The first expectancy they violate is that of symmetrical lane use. Pedestrians and drivers expect an equal number of lanes in both directions on a roadway, or that all traffic travels in the same direction on a one-way street. The “taking” of a lane for a contraflow HOV facility, especially if it is just during the peak period, violates this expectation. The operation of a peak period contraflow HOV lane also violates a traffic control expectancy of non-HOV drivers. The signs and markings of this type of “temporary” contraflow HOV lanes supersede the regular traffic control. A safety problem occurs when drivers or pedestrians continue to operate in a normal manner when the contraflow HOV lane is in operation. Typically, there is an adjustment period in the operation of contraflow HOV lanes when accident rates may be slightly elevated. However, these rates tend to go down as people become accustomed to the presence of the facility (8).

A violation of the expectancies described above by contraflow HOV lanes has made the presence of conflicting pedestrian movements a major safety concern in the operation of these facilities. In several instances this issue has forced the closure of contraflow HOV lanes (8, 17, 25). In fact, the operation of four contraflow HOV lanes in the Chicago CBD were changed to concurrent flow due to pedestrian safety problems (17, 26). These four facilities were one of the case studies chosen for closer evaluation as part of this project. The safety of their current operation is discussed in the next section of this report.

The safety of contraflow HOV lanes is also related to the presence of conflicting vehicular movements at its intersections (crossing roadways and access points) and terminal points. These issues are of a particular concern for median, rather than curbside, contraflow HOV lanes because the users of these facilities must contend with left-turning vehicles from both directions. In addition, the layout of median contraflow HOV lane terminal points may produce a situation where the HOVs must weave across several mixed-traffic lanes to enter/exit the facility (8). The safety aspects of these characteristics, although still a concern, are not as significant for curbside contraflow HOV lanes (on one-way streets) because they are typically located in a CBD where traffic moves more
slowly, access is limited, cross streets have one-way operation, and HOVs can easily and safely enter/exit the facility. However, parked or stopped vehicles can be a major safety issue for this type of contraflow lane.

Finally, there are also some safety-related characteristics which are unique to contraflow HOV lanes. First, there is the type of separation used between the HOV and mixed-traffic lanes. Head-on collisions are not a significant problem along contraflow HOV lanes, but different separation designs allow different evasive maneuvers to be taken by buses (8, 25). The ability to take these evasive actions is especially important in high volume pedestrian areas. Two other safety-related characteristics of contraflow HOV lanes are their peak period set up and removal, and the allowance of bicycles (8, 25). These characteristics are specifically related to the hours a contraflow lane operates, and the visibility and expectancy of a bicycle on this type of facility.

Queue “Jumper” Lanes

There have been no studies done on the safety aspects of arterial queue “jumper” HOV lanes. The safety-related characteristics listed in Table 2 and discussed in the following paragraphs are based on those identified in the literature for toll booth and ramp meter bypass HOV lanes, and the professional judgement of the author. In general, it is speculated that the safety impacts of these facilities are relatively small because of their short length.

Overall, it was concluded that most of the safety-related characteristics of queue “jumper” HOV lanes are similar to those already discussed. For example, turning movements and the presence of pedestrians must also be considered for safety reasons along these facilities. The operation of queue “jumper” HOV lanes, especially with a separate lead green phase, must take pedestrian crossing and awareness into account. In addition, the characteristics of the lead signal phase (for the HOVs) must consider the levels and operation of conflicting and crossing vehicle movements. Both the user and non-user of a queue “jumper” HOV lane must clearly understand its operation.

There are two safety-related characteristics which are believed to be somewhat unique to queue “jumper” HOV lanes. The first characteristic is similar to one that has been identified in the literature for toll booth and ramp meter bypass HOV lanes. Basically, a queue “jumper” HOV lane must have enough length to allow HOVs to safely merge into it, bypass the queue, and then safely merge back into mixed-traffic after the capacity restriction (i.e., the signalized intersection) has been passed (8, 27). Therefore, the length of the lane is important for safety reasons. A second characteristic which may be related to the safety of queue “jumper” HOV lanes is the location of bus stops on these facilities. Specifically, the stop(s) should be located and designed to minimize pedestrian crossings and maximize the bypass capabilities of vehicles following buses. In addition, the stop should be located in a position which allows buses to safely merge into the mixed-traffic.
SAFETY ASPECTS OF CASE STUDIES

Telephone interviews with users and/or operators of existing arterial HOV roadway and lane treatments were also done as part of this study. The knowledge gained through these interviews was used to verify, validate, and/or supplement the information documented in the literature and discussed in the previous sections of this report.

In general, the safety aspects of at least two or three examples of the four HOV roadway and lane treatments described in this report were the subject of telephone interviews. Overall, eight people were interviewed about fourteen arterial HOV facilities. The characteristics of the case studies chosen were intentionally varied to represent a wide spectrum of the possible HOV priority treatment designs.

The questions asked during the telephone interviews were intended to elicit information on the case study characteristics which were believed to affect their safety. The questions asked are given below:

- Are there or have there been, in your opinion, any safety-related concerns with the operation of this HOV facility?
- Have you made any safety-related improvements during the regular maintenance of the facility (beyond maintaining the pavement markings and signs)? If so, what?
- Have you ever had to immediately change the operation of the facility due to safety-related concerns? If so, what?

As one can see, the questions were designed to be open-ended. This was done purposely in order to allow the person interviewed to offer their best opinion on the safety concerns, if any, connected to the HOV facility of interest.

The information collected from the telephone interviews is described in the following paragraphs. The results of the interviews are not quantitative or statistically valid, but simply represent a documentation of the opinions and recollections of various users and/or operators of several arterial HOV roadway and lane treatments in North America.

Bus Street Examples

Telephone interviews about the bus streets in three cities were done (26, 28, 29). The facilities discussed included State Street in Chicago, Illinois, Nicollet Mall in Minneapolis, Minnesota, and 5th and 6th Streets in Portland, Oregon. As expected, there were no significant safety concerns identified with respect to the operation of these facilities.
The potential safety concerns documented in the literature did not seem to materialize at any of the three case study locations. Again, this is most likely due to their inherently safe environment, and the consideration of three properly designed facilities.

State Street. Chicago, Illinois

State Street is a 24-hour two-lane bus street (one lane in each direction), approximately 0.75 mile long, with bus stop pullouts. In general, the operation of this facility has produced no specific safety concerns (26). However, the street will revert back to mixed-traffic in the next few years. This change is generally due to the economic concerns of adjacent business owners.

Nicollet Mall. Minneapolis, Minnesota

The Nicollet Mall is approximately one mile long and allows both buses and taxis. This facility has produced no safety concerns related to pedestrians or crossing traffic. Its operation is generally considered safe. Some safety concerns do exist about the allowance of bicycles on the facility because it is only 24 feet wide (28). The operation of the bus street with bicycles allowed is being tested for one year.

5th and 6th Streets. Portland, Oregon

The operation of the 5th and 6th Street bus facilities in Portland is somewhat different than the two bus streets previously discussed. 5th and 6th Street are a one-way pair which consist of three lanes: two limited to buses, and one which allows non-HOV vehicles for discontinuous three block lengths and delivery vehicles at specific locations. No turning is allowed across the bus lanes, and the cross streets typically have one-way flow.

In general, this facility is also considered to operate safely. No safety concerns have been produced by the intermixing of buses and non-HOVs on the bus streets because they are more or less avoided by the non-HOV users (due to their lack of continuity). The only safety concern that was mentioned in the telephone interview was related to buses from neighboring communities using 5th and 6th Streets. These drivers need to be trained in order for the bus streets to continue operating safely (29). For example, one special rule on these facilities is that stopped buses have right-of-way.

Concurrent Flow Lane Examples

Telephone interviews about arterial concurrent flow HOV lanes in three cities were done (26, 30, 31). HOV facilities in Chicago, Seattle, and Toronto were discussed. In general, the HOV lanes in Chicago were located in its CBD, but the others were in non-CBD locations. All of the HOV facilities discussed in the interviews were located on the right side of the roadway.

Various CBD Streets. Chicago, Illinois

A telephone interview was conducted in which four concurrent flow HOV lanes in the CBD of Chicago were discussed. The implementation of these facilities was directly related to safety.
In fact, until 1985 all four of these lanes operated in a contraflow mode, but they were changed to concurrent flow HOV lanes due to problems with pedestrian safety (17, 26).

The concurrent flow HOV lanes on Madison Street, Adams Street, Washington Boulevard, and Jackson Boulevard are approximately one mile long and used by buses only. Their operation is very stable, and no significant safety concerns were identified in the telephone interview (26). The bus routes along these HOV lanes operate in a skip-stop mode (i.e., they stop every other block) which allows the current concurrent operation to produce nearly the same operational benefits as the previous contraflow operation (17, 32). However, there has been some reduction in the level of service provided to transit patrons. One operational issue that was discussed, and is somewhat related to safety, is the blocking of the lanes by parked or stopped vehicles (32). This forces the buses out of the HOV lane (which can be an unsafe maneuver) and is generally considered a HOV lane enforcement problem.

Eglinton Avenue. Toronto, Ontario Canada

The HOV facility along Eglinton Avenue in Toronto is a peak-hour concurrent flow lane that allows buses, and carpools with three or more people. This facility is over 11 kilometers (7.0 miles) long, operates on the right side of the roadway, and is used by mixed-traffic in the non-peak hours. The roadway (i.e., Eglinton Avenue) corridor within which the HOV facility is located experiences high volumes of traffic, and has a number of roadside access points to commercial and industrial land uses.

Two safety-related concerns were identified with respect to the operation of the Eglinton Avenue HOV facility (31). The first had to do with turning movements across the facility. In general, because of the high levels of congestion in the mixed-traffic lanes left-turning vehicles must be offered a “courtesy gap” in order to perform their intended maneuver. Thus, these vehicles cross the mixed-traffic lanes safely, but they then collide with a higher speed vehicle in the HOV lane. This safety problem is related to expectancy and a lack of sight distance (due to the stopped vehicles in the mixed-traffic lanes). It was the opinion of the person interviewed that this problem may be lessened if buses, due to their increased height, were the only vehicle allowed in the HOV lane (31).

The second safety concern identified was related to the weaving maneuvers in one section of the HOV facility. A major employer is located in this section of the HOV facility, and its access point is just downstream of a major highway exit. This situation has forced a number of vehicles to move across the HOV lane, merge into the mixed-traffic lanes, and then merge back into the HOV lane to turn right into the employers driveway. This maneuver has caused some safety concern, but the problem is planned for mitigation through a change in geometry (31).


The SR 522 and SR 99 HOV facilities have been the subject of an accident analysis study (24). The results of this analysis were discussed previously. The study generally found that the HOV lane on SR 522, which operates in a restricted access environment, produced no apparent increase in total accidents. The HOV facility on SR 99, on the other hand, experienced over four
times more accidents than a comparable roadway lane (24). The largest difference between SR 522 and SR 99 is that the latter facility has almost unlimited roadside access.

The information obtained through the telephone interview qualitatively verified the study results described above. The HOV facility on SR 522 was believed to operate relatively safely, but there were some safety concerns with respect to the operation of the HOV lane on SR 99 (30).

The most significant HOV lane safety issue on SR 99 is similar to that of Eglinton Avenue in Toronto. The congested operation of the mixed-traffic lanes forces drivers to offer left-turning vehicles a “courtesy gap”, and these vehicles subsequently collide with a HOV lane user. The study described above recommended better and more frequent HOV lane markings to improve the safety of SR 99 (24). However, this recommendation was only offered as a more acceptable solution to the safety problem than the reduction of access points or the construction of a raised median.

One action that has been taken to mitigate the safety problem of the SR 99 HOV lane is the installation of specially designed signs which are intended to make the drivers in the mixed-traffic lanes and the HOV lane more aware of the potential left-turn conflict (30). Figure 7 shows the typical design of these signs which have been placed over the roadway.

Other safety concerns related to the operation of the HOV facility on SR 99 pertain to right-turning vehicles and the speed differential between mixed-traffic and the HOVs (30). Drivers of right-turning vehicles must be aware of the fact that they can turn from the HOV lane and that they should not turn across it. This maneuver is not a problem once the public is educated about the operation of the HOV lane. An additional safety concern is the speed differential between the HOV lane and the highly congested mixed-traffic lanes. This difference in speed makes merging into and out of the HOV lane somewhat unsafe.

Contraflow Lane Examples

Two arterial contraflow HOV lanes were discussed in telephone interviews (28, 33). One of the case studies was a pair of contraflow lanes in Minneapolis, Minnesota which operate on one-way streets. The other case study was a peak hour contraflow lane located next to the median in Honolulu, Hawaii.

Marquette and 2nd Avenues. Minneapolis, Minnesota

The contraflow HOV lanes along Marquette and 2nd Avenues are located in the Minneapolis CBD, and are approximately one mile long. They operate along the right side (looking in the direction of mixed-traffic flow) of two one-way streets, and are limited to buses use only except in the off-peak hours. At these times commercial vehicles are allowed to load and unload at specific locations where the contraflow lane widens and allows buses to pass (24). The contraflow lanes are 24 hour facilities, and are separated from mixed-traffic by a mountable raised median. Left-turns are allowed across the HOV lane.
Figure 7. Special Concurrent Flow HOV Lane Signing (35).

Note: This sign is placed over the center two-way-left-turn lane.

Note: This sign is placed over the HOV lane.
Telephone interviews about the safety concerns related to these facilities showed that they were well planned and engineered, and that they have no significant safety problems (28, 34). This fact could be due to the approach taken in their implementation. Both HOV lanes were first implemented on a temporary basis, and their design was adjusted to improve their operation before permanent construction began (18). In addition, both bicycle and vehicle safety were taken into account in their planning (18).

Three points were made in one of the telephone interviews about the operation of the Marquette and 2nd Avenue contraflow HOV lanes (29). First, pedestrians appear to generally be aware of the existence of the lanes, but visitors (both pedestrians and drivers) may experience some confusion. Second, the left turns which are allowed across the HOV lane have not been a safety problem because in most cases the buses in the contraflow lane must stop every block. Third, the mountable raised median which separates the contraflow lane from the mixed-traffic lanes allows buses to bypass vehicles blocking the lane, and if needed avoid errant pedestrians. The existence of this mountable median not only improves the operation of the facility, but also its safety.

Kalanianaole Highway. Honolulu, Hawaii

The contraflow HOV lane along the Kalanianaole Highway is approximately two miles long and is located in a non-CBD area of Honolulu. The HOV lane is located on a divided arterial roadway and generally “takes” one of the three lanes in the off-peak direction. This facility only operates in the morning peak period and only allows express-type (i.e., users that use its entire length) buses, and carpools with two or more people. Traffic traveling in the off-peak direction is allowed to turn left at a few locations along the roadway, but the same maneuver for traffic traveling in the opposite direction (i.e., the same direction as the HOVs) is prohibited. The contraflow lane is separated from oncoming traffic by plastic cones.

Telephone interviews with the users and operators of the contraflow HOV lane on the Kalanianaole Highway revealed a general belief that the facility operates relatively safely (33, 36). No safety concerns could be identified with respect to pedestrians, the separation design, its set up and breakdown, or the allowed left-turns (33). In addition, the allowance of carpools in the HOV lane, and their interaction with bus operations, has not produced any safety problems (33). Congestion was the only issue related to safety that was identified (33). In general, it increases in the off-peak direction because of the lane “taken” for the HOVs, and especially when the contraflow HOV lane does not operate. Increased congestion levels can increase the potential for accidents.

There have been other roadways in Hawaii that have been considered for similar contraflow HOV lanes. However, their implementation was rejected along these roadways due to limited sight distance, and the lack of a safe refuge for avoidance maneuvers (37). Both of these characteristics should also be considered in the planning, design, and operation of a contraflow HOV lane.

Queue “Jumper” Lane Examples

There are only a few examples of queue “jumper” HOV lanes on arterial roadways, and their safety aspects are rarely considered. Telephone interviews were conducted about two queue “jumper” HOV lanes in the Seattle, Washington area (30, 38).
NE Pacific Street. Seattle, Washington

The queue “jumper” HOV lane on NE Pacific Street consists of an added right-turn lane on its approach to Montlake Boulevard, NE. The lane is approximately 1000 feet long, operates all day, and allows buses, and carpools with four or more people. In general, the facility was built to allow buses to bypass the queue produced by the signal at this intersection, and to provide them with a separate signal phase which gives them a small “jump” on the mixed-traffic lanes.

There were no significant safety concerns identified which were related to the operation of this facility (30). In fact, the only issue discussed which was somewhat related to safety pertains to the bus stop at this location. In this case, the bus stop is located after the “jump” is provided. This forces the bus to stop, load/unload passengers, and then force its way into the congested traffic on Montlake Boulevard, NE (30). This type of merge maneuver is not desirable from a safety point of view.

Airport Road. Snohomish County, Washington

The queue “jumper” HOV lane on Airport Road is provided at its intersection with 112th Street, SW. The continuous concurrent flow HOV lane that operates on Airport Road shifts one lane to the left approximately 300 feet beyond this intersection (38). A HOV queue “jump” is provided at this intersection through the addition of a separate lead green phase (6 to 10 seconds long) for the buses and carpools (two or more people) using the HOV lane. This added phase allows the HOVs to more easily merge to the left and continue travel on the HOV lane after the intersection. The queue “jumper” and continuous HOV lane operate in the evening peak period only.

There were no significant safety problems identified which were related to the operation of this queue “jumper” HOV lane (38). However, there were some roadway geometry issues which caused some safety concerns when combined with the operation of this facility. Specifically, there is a vertical sight distance problem in the HOV/mixed-traffic weaving area downstream of the intersection (38). A small rise in the roadway topography occurs just past 112th Street, SW at approximately the same point that the HOVs are shifting to the left, and the mixed-traffic is shifting to the right in order to turn at the following intersection. This combination of limited sight distance and weaving maneuvers increases the potential for accidents. This situation also offers some insight into the proper location for queue “jumper” HOV lanes, and is generally included under the previously discussed rule that the implementation of a HOV facility should never make a poor geometric situation worse.

Summary

The results of the interviews were somewhat varied (see Table 3), but generally verified the information discussed in this report and documented in the literature. In addition, the interview discussions provided proof that many of the characteristics identified in the literature do not produce any significant safety concerns in the current operation of existing arterial HOV facilities. Obviously, the potential for safety problems still exists for facilities with these characteristics, but
it would appear that they were adequately considered in the design of the HOV treatment. In fact, the results of the interviews indicated that the majority of the case studies considered were believed to operate safely. The five safety-related concerns which were mentioned in the interviews but not in the literature included: the allowance of bicycles on bus streets, the “courtesy gap” issue on concurrent flow HOV lanes and whether non-bus HOVs should be allowed to use these facilities, and the need for refuge areas along contraflow HOV lanes. The safety concerns connected to bus stop locations on queue “jumper” HOV lanes were also verified.

Table 3. Summary of Telephone Interview Results (26, 28-34, 36-38).

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<td>5th and 6th Streets. Portland, Oregon</td>
<td>Bus Driver Training</td>
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<td><strong>Concurrent Flow Lane Examples</strong></td>
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<td>Various CBD Streets. Chicago, Illinois</td>
<td>Parked and Stopped Vehicles</td>
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<td><strong>Contraflow Lane Examples</strong></td>
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<td>Kalanianaole Highway, Honolulu, Hawaii</td>
<td>Congestion in the Off-Peak Direction, Sight Distance, and Refuge Areas</td>
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<td><strong>Queue “Jumper” Lane Examples</strong></td>
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<td>Airport Road. Snohomish County, Washington</td>
<td>Weaving and Vertical Sight Distance</td>
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CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Several conclusions about the safety-related characteristics and operation of arterial HOV roadway and lane treatments have been reached based on the research done for this report. These conclusions are listed below.

- Arterial HOV roadway and lane treatments can generally be operated safely and efficiently if the characteristics identified in this report are considered early in their planning and design.

- Many of the safety concerns connected with arterial HOV priority treatments can be solved by careful planning and design.

- The majority of arterial HOV priority treatment case studies evaluated as part of this research appear to operate safely. Few significant safety concerns were identified.

- Bus streets offer the safest arterial HOV environment of the four treatments reviewed.

- Some of the safety-related characteristics of concurrent flow HOV lanes are dependant upon their location on the roadway (i.e., next to the median or curb).

- Contraflow HOV lanes have a reputation for producing unsafe conditions. However, these type of facilities are operated safely in numerous locations.

- The safety aspects or accident experiences of queue “jumper” HOV lanes have not been adequately studied or evaluated.

- Most arterial roadways experience increases in accident rates immediately after the implementation of a HOV facility. However, these rates typically go down as drivers and pedestrians become accustomed to the operation of the HOV facility.

- There are several safety-related characteristics which should be considered in the planning, design, and operation of all HOV facilities (arterial or freeway).

- There are also safety-related characteristics which should only be considered in the planning, design, and operation of specific types of arterial HOV roadway and lane treatments.

- Conflicting vehicle and pedestrians movements are two safety-related characteristics which must be seriously considered in the planning, design, and operation of all arterial HOV priority treatments.
**Recommendations**

In practice, safety is inherently considered in the planning, design, and operation of arterial HOV facilities. This conclusion is supported by the fact that the majority of the case studies evaluated in this project were considered to operate in a safe manner by their users and/or operators. The checklists and guidelines produced by the author as a result of this study (see Tables 4 to 10) simply formalize the consideration of safety-related characteristics in the planning, design, and operation of arterial HOV priority treatments. In addition, the checklists and guidance provided allow safety-related fatal flaws to be identified for the type of HOV roadway or lane treatment chosen, and a verification of the fact that the most important safety-related characteristics have been seriously considered.

The emphasis of this project has been on the identification of the safety-related characteristics of four arterial HOV roadway and lane treatments. The information gathered from the literature search and the telephone interviews done during this project was used to produce the following checklists of safety-related characteristics. Tables 4, 5, 6, and 7 include the characteristics for bus streets, concurrent flow lanes, contraflow lanes, and queue “jumper” lanes, respectively. It is recommended that the appropriate checklist be used in the planning, design, and operation of the specific arterial HOV roadway or lane treatment being considered. Tables 8, 9, and 10 offer a series of questions which are intended to assist in the proper consideration of the characteristics identified in Tables 4, 5, 6, and 7. The guidance questions provided help define what is desirable for each characteristic, and whether mitigation, if needed, can improve the current situation.

In conclusion, there has been an attempt to make the following checklists and guidance as comprehensive as possible, but there are undoubtedly some safety-related characteristics which have not been identified. In the future, as arterial HOV priority treatments become more common, and more “before and after” accident studies are done on their operation, the ability to identify what factors to include in these checklists, and their desirable traits, will increase. Additional items may need to be added to the lists, and existing items deleted or altered. At this time, however, the lists and guidance provided are considered the most comprehensive of their type.
Table 4. Bus Street Characteristics Related to Safety.¹,²

<table>
<thead>
<tr>
<th>Lane Treatment</th>
<th>Characteristic</th>
<th>Considered?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Streets</td>
<td>Government Agency and Public Involvement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Geometric Design and Traffic Control Standards</td>
<td></td>
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<tr>
<td></td>
<td>Lighting and Maintenance</td>
<td></td>
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<tr>
<td></td>
<td>Bus Conspicuity</td>
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<td></td>
<td>HOV Volumes/Headways</td>
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<tr>
<td></td>
<td>Bus Driver Training</td>
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<td></td>
<td>Incident Detection/Mitigation</td>
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<tr>
<td></td>
<td>Number of Intersections</td>
<td></td>
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<tr>
<td></td>
<td>Operation of Cross Streets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Facility Terminal Point Layout</td>
<td></td>
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<tr>
<td></td>
<td>Facility User Eligibility (e.g., Bicycles)</td>
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<tr>
<td></td>
<td>Pedestrian Volumes</td>
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<tr>
<td></td>
<td>Pedestrian Crossing Behavior</td>
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<tr>
<td></td>
<td>Enforcement of “Jay-Walking” Ordinances</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pedestrian Mall Design</td>
<td></td>
</tr>
</tbody>
</table>

¹See body of report for detailed explanation of characteristics listed.
²This table should be used in conjunction with guidance Tables 8, 9, and 10.
Table 5. Concurrent Flow Lane Characteristics Related to Safety.\textsuperscript{1,2}

<table>
<thead>
<tr>
<th>Lane Treatment</th>
<th>Characteristic</th>
<th>Considered?</th>
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</thead>
<tbody>
<tr>
<td>Concurrent Flow Lanes</td>
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<tr>
<td></td>
<td>Geometric Design and Traffic Control Standards</td>
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<tr>
<td></td>
<td>“Add” or “Take” a Lane</td>
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<td></td>
<td>Lighting and Maintenance</td>
<td></td>
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<tr>
<td></td>
<td>Bus/HOV Conspicuity</td>
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<tr>
<td></td>
<td>HOV Volumes/Headways</td>
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<tr>
<td></td>
<td>Bus/HOV Driver Training</td>
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<tr>
<td></td>
<td>Incident Detection/Mitigation</td>
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</tr>
<tr>
<td></td>
<td>Number of Access Points and Intersections</td>
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<tr>
<td></td>
<td>Operation of Cross Streets</td>
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<tr>
<td></td>
<td>Right- and/or Left-Turn Volumes and Restrictions</td>
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<td></td>
<td>Facility User Eligibility (e.g., Carpoools)</td>
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<td></td>
<td>Enforcement of Stopping/Parking/Loading Restrictions</td>
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<td></td>
<td>Median and Access Point Design</td>
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<td></td>
<td>Weaving and Speed Differential</td>
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<td></td>
<td>Pedestrian Volumes</td>
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<td></td>
<td>Pedestrian Crossing Behavior</td>
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<tr>
<td></td>
<td>Enforcement of “Jay-Walking” Ordinance</td>
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</tr>
</tbody>
</table>

\textsuperscript{1}See body of report for detailed explanation of characteristics listed.
\textsuperscript{2}This table should be used in conjunction with guidance Tables 8, 9, and 10.
Table 6. Contraflow Lane Characteristics Related to Safety.¹, ²

<table>
<thead>
<tr>
<th>Lane Treatment</th>
<th>Characteristic</th>
<th>Considered?</th>
</tr>
</thead>
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<td>Geometric Design and Traffic Control Standards</td>
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<tr>
<td></td>
<td>“Add” or “Take” a Lane</td>
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<tr>
<td></td>
<td>Lighting and Maintenance</td>
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<tr>
<td></td>
<td>Bus/HOV Conspicuity</td>
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<tr>
<td></td>
<td>HOV Volumes/Headways</td>
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<tr>
<td></td>
<td>Bus/HOV Driver Training</td>
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<tr>
<td></td>
<td>Incident Detection/Mitigation</td>
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<tr>
<td></td>
<td>Number of Access Points and/or Intersections</td>
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<tr>
<td></td>
<td>Operation of Cross Streets</td>
<td></td>
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<tr>
<td></td>
<td>Left-Turn Volumes and Restrictions</td>
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<tr>
<td></td>
<td>Facility Terminal Point Layout</td>
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<td></td>
<td>Facility User Eligibility (e.g., Bicycles)</td>
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<tr>
<td></td>
<td>Enforcement of Stopping/Parking/Loading Restrictions</td>
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<tr>
<td></td>
<td>Separation Design/Refuge Areas</td>
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<tr>
<td></td>
<td>Hours of Operation/Set Up and Removal Procedures</td>
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<td></td>
<td>Pedestrian Volumes</td>
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<tr>
<td></td>
<td>Pedestrian Crossing Behavior</td>
<td></td>
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<tr>
<td></td>
<td>Enforcement of “Jay-Walking” Ordinance</td>
<td></td>
</tr>
</tbody>
</table>

¹See body of report for detailed explanation of characteristics listed.
²This table should be used in conjunction with guidance Tables 8, 9, and 10.
Table 7. Queue “Jumper” Lane Characteristics Related to Safety.\(^1,\!\!^2\)

<table>
<thead>
<tr>
<th>Lane Treatment</th>
<th>Characteristic</th>
<th>Considered</th>
</tr>
</thead>
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<tr>
<td>Queue “Jumper” Lane</td>
<td>Government Agency and Public Involvement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Geometric Design and Traffic Control Standards</td>
<td></td>
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<tr>
<td></td>
<td>Lighting and Maintenance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bus/HOV Conspicuity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HOV Volumes/Headways</td>
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<tr>
<td></td>
<td>Bus/HOV Driver Training</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incident Detection/Mitigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of Access Points</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operation of Cross Street</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right- and/or Left-Turn Volumes and Restrictions</td>
<td></td>
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<tr>
<td></td>
<td>Weaving</td>
<td></td>
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<tr>
<td></td>
<td>Bus Stop Location</td>
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<tr>
<td></td>
<td>Lane Length</td>
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<tr>
<td></td>
<td>Pedestrian Volumes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pedestrian Crossing Behavior</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enforcement of “Jay-Walking” Ordinance</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)See body of report for detailed explanation of characteristics listed.
\(^2\)This table should be used in conjunction with guidance Tables 8, 9, and 10.
Table 8. Guidance for General Characteristics.1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Applicable HOV Facility2</th>
<th>Questions to be Answered</th>
</tr>
</thead>
</table>
| 1. Government Agency and Public Involvement | BS, CC, CF, and QJ      | • Have all interested parties had an opportunity to participate in the process?  
• If not, they should become involved at this point.                                                                                                                                                                       |
| 2. Geometric Design and Traffic Control Standards | BS, CC, CF, and QJ      | • Can all minimum standards be met?  
• If not, can the problems be mitigated?                                                                                                                                                                                 |
| 3. “Add” or “Take” a Lane              | CC, and CF               | • Does the “taking of a lane for a HOV lane significantly increase mixed-traffic congestion?  
• If so, is the addition of a lane possible?                                                                                                                                                                              |
| 4. Lighting and Maintenance            | BS, CC, CF, and QJ      | • Can the facility be properly lighted and maintained?  
• If not, can lights be added, and personal hired or contracted for maintenance?                                                                                                                                          |
| 5. Bus/HOV Conspicuity                 | BS, CC, CF, and QJ      | • Are buses/HOVs relatively conspicuous to non-HOV drivers and pedestrians (consider past accident history of buses)?  
• If not, can vehicles be made more conspicuous.  
• Can turning vehicles see the buses/HOVs in the lane (i.e., “courtesy gap” issue)?  
• If not, can signs be implemented to awareness or HOV lane, or will problem be solved by limiting use of lane to buses?                                                                                                       |
| 6. HOV Volumes/Headways                | BS, CC, CF, and QJ      | • Are or will HOV volumes be significant enough to ensure non-HOV driver and pedestrian awareness of HOV lane operation?  
• If not, is HOV lane needed or feasible?  
• Can HOV use be increased?                                                                                                                                                                                               |
| 7. Bus/HOV Driver Training             | BS, CC, CF, and QJ      | • Is there a program (planned or existing) to educate the public and bus drivers in the proper operation of the HOV lane?  
• If not, one should be implemented.                                                                                                                                                                                        |
| 8. Incident Detection/Mitigation        | BS, CC, CF, and QJ      | • Is there a quick response mechanism to detect/mitigate incidents on the HOV facility?  
• Is not, can one be implemented, and what are possibilities for collisions and breakdowns on the HOV facility?                                                                                                              |

1This table should be used in conjunction with Tables 4, 5, 6, and 7.
2BS = Bus street, CC = Concurrent flow lane, CF = Contraflow lane, and QJ = Queue “jumper” lane.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Applicable HOV Facility</th>
<th>Questions to be Answered</th>
</tr>
</thead>
</table>
| 1. Number of Access Points and/or Intersections (see No. 3 also) | BS, CC, CF, and QJ     | • Does the number of intersection/access points limit the safety and feasibility of the HOV facility?  
• Is the number of intersection/access points responsible for the high number of turning/crossing vehicles?  
• Can some access points be combined or eliminated?  
• Can intersections be eliminated or changed to one-way operation? |
| 2. Operation of Cross Streets (see No. 1 and No. 3 also)      | BS, CC, CF, and QJ     | • Are cross streets one- or two-way?  
• Are there significant turn volumes at the two-way cross street junctions?  
• If cross street is two-way can it be changed (especially if turn volumes high)? |
| 3. Right- and/or Left-Turn Volumes and Restrictions         | CC, CF, and QJ         | • Are left/right-turn volumes high to limit the safety or operation of HOV lane?  
• Can turning be prohibited or controlled? |
| 4. Facility Terminal Point Layout                      | BS and CF              | • Can buses/HOVs enter/exit facility safely?  
• If not, are terminal points in the appropriate location, or can they be redesigned? |
| 5. Facility User Eligibility (see No. 5 in Table 8 also)    | BS, CC, and CF         | • Can facility width and operation allow users other than HOVs (e.g., bicycles)?  
• Will non-bus HOVs or bicycles be conspicuous enough on the HOV facility?  
• Can facility be widened or operated without endangering non-HOVs?  
• Should non-bus HOVs or bicycles be allowed or can they be made more conspicuous? |
| 6. Enforcement of Stopping/Parking/Loading Restrictions  | CC and CF              | • Is enforcement of violations possible?  
• If not, is the possibility of violations significant?  
• Can HOV lane position be shifted?  
• Is a quick removal program feasible? |
| 7. Median and Access Point Design (See No. 1 also)         | CC                     | • What type of median exists or is planned?  
• Can access points be easily entered, and are they clearly defined?  
• Can a raised median be constructed?  
• Can access points be redesigned for easier access and better locational delineation? |

1 This table is continued on the next page, and should be used in conjunction with Tables 4, 5, 6, and 7.
2 BS = Bus street, CC = Concurrent flow lane, CF = Contraflow lane, and QJ = Queue “jumper” lane.
### Table 9 (Continued). Guidance for Vehicular-Related Characteristics.  

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Applicable HOV Facility</th>
<th>Questions to be Answered</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Separation Design/Refuge Areas</td>
<td>CF</td>
<td>• Are evasive or bypass capabilities required?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can mountable median (preferably) be implemented?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Is this a high pedestrian location?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can raised median (preferably) be implemented?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Is space available for intermittent refuge areas?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• If not, is the probability of lane violation or breakdown high, and what are the consequences if either happens without refuge areas?</td>
</tr>
<tr>
<td>9. Hours of Operation/Set Up</td>
<td>CF</td>
<td>• If a peak period operation, can the barrier be set up/removed safely?</td>
</tr>
<tr>
<td>and Removal Procedures</td>
<td></td>
<td>• If not, is a different type of operation feasible (e.g., different flow or hours)?</td>
</tr>
<tr>
<td>10. Weaving and Speed Differential</td>
<td>CC and QJ</td>
<td>• Are there locations where non-HOVs must cross HOV facility and then quickly re-enter it to turn?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Are there sections of the facility where excessive amount of weaving maneuvers will occur?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Will or is the speed differential greater than 10 miles per hour?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can weaving areas be geometrically or operationally mitigated?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can be speed differential be limited (e.g., traffic control).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Is excessive speed differential caused by excessive volumes in the mixed-traffic lanes (see No. 3)?</td>
</tr>
<tr>
<td>11. Bus Stop Location</td>
<td>QJ</td>
<td>• Are stop(s) located to allow easy bus merging and or bypass capability?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• If not, can they be relocated or eliminated, or a pullout be added?</td>
</tr>
<tr>
<td>12. Lane Length</td>
<td>QJ</td>
<td>• Is the lane long enough to allow bypass in almost every instance?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• If not, can the lane be lengthened?</td>
</tr>
</tbody>
</table>

1This table should be used in conjunction with Tables 4, 5, 6, and 7.

2**BS** = Bus street, **CC** = Concurrent flow lane, **CF** = Contraflow lane, and **QJ** = Queue “jumper” lane.
Table 10. Guidance for Pedestrian-Related Characteristics.¹

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Applicable HOV Facility²</th>
<th>Questions to be Answered</th>
</tr>
</thead>
</table>
| **1. Pedestrian Volumes** BS, CC, CF, and QJ |                          | • Are sidewalks wide enough to adequately serve pedestrian traffic and loading/unloading of buses (both may increase if transit service is increased)?  
• Can the sidewalks be widened?  
• Will significant pedestrian crossing volumes severely limit HOV facility time savings?  
• Can large crossing movements be mitigated (e.g., pedestrian bridges)? |
| **2. Pedestrian Crossing Behavior** BS, CC, CF, and QJ |                          | • Where do pedestrians normally cross?  
• If not at designated locations, can crossing locations be designated, signalized, or mitigated?  
• Can errant pedestrians be controlled (e.g., fencing medians) and funneled to designated crossing areas? |
| **3. Enforcement of “Jay-Walking” Ordinance (see No. 2 also)** BS, CC, CF, and QJ |                          | • Is enforcement of violations possible?  
• If not, is the occurrence of “jay-walking” significant enough to be a safety problem and require control by different methods? |
| **4. Pedestrian Mall Design** BS |                          | • Have the amenities been placed to ensure adequate sight distance?  
• If not, can they be removed or adjusted? |

¹This table should be used in conjunction with Tables 4, 5, 6, and 7.
²BS = Bus street, CC = Concurrent flow lane, CF = Contraflow lane, and QJ = Queue “jumper” lane.
ACKNOWLEDGMENTS

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REFERENCES


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