Shared Roadway Implementation Guidance

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Abstract: Shared roadways have automobiles and bicycles operating in the same traveled way, which may negatively affect traffic operations; there is limited guidance on appropriate shared roadway implementation. To provide guidance on shared roadway implementation, this paper uses microsimulation models and a sensitivity analysis to evaluate automobile quality of service on shared roadways. After the sensitivity analysis, automobile quality of service is compared to bicycle quality of service on shared roadways. Using the results of the sensitivity analysis and comparison, guidance is provided on the implementation of shared roadways. This study finds that outside lane width and bicycle volume affect automobile quality of service on shared roadways. Additionally, higher values for unsignalized access points per kilometer (per mile), heavy vehicle percent, and signalized intersection crossing distance result in bicycle quality of service being less than automobile quality of service. Using this study's findings, shared roadway implementation guidance is provided for four-lane divided urban street segments. Future research should develop shared roadway implementation guidance using microsimulation models calibrated to observed data. **DOI:** 10.1061/(ASCE)TE.1943-5436.0000563.

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Introduction

In areas with limited right-of-way, shared roadways are a cost-effective method for providing bicycle facilities; however, shared roadways may negatively affect automobile operations and there is limited guidance on appropriate implementation. One example of implementation guidance, developed by the Oregon Department of Transportation (ODOT), uses automobile volume and automobile speed to provide recommendations on shared roadway use; it suggests shared roadways are less acceptable at higher automobile speeds and automobile volumes (ODOT 2009). Professionals seem to have used engineering judgment in the development of ODOT's draft guidance, not quantitative analysis. One limitation of ODOT's draft guidance is that it ignores bicycle demand in the evaluation of bicycle facilities; furthermore, it does not directly take into account the operational performance of shared roadways (ODOT 2009). To address these limitations, this paper provides guidance on the implementation of shared roadways that takes into account operational performance. To accomplish this, three questions are addressed:

1. How do shared roadways affect automobile quality of service?
2. On shared roadways, how does automobile quality of service compare to bicycle quality of service?
3. When should transportation professionals implement shared roadways?

This paper was originally conducted using U.S. customary units and later converted to metric.

Background

Shared use paths, bicycle lanes, and shared roadways are three types of bicycle facilities; this paper focuses on shared roadways (AASHTO 1999). Shared roadways require bicycle users to be comfortable operating bicycles in the traveled way, which makes amateur cyclists and experienced cyclists the intended users (children should not operate bicycles in the traveled way). The preferred width of a shared roadway facility is 4.6 m (15 ft), which provides room for automobiles to pass bicycles without changing lanes. However, when there is insufficient lane width, less than 4.3 m (14 ft), cyclists are encouraged to ride their bicycles in the center of the lane (League of American Bicyclists 2010); this means automobiles will have to change lanes to pass bicycles, which might influence automobile level of service (LOS).

LOS is "a quantitative stratification of a performance measure or measures that represent quality of service, measured on an A-F scale, with LOS A representing the best operating conditions from the traveler's perspective and LOS F the worst" (Transportation Research Board 2010). On urban street segments, the *2010 Highway Capacity Manual* (HCM) uses percent free-flow speed to determine automobile LOS. Alternatively, the 2010 HCM determines bicycle LOS using a model that includes traffic characteristics (e.g., automobile volume and heavy vehicle percent) and geometric design (e.g., outside lane width and unsignalized access points per mile).

With most bicycles operating at a travel speed between 12.1 and 20.0 km/h (7.5 and 12.4 mi/h), shared roadways are likely to reduce automobile LOS (Allen et al. 1998). To evaluate the effect of shared roadways on automobile LOS, this paper uses *VISSIM 5.10*, a data-intensive microsimulation program. *VISSIM 5.10* is capable of simulating bicycles in the traveled way; however, the authors were unable to identify prior efforts using *VISSIM 5.10* to evaluate operational effects of bicycles.

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Methodology

These research uses microsimulation to generate data for a sensitivity analysis of automobile quality of service on shared roadways. The sensitivity analysis investigates changes in automobile quality of service associated with changes in identified independent variables. In this paper, the measure of effectiveness (MOE) for automobile quality of service is automobile LOS threshold. The authors define automobile LOS threshold as the maximum automobile flow rate for a given LOS. For example, the automobile LOS D threshold is the maximum automobile flow rate on a facility before the automobile LOS becomes E.

Following the sensitivity analysis of automobile quality of service, automobile LOS thresholds were compared to bicycle LOS thresholds. To obtain bicycle LOS D thresholds (the maximum automobile flow rate for a given bicycle LOS), the authors manipulated the bicycle LOS methodology in the 2010 HCM; LOS was made an input and automobile volume an output. Using the results of the comparison, guidance is provided on the implementation of shared roadways.

Variable Selection

To determine which independent variables to evaluate in this study, two criteria were used:

1. The independent variable is changeable in *VISSIM 5.10*; and
2. The independent variable is part of the 2010 HCM bicycle LOS model.

The independent variable values in this research are representative of four-lane divided minor arterials and collectors. A four-lane road was selected for the analysis because vehicles cannot change lanes on a two-lane road and six-lane roads have characteristics that discourage shared lane use. Table 1 provides the independent variables and values used in this research. In addition to the values shown in Table 1, breakdowns of the unsignalized access points per kilometer (per mile) and signal offset by free-flow speed (FFS) are provided in Tables 2 and 3, respectively.

VISSIM 5.10 uses desired speed distributions to assign speeds to simulated vehicles. This research assumes uniform speed distributions with a median speed equal to the FFS; the minimum and maximum values for the speed distributions are 8.0 km/h (5 mi/h) lower and 8.0 km/h (5 mi/h) greater than the FFS. his study uses 8.0 km/h (5 mi/h) because it is the recommended standard deviation used to calculate the number of observations needed in a spot speed study (Box and Oppenlander 1976). For example, the 56.3 km/h (35 mi/h) FFS microsimulation model has a uniform speed distribution with a median speed of 56.3 km/h and a minimum and maximum speed of 48.3 km/h (30 mi/h) and 64.4 km/h (40 mi/h), respectively.

Unsignalized access points per mile is the total number of unsignalized access points on one side of the roadway segment divided by the length of the roadway segment, converted to a per kilometer (per mile) equivalent (Transportation Research Board 2010). A recommended access point spacing is stopping sight distance (SSD), which varies by free-flow speed (Stover and Koepke 2006; Transportation Research Board 2003). Assuming the minimum spacing of SSD from center of driveway to center of driveway, maximum access is the maximum number of access points on a 402.3-m (1,320-ft) roadway segment; half access is half the maximum access value (values found in Table 2).

Signal offset is also dependent on FFS. This study uses signal offsets equal to the segment length divided by FFS, converted to seconds. This means vehicles traveling near the FFS should clear the downstream intersection under low volumes; this is an idealized condition. The signal offsets are provided in Table 3.

Table 1. Sensitivity Analysis Independent Variables and Values

Independent variable	Criteria met	Value(s)
	Geometric design	
Number of directional through lanes	Both	2
Outside lane width	Both	3.66 and 4.57 m
Segment length	Simulation	402.3 and 804.7 m
Roadway division	2010 HCM	Divided
Unsignalized access points per kilometer	2010 HCM	Table 2
Signalized intersection crossing distance	2010 HCM	11.6, 18.9, and 26.2 m
Percentage of roadway segment with occupied on-street parking	2010 HCM	0, 50, and 100%
Federal Highway Administration's five-point pavement surface condition rating	2010 HCM	2, 3, and 4
	Traffic characteristics	
Automobile FFS	Both	40.2, 48.3, 56.3, 64.4, and 72.4 km/h
Automobile flow rate	Both	300 to 1,500 vehicles/h (increments of 150 or 300 vehicles/h)
Bicycle FFS	Simulation	12.1–20.0 km/h
Bicycle flow rate	Simulation	0, 25, 50, and 100 bikes/h
Cycle length	Simulation	90 and 120 s
Green-time ratio	Simulation	0.20 and 0.40
Signal offset	Simulation	Table 3
Heavy vehicle percent	2010 HCM	0, 5, and 10%
Peak hour factor	2010 HCM	1.0

Table 2. Unsignalized Access Points Comparison Rates by FFS

FFS (km/h)	Minimum spacing (m)	No access (points per kilometer)	Half access (points per kilometer)	Maximum access (points per kilometer)
40.2	147.2	0	8.70	17.40
48.3	161.0	0	6.21	12.43
56.3	176.2	0	4.97	19.94
64.4	193.0	0	3.73	17.46
72.4	109.7	0	2.49	14.97

Table 3. Signal Offset by FFS and Segment Length

	Signal offset (s)	
FFS (km/h)	402.3-m segment	804.7-m segment
40.2	36	72
48.3	30	60
56.3	26	51
64.4	23	45
72.4	20	40

Microsimulation Models

Unless otherwise stated, this paper follows the California Department of Transportation (Caltrans) guidelines for applying microsimulation modeling software (Dowling et al. 2002). There are 96 ways to combine microsimulation variables; this does not include automobile FFS and automobile flow rate combinations. Including automobile FFS and automobile flow rate, there are 2,400 combinations. This paper reduces the number of combinations evaluated by limiting the investigation to values found in Table 1 and by not evaluating the combined effect of independent variables. This means in the investigation of segment length, only segment length is changed and all other variables remain constant. This approach results in six models, with each model having one to three simulation scenarios (these scenarios do not include the 25 automobile FFS and automobile flow rate combinations); the connections between models, scenarios, FFSs, and automobile flow rates are shown in Fig. 1. The independent variable values for each model and scenario are shown in Table 4.

For each model, all the scenarios and speed conditions were run simultaneously. This means each model has five roadway segments for each scenario (one for each speed condition). This is done by creating roadway segment sets; there is one roadway segment set for each speed condition. An example of a roadway segment set is shown in Fig. 2. The number of roadway segments in each roadway segment set is dependent on the number of scenarios. For example, Model 1 has three scenarios, which means it has three roadway segments in each set; Model 4 has two scenarios, which means it has two roadway segments in each set. Each model has five roadway segment sets, one for each free-flow speed. Additionally, 12 to 18 seeds (values used within VISSIM to randomly assign vehicles speeds using the desired speed distributions) are run for each volume, beginning with seed 40 and going up in increments of 3. Lower volumes use 12 seeds and higher volumes use 18 seeds. A limitation of this approach is running different scenarios and different automobile FFS combinations on different roadway segments in the model; this could result in minor differences, which running 12 to 18 seeds should account for.

As an unfunded effort, the authors were not able to collect data to calibrate the model for capacity and demand related factors; adjustments were made for realism. A practicing transportation engineer with bicycle experience assisted in calibrating the interaction between automobiles and bicycles. The practicing transportation engineer assisted researchers in calibrating three behaviors: automobiles passing bicycles in 3.66-m (12-ft) lanes, automobiles passing bicycles in 4.57-m (15-ft) lanes, and bicycles pulling to the right of automobiles at intersections. The resulting models allow automobiles to pass a bicycle if they can maintain a minimum separation of 0.91 m (3 ft) at any speed; as of 2010, this is the minimum legal clearance when passing a bicycle in an automobile for 15 states (Bisbee 2010). The resulting models also allow bicycles to pull to the right of automobiles at an intersection if they can maintain a separation of 0.30 m (1 ft) at 0 km/h (0 mi/h) and 0.61 m (2 ft) at 50 km/h (31 mi/h).

Table 4. Microsimulation Models and Scenarios

Model	Scenario	Bicycle flow rate (bikes/h)	Outside lane width (m)	Green-time ratio	Cycle length (s)	Segment length (m)
1	1.1	000	3.66	0.4	090	402.3
	1.2	050	3.66	0.4	090	402.3
	1.3	050	4.57	0.4	090	402.3
2	2.1	025	3.66	0.4	090	402.3
3	3.1	100	3.66	0.4	090	402.3
4	4.1	000	3.66	0.2	090	402.3
	4.2	050	3.66	0.2	090	402.3
5	5.1	000	3.66	0.4	120	402.3
	5.2	050	3.66	0.4	120	402.3
6	6.1	050	3.66	0.4	090	804.7

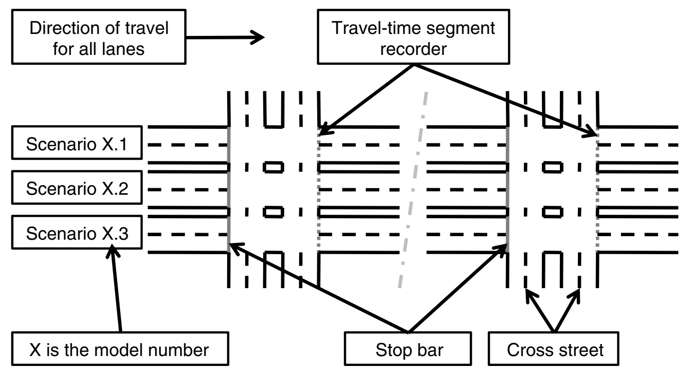

Fig. 2. Example of a roadway segment set; there are five sets in each model, one for each FFS

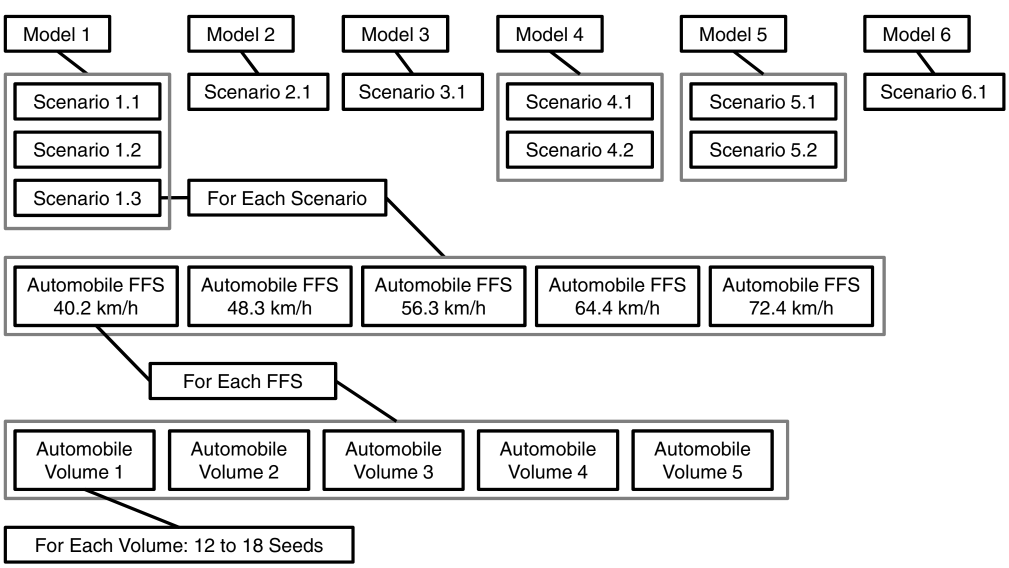

Fig. 1. Connections between models, scenarios, FFSs, and flow rate

Determining Automobile LOS Thresholds

To determine the automobile LOS thresholds, this paper uses outputs from the microsimulation models. For each seed, the microsimulation model outputs average travel time and automobile volume. Using segment length, average travel time is converted to average travel speed; average travel speed is then divided by free-flow speed to obtain percent free-flow speed. To obtain automobile volume-to-capacity ratios, the automobile volume was divided by the automobile capacity for the roadway segment. To determine capacity, simulations were run with automobile flow rates greater than the roadway segments through movement capacity; this means capacity was the average maximum number of vehicles that could traverse the corridor in 60 simulation minutes.

After determining percent free-flow speed and automobile volume-to-capacity ratio, each scenario is plotted and a regression equation is fit to the data. The regression equations are then used to solve for the automobile LOS thresholds. Fig. 3 contains an example of data plotted for this purpose; it also indicates how the authors solved for LOS D thresholds. Using the threshold values, a sensitivity analysis is conducted of automobile LOS on shared roadways.

Automobile Quality of Service Analysis

Of the five variables investigated in the automobile LOS D sensitivity analysis (outside lane width, segment length, bicycle flow rate, cycle length, and green-time ratio), it was found that outside lane width and bicycle flow rate influenced automobile quality of service on shared roadways. The influence of outside lane width and bicycle flow rate are documented in Fig. 4, which shows a higher automobile LOS D threshold for 4.57-m (15-ft) lanes and lower bicycle volumes. The results of the outside lane width comparison [Fig. 4(a)] indicate the difference in automobiles' ability to pass bicycles (they had to change lanes in the 3.66-m (12-ft) outside lanes); the results of the bicycle volume comparison [Fig. 4(b)] indicate differences caused by how often automobiles had to pass bicycles. These findings indicate shared roadway implementation guidance should consider outside lane width and bicycle volume.

While there were differences in automobile LOS D thresholds associated with the other three variables, these differences were equivalent to the difference in capacity associated with the change in the variable's value. For example, the difference in automobile LOS D thresholds between a 90-s cycle and a 120-s cycle is the same as the difference in capacity between a 90-s cycle and a 120-s cycle. While this indicates cycle length is not influencing automobile LOS on shared roadways, it also indicates that shared roadway implementation guidance should account for differences in automobile capacity.

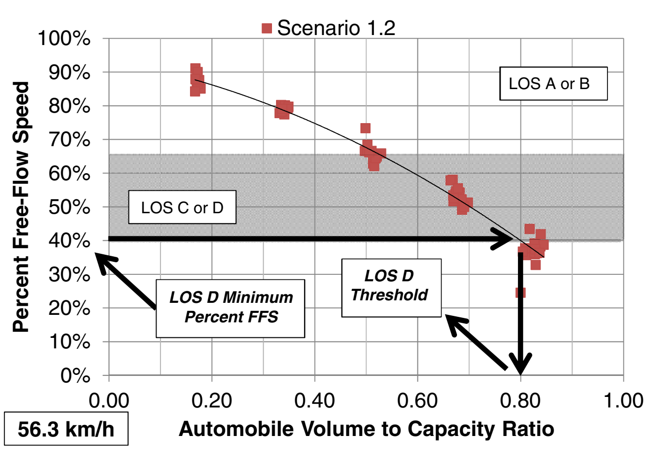

Fig. 3. Example of plotted data and solving for automobile LOS D threshold value

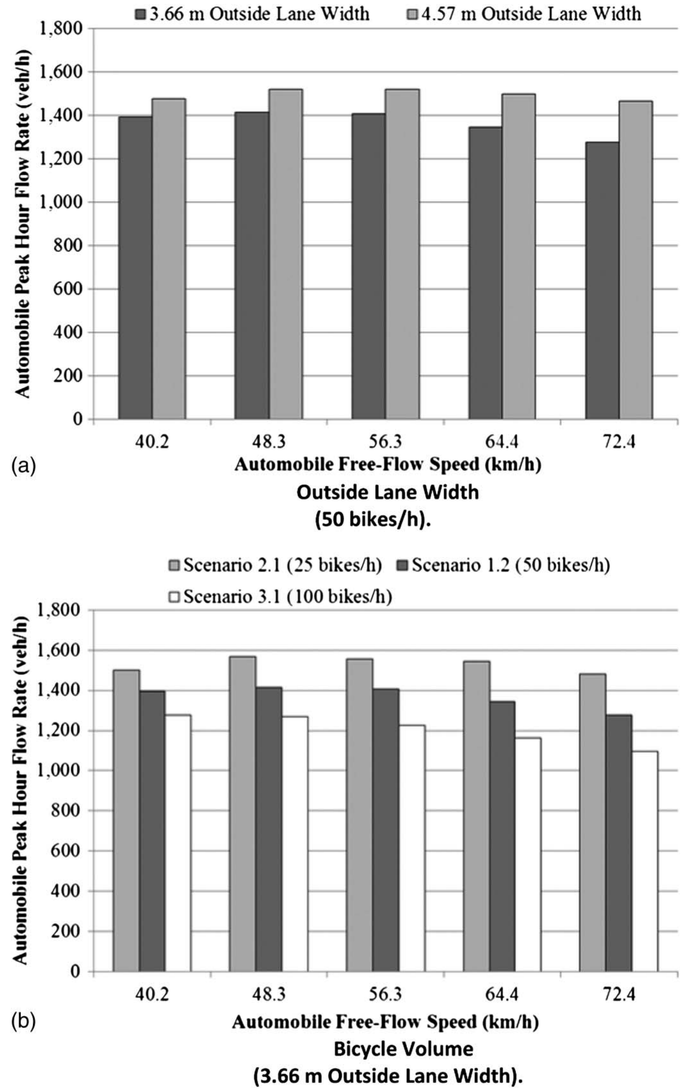

Fig. 4. Automobile LOS D thresholds: (a) outside lane width (50 bikes/h); (b) bicycle volume (3.66 m outside lane width)

Automobile and Bicycle Quality of Service Comparison

The comparison of automobile LOS D thresholds to bicycle LOS D thresholds indicates that automobile LOS D thresholds are often lower than bicycle LOS D thresholds. Of the variables included in the 2010 HCM bicycle LOS model, only unsignalized access points per kilometer (per mile), heavy vehicle percent, and signalized intersection crossing distance can take values that make bicycle LOS D thresholds less than automobile LOS D thresholds. To assist in the creation of shared roadway implementation guidance, it was determined what values each of the variables needed to take for bicycle LOS D thresholds to be less than automobile LOS D thresholds; those values are provided in Table 5. Values greater than those found in Table 6 indicate that bicycle LOS D is lower than automobile LOS D. For example, if a divided four-lane arterial with 3.66-m (12-ft) outside lanes and a posted speed limit of

Table 5. Bicycle Considerations, Shared Roadway Implementation Guidance

Posted speed limit (km/h)[a]	Unsignalized access points per kilometer		Heavy vehicle percent (%)		Signalized intersection crossing distance (m)	
	3.66-m lane	4.57-m lane	3.66-m lane	4.57-m lane	3.66-m lane	4.57-m lane
40.2	6.03	10.75	12.1	18.1	30.5	45.1
48.3	5.47	10.25	9.2	14.6	29.6	43.9
56.3	5.22	10.00	8.1	13.2	29.3	43.9
64.4	5.47	10.13	8.0	12.5	30.2	44.5
72.4	5.84	10.25	8.0	12.1	31.1	45.7

[a]Also called the free-flow speed for the facility.

Table 6. Shared Roadways Percent Free-Flow Speed

Scenario	Speed limit (km/h)	Volume-to-capacity ratio (%)				
		0.5	0.6	0.7	0.8	0.9
3.66-m lane	40.2	73	66	57	47	35
	48.3	71	63	54	43	31
	56.3	68	59	50	40	29
	64.4	64	55	45	35	23
	72.4	61	51	41	30	18
4.57-m lane	40.2	77	70	62	52	41
	48.3	77	70	61	51	39
	56.3	77	69	59	48	35
	64.4	74	66	56	45	32
	72.4	72	64	53	42	29

Note: Data given for 50 bicycles/h.

56.3 km/h (35 mi/h) has 8.5% heavy vehicles, the bicycle LOS D threshold is less than the automobile LOS D threshold (8.5% is greater than 8.1%, from Table 5). These findings indicate that guidance on shared roadway implementation should consider automobile quality of service and bicycle quality of service. Additionally, unless the unsignalized access points per kilometer (per mile), heavy vehicle percent, or signalized intersection crossing distance are large, automobile quality of service should be a primary concern when considering shared roadway implementation.

Shared Roadway Implementation Guidance

The results from the automobile quality of service analysis and comparison to bicycle quality of service indicate shared roadway implementation guidance should consider both modes. Additionally, automobile quality of service is often the primary concern and shared roadway implementation guidance should consider automobile capacity. Based on these findings, the following shared roadway implementation guidance is proposed. The microsimulation model was not calibrated to observed data; for this reason, use caution in precise application. Better delay estimates are possible through a data collection effort and proper model calibration.

Automobile Quality of Service Considerations

This guidance assumes agencies should not implement shared roadways if the automobile LOS or bicycle LOS is F. This guidance assumes shared roadways are acceptable if the automobile LOS and bicycle LOS are A, B, or C. If either the automobile LOS or bicycle LOS is D or E, then conducting a more detailed analysis is recommended. Using LOS as a metric is recommended because *A Policy on the Geometric Design of Highways and Streets* uses LOS D to determine if a highway needs climbing lanes, which is similar to the need for a bicycle facility other than shared roadways (AASHTO 2004). If the LOS of a highway is less than LOS D, *A Policy on the Geometric Design of Highways and Streets* recommends adding a climbing lane to improve the level of service.

In Fig. 5, a graphical representation of these recommendations is provided for facilities with 3.66-m (12-ft) and 4.57-m (15-ft) outside lane widths. In these graphs, the x-axis is the automobile volume-to-capacity ratio (as determined by 2010 HCM methodologies) and the y-axis is the posted speed limit (or free-flow speed). The values in Fig. 5 assume a bicycle flow rate of 50 bicycles per hour. When conducting a more detailed analysis, estimating percent free-flow speed for the facility, which is the basis for automobile LOS, is recommended. Similar to the LOS D criteria in *A Policy on the Geometric Design of Highways and Streets*, the authors recommend not using shared roadways if the automobile LOS is E or F, meaning the percent free-flow speed is 40% or less.

Detailed Automobile Analysis

Using data from the microsimulation models, a means for conducting a more detailed analysis of automobile LOS that

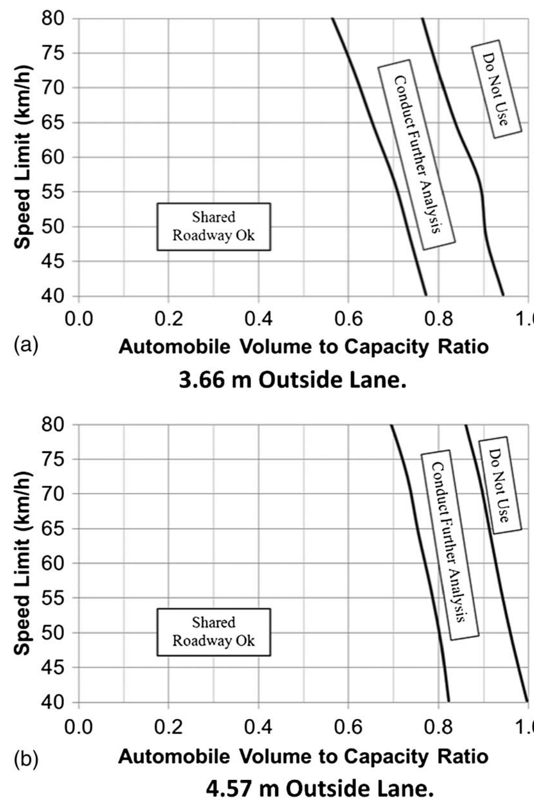

Fig. 5. Shared roadway implementation guidance (50 bikes/h): (a) 3.66-m outside lane; (b) 4.57-m outside lane

Table 7. Bicycle Volume Adjustment Factors

Scenario	Speed limit (km/h)	Volume-to-capacity ratio				
		0.5	0.6	0.7	0.8	0.9
25 bikes/h, 3.66-m lane	40.2	1.07	1.09	1.12	1.16	1.23
	48.3	1.10	1.13	1.17	1.24	1.36
	56.3	1.12	1.15	1.19	1.24	1.32
	64.4	1.13	1.18	1.24	1.35	1.57
	72.4	1.14	1.20	1.28	1.42	1.75
100 bikes/h, 3.66-m lane	40.2	0.92	0.90	0.87	0.82	0.75
	48.3	0.92	0.89	0.84	0.75	0.58
	56.3	0.91	0.86	0.79	0.67	0.43
	64.4	0.88	0.83	0.74	0.59	0.26
	72.4	0.85	0.80	0.72	0.59	0.27

considers bicycle volume is provided. When conducting further analysis, the first step is to round the calculated automobile volume-to-capacity ratio to the nearest tenth. Then, using Table 6, determine the base percent FFS; for example, the base percent FFS is 45% on a facility with 3.66-m (12-ft) outside lanes, a 64.4 km/h (40 mi/h) speed limit, and a volume-to-capacity ratio of 0.7. After determining the base percent FFS, adjust the average travel speed by the factors in Table 7. The factors account for differences in average travel speed caused by a difference in bicycle volume. For example, if the bicycle volume is not 50 bikes per hour, but is 100 bikes per hour, the adjustment factor is 0.74. Multiplying 45% by 0.74 yields a percent FFS of 33%; because this value is less than the value for LOS D (40%), a shared roadway facility is unacceptable.

Bicycle Quality of Service Considerations

When considering bicycle quality of service on a shared roadway, there are two options. One option is to calculate bicycle LOS on the facility using the bicycle LOS model in the 2010 HCM; however, this method is data intensive. Alternatively, to determine the bicycle quality of service quickly, professionals can use the values in Table 5. If the unsignalized access points per kilometer (per mile), heavy vehicle percent, or signalized intersection crossing distance are at or greater than the values in Table 5, bicycle LOS is likely E or F and a shared roadway facility is unacceptable.

Conclusions and Recommendations

According to the automobile quality of service analysis, bicycle volume and outside lane width are primary factors in the evaluation of automobile quality of service on shared roadways. The negative effects of shared roadways increase as bicycle volume increases; additionally, the negative effect of shared roadways is greater on shared roadways with 3.66-m (12-ft) outside lane widths than on shared roadways with 4.57-m (15-ft) outside lane widths. These findings indicate transportation professionals should consider automobile quality of service when considering the implementation of shared roadways. However, this is not an indication to exclude bicycles from the corridor; it indicates professionals should consider alternative solutions in the provision of bicycle facilities (e.g., bicycle lanes).

In the scenarios looked at as part of this research, bicycle LOS D thresholds are often greater than automobile LOS D thresholds; this means decision makers should consider automobile quality of service when considering shared roadway implementation. However, according to the automobile and bicycle quality of service comparison, unsignalized access points per kilometer (per mile), heavy vehicle percent, and signalized intersection crossing distance are capable of dropping bicycle LOS D thresholds below automobile LOS D thresholds; this suggests using a multimodal approach for evaluating shared roadways.

The guidance developed as part of this research shows that as automobile free-flow speed and volume-to-capacity ratio increase, shared roadways become less acceptable, which matches the guidance developed by ODOT. Additionally, this research provides estimates of unsignalized access points per kilometer (per mile), heavy vehicle percent, and signalized intersection crossing distances that demonstrate when bicycle quality of service becomes the primary concern on shared roadways. These values indicate that bicycle LOS limits the implementation of shared roadways when a corridor has more than 5.22 unsignalized intersections per kilometer (8.4 per mile), a traffic flow with more than 8% heavy vehicles, or a signalized intersection crossing distance more than 29.3 m (96 ft).

The findings of this research have the following limitations:

- Guidance is based on traffic operations and does not consider facility safety.
- The microsimulation models were not calibrated to observed data.
- The results only apply to four-lane divided shared roadways with free-flow speeds of 40.2 km/h (25 mi/h), 48.3 km/h (30 mi/h), 56.3 km/h (35 mi/h), 64.4 km/h (40 mi/h), or 72.4 km/h (45 mi/h).
- Only one bicycle speed distribution was considered.
- Guidance assumes a bicycle flow-rate of 50 bicycles per hour, which may be higher than some jurisdictions will experience.
- In *VISSIM 5.10*, each speed condition was run on a different roadway segment (this may create minor differences between each scenario, 12 and 18 seeds were run to limit the affect).

Given the limitations of this research, the authors recommend data collection efforts to quantify the effect of bicycles in the traveled way. If future efforts seek to calibrate microsimulation models to observed data, the authors provide the following insights:

- Observe speed distributions for each FFS.
- Observe speed distributions for bicycles taking into consideration roadway geometry (such as grade).
- Observe lateral interactions between automobiles and bicycles; specifically, obtain speed and lateral clearance values for input in VISSIM.
- The driver following and passing models may not properly model automobile driver behavior behind bicycles (the models were developed for automobile behind automobile).

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