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EVALUATING SPEEDS OF WEAVING SECTIONS AT U-TURN SLOTS IN METRO MANILA USING HCM 2000

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ABSTRACT

The closure of signalized intersections and the rerouting of traffic into midblock U-turn median openings (U-turns) paved the way for free-flow traffic conditions (uninterrupted flow) in an intersection. However, direct left turn vehicles will now have to take a series of right-turn plus U-turn (RTUT) maneuvers in order to duplicate the same path taken prior to the closure. As a consequence, RTUT vehicles must lane change across into the innermost lane towards the U-turn slot, thus creating weaving areas. Currently, methods for analyzing the speeds in the weaving segment were derived exclusively on freeway weaving sections. The weaving maneuver that closely compares to the weaving of a RTUT vehicle is the two-sided Type C freeway weave. The HCM Weaving Model for Type C was used to predict weaving and nonweaving speeds. Results of the HCM model show that weaving and nonweaving speeds were poorly predicted.
Key Words: Arterial weaving speed, U-turn, models, estimation

1. INTRODUCTION

The closure of a significant number of signalized intersections and the rerouting of traffic into midblock U-turn median openings (U-turn slots) by the Metro Manila Development Authority (MMDA) paved the way for free-flow traffic conditions (uninterrupted flow) and increased progression of through vehicles in the arterial. This does not hold true for traffic from the secondary street as they are the subject of diversion. Direct left turn (DLT) movements will now have to take a right-turn plus U-turn (RTUT, for vehicles from the secondary street) or U-turn plus right-turn movements (UTRT, for those from the major arterial) as shown in Figure 1. Whereas, through movements from the secondary street is replaced by a series of the two previous movements, RTUTR (Zhou, 2003). As a consequence, weaving areas are formed between the intersection approach and the adjacent midblock median U-turn opening.

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The paper is organized as follows. In Section 2, the objectives of the paper are given while the significance is discussed in Section 3. In Section 4, an overview on HCM 2000 methodology for weaving analysis. The characteristics of arterial weaving is discussed in Section 5 followed by the survey methodology in Section 6. The results of the modelling estimation and discussion follow in Sections 7 and 8, respectively. Finally, concluding remarks and recommendations are presented in Section 9.

2. OBJECTIVES

The objective of this study is to evaluate the applicability of the HCM 2000 models for predicting weaving and nonweaving speeds of Type C (two-sided weave) weaving areas on urban arterials. The research will focus on the section between the intersection approach and U-turn slot. Specifically, the research aims to:

- Describe the traffic characteristics within an urban street weaving area formed after the closure of a signalized intersection; and
- Evaluate the HCM 2000 weaving speed models for the prediction of weaving and nonweaving speeds in an urban street weaving area.

3. SIGNIFICANCE

In this research, the weaving section is the segment between the sidestreet and the adjacent U-turn median opening (Figure 1). This weaving section has been classified as a Type C weave section (2-sided weave) as described in Chapter 13 of the Highway Capacity Manual (HCM 2000).

Weaving sections have unique operational characteristics and require special design consideration. In the past, weaving section research has concentrated almost exclusively on freeway weaving sections. As a result, transport practitioners are in the dark when analyzing urban arterial weaving sections. A procedure is needed for analyzing arterial weaving sections. A first step towards this goal is the evaluation of existing weaving models for applicability in urban arterials.

4. HCM 2000 WEAVING ANALYSIS METHODOLOGY

The level-of-service criteria used for a freeway weaving segment is the density of vehicles within the section. The methodology presented in the HCM 2000 has five distinct components, two of which are the subject of this study (as shown also in the study framework) and are listed below:

- Models predicting the space mean speed (average running speed) of weaving and nonweaving vehicles in the weaving segment (models are specified for each configuration type and for unconstrained and constrained operations);
- Models describing proportional use of lanes by weaving and nonweaving vehicles, used to determine whether operations are unconstrained or constrained;

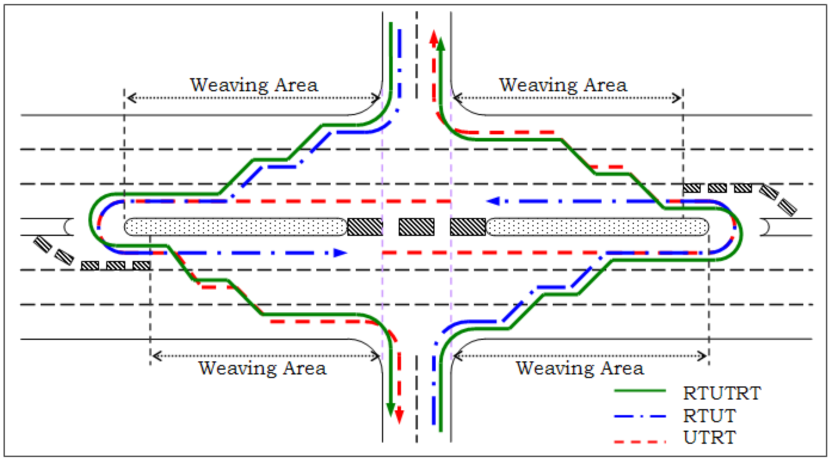

Figure 1. Alternative Paths Formed after Closing Intersection

Figure 2 summarizes the part in the HCM weaving methodology included in this research (area inside the dashed line). The weaving and nonweaving speeds are estimated based on the data collected. After which, the number of lanes required for equilibrium operation of weaving vehicles is computed and compared with the maximum number of lanes that the weaving vehicles are allowed to use (based on the weaving configuration). The weaving and nonweaving speeds are again computed based on the prevailing condition.

4.1. Determining Weaving and Nonweaving Speeds

The heart of the weaving segment analysis procedure is the prediction of space mean speeds of weaving and nonweaving flows (Equation 1) within the weaving segment. They are predicted separately because under some conditions they can be quite dissimilar.

The algorithm for the prediction of average weaving and nonweaving speeds may be generally stated as,

$$S_i = S_{min} + \frac{S_{max} - S_{min}}{1 + W_i} \tag{1}$$

where S_i = average speed of weaving ($i = w$) or nonweaving ($i = nw$) vehicles,
S_{min} = minimum speed expected in a weaving segment,
S_{max} = maximum speed expected in a weaving segment, and
W_i = weaving intensity factor for weaving ($i = w$) and nonweaving ($i = nw$) flows

The weaving intensity factor, W which is a measure of weaving activity and its intensity has the general form,

$$W_i = \frac{a\,(1 + VR)^b \left(\frac{v}{N}\right)^c}{L^d} \tag{2}$$

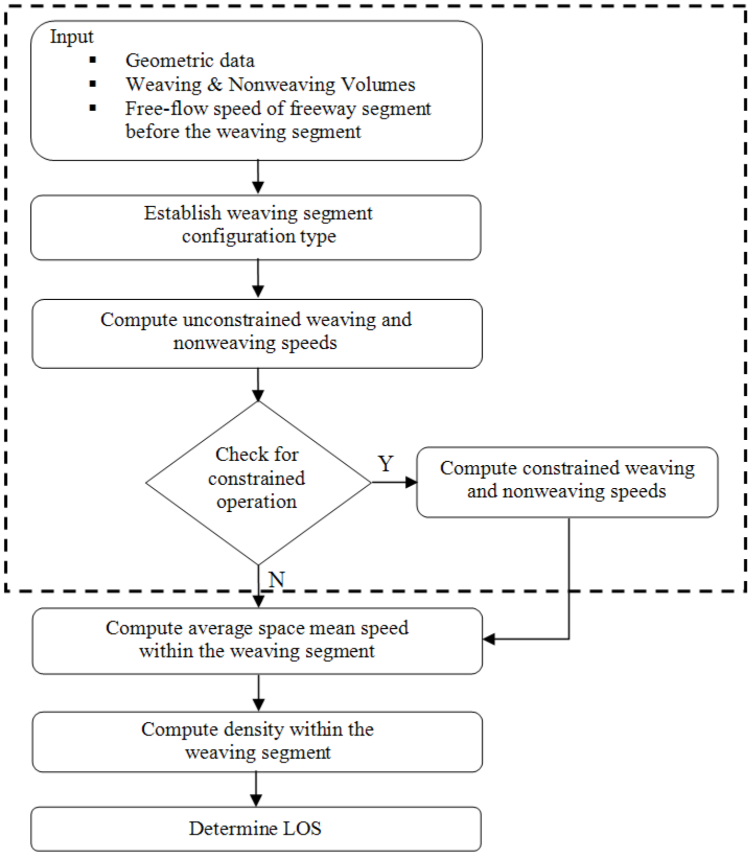

Figure 2. Portion of the HCM Weaving Methodology Covered in the Study (HCM 2000)

where VR = the ratio of weaving flow rate to total flow rate in the weaving segment,
v = total flow rate in the weaving segment,
N = total number of lanes in the weaving segment,
L = length of weaving segment,
a, b, c, d = calibrated regression coefficients (values are in Table I).

Initial estimates of speed are always based on the assumption of unconstrained operation. This assumption is then tested, and speeds are recomputed if operations turn out to be constrained.

4.2. Determining Type of Operation

Under normal circumstances, weaving and nonweaving vehicles will reach equilibrium operation in which weaving vehicles effectively occupy N_w lanes of the segment, with nonweaving vehicles occupying the remaining lanes.

Constants for Weaving Speed, Sw				
	a	B	C	D
Unconstrained	0.08	2.30	0.80	0.60
Constrained	0.14	2.30	0.80	0.60
Constants for Nonweaving Speed, Snw				
Unconstrained	0.0020	6.00	1.10	0.60
Constrained	0.0010	6.00	1.10	0.60

Table I. Regression Coefficients for Type C Configuration (HCM 2000)

For a two-sided Type C weaving configuration, all freeway lanes may be used by weaving vehicles as illustrated in Figure 3. For a three-lane one-way arterial, all three lanes can be utilized by weaving and nonweaving vehicles. Because of this, more often than not, two-sided configurations will most likely be unconstrained.

The determination of whether a particular weaving segment is operating in an unconstrained or constrained state is based on the comparison of two variables,

N_w = number of lanes weaving vehicles must occupy to achieve equilibrium operation with nonweaving vehicles, and

$N_w(max)$ = maximum number of lanes that can be occupied by weaving vehicles based on geometric configuration.

Cases for $N_w < N_w(max)$ are unconstrained because there are no impediments to weaving vehicles using the number of lanes required for equilibrium. But if $N_w \geq N_w(max)$, weaving vehicles are constrained to using $N_w(max)$ lanes and therefore cannot occupy as much of the roadway as would be needed to establish equilibrium operations.

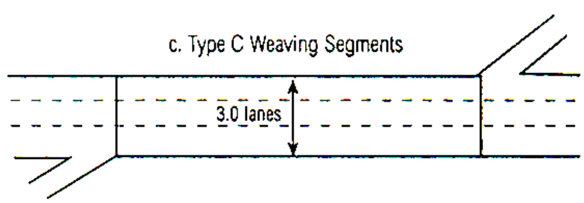

Figure 3. Maximum Number of Lanes Occupied by Weaving Vehicles for Type C Weaving Configuration (HCM 2000)

The equation in Table II uses the predicted unconstrained weaving and nonweaving speeds to compute the number of lanes weaving vehicles would have to occupy to achieve unconstrained speeds. If the result indicates that constrained operations exist, speeds must be recomputed using constrained equations.

5. PHYSICAL AND OPERATIONAL ANALYSIS OF ARTERIAL WEAVING

As a result of the closure of a significant number signalized intersections and the rerouting of the subsequent traffic into midblock U-turn median openings, DLT vehicles will have to

Configuration	Number of Lanes Required for Unconstrained Operation, N_w	$N_w(max)$
Type C	$N[0.761 + 0.047VR - 0.00011 - 0.005(S_{nw} - S_w)]$	3.0^a

Note: a. For a 3-lane two-sided weaving segment, all freeway lanes may be used by weaving vehicles.

Table II. Unconstrained Operation of Type C Weaving Areas (HCM 2000)

negotiate a RTUT maneuver. A typical RTUT maneuver requires four steps: (1) stop at the secondary street opening, and make a right turn when a suitable (acceptable) gap from the major arterial through traffic (left side through traffic); (2) accelerate and weave to the inside-most (innermost) lane, and decelerate to a stop at the U-turn median opening; (3) wait for a suitable gap to make a U-turn (if U-turn slot is not protected); and (4) accelerate to the operating speed of through traffic. Steps 2 and 3 (weaving and U-turns) are the key elements for completing this type of maneuver (Zhou, 2003). The weaving element is the subject of this study.

The weaving maneuver that closely compares to that of the weaving on an RTUT maneuver is the two-sided Type C freeway weave as described in Figure 4. This type of weaving configuration is formed by a right-hand on-ramp followed by a left side off-ramp. The through volume of the freeway functionally acts as a weaving movement and does not require a lane change (except in avoiding slow moving vehicles). The other movement, the ramp-to-ramp flow on the other hand would require vehicles to change lanes three times. Similarly, the RTUT maneuver has to perform three lane changes upon entering the roadway to stopping at the adjacent median opening on a three-lane (one-way) arterial. Major arterial through traffic does not have to change lanes except to avoid conflicts with slow weaving vehicles in the weaving section or preposition to the next lane.

5.1. *Angle and Speed of Entry*

Weaving vehicles in an arterial enter the through traffic stream from a stopped of slowed speed from the secondary street. This is due to the sharp angle of entry and lack of site distance of the entering vehicle. The angle between the secondary street and the major arterial is relatively steep (˜90° , right-angle) compared to the off-ramp entering the freeway which is smoother (<< 90°). Although tapering can be introduced at the entry of the arterial, entry speeds of weaving vehicles are still substantially lower versus freeway entry speeds. Also, tapering in an intersection corner is restricted by the existence of development in the urban intersection. In addition, the driver has to select an acceptable gap before entering the major arterial. Acceleration and deceleration ramp lanes are also provided in freeways such that the weaving vehicles have appropriate entering and exiting speeds whereas in urban arterials, most of the time there is none.

5.2. *Weaving Length*

As for the weaving length, there is a problem in applying the HCM procedure in determining the weaving segment length for Type C weaving configuration. This is especially true when the angle of entry and exit at the ramp is sharp (90 degrees). For simplicity in this study, weaving length for the two-sided weave was simplified as shown in Figure 4.

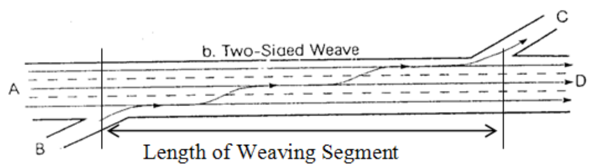

Figure 4. Length of Weaving Segment for Type C: 2-Sided Weave (HCM 2000)

5.3. Movements

Based on field observations of the selected study sites, there are generally three classifications of the weaving movement of the vehicles coming from the secondary street in a weaving section regardless of the length of the weaving section (illustrated in Figure 5). They are: (1) Drivers will select an acceptable simultaneous gap in all through lanes and make a direct entry into the innermost lane in order to make the U-turn median opening (Movement 1, Aggressive drivers). Gap-forcing sometimes occur if there are no simultaneous gap available. (2) A suitable gap in the outermost lane is selected, turn into the lane, accelerate, and then make lane changes gradually into the innermost lane towards the U-turn (Movement 2, Conservative drivers). (3) The driver turns into the right-side lane, accelerates, changes lane but takes the U-turn from a lane other than the innermost (Movement 3, Unfamiliar drivers). This happens either when the queue in the innermost lane is long or the driver is not familiar with the proximity of the U-turn slot.

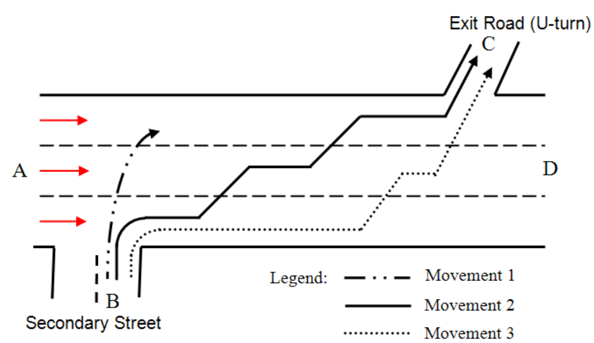

Figure 5. Classification of Weaving Movements Based on Field Observations

6. SURVEY METHODOLOGY

6.1. Data Collection

Data were collected during weekdays under normal traffic conditions, good weather, and dry pavement conditions. Data collection activities for this study included traffic volume, vehicle classification, speed, and weaving section geometry. All operational data were collected using the video recording equipment. The weaving section geometry was obtained from field measurements.

Operational data were collected using video recording equipment that was mounted on a tripod and stationed at the adjacent pedestrian overpass immediately upstream of the subject weaving areas. The video camera was positioned such that the operation of the entire weaving section could be observed. One video camera was used to record the operation of the vehicles coming from the secondary street and arterial in the weaving segment. The video camera captured the movement of each vehicle within the weaving section. The weaving segment was defined as the area on the arterial road between the secondary street and the adjacent U-turn median opening as described in Figure 5. The video recordings were then transferred and converted into digital format on a computer for ease of data extraction. For vehicle speeds, a trap length was defined within the sections in order to estimate the actual vehicle speeds. Other appropriate operational data were obtained directly by repeated viewing of the recording on a computer monitor.

Figure 6. Snapshot of Site 1 (left) & Site 2 (right)

The two study sites considered for this research satisfied all of the requirements in the previous paragraph. Both sites are located in the same segment of the arterial roadway (Quezon Avenue). Both arterial roads support 8 lanes (2-way) divided by a 5-meter nontraversable median. The secondary streets are two lanes each. Basically, they have the same geometric configurations except for the weaving lengths. The weaving length of Site 1 (Banaue - Quezon Ave.) is 185 m. while Site 2 (Scout Borromeo - Quezon Ave.) supports a 120-meter segment.

6.2. Site 1 Description (Banaue Ave. - Quezon Ave. Westbound)

Site 1 is located at the intersection of Banaue Avenue and Quezon Avenue was selected based on convenience of setting up the video recording equipment on the adjacent pedestrian overpass aside from satisfying the site selection criteria. The section is along Quezon Avenue and is between Banaue Avenue and Cordillera Avenue to the west. The traffic considered is the westbound flow (towards Manila). The Figure 6 shows a snapshot of the perspective from the video recording equipment.

6.3. Site 2 Description (Scout Borromeo - Quezon Ave. Eastbound)

Site 2 is located at the intersection of Scout Borromeo and Quezon Avenue. Similar to Site 1, a pedestrian overpass is located adjacent to Site 2. The section is along Quezon Avenue between Scout Borromeo to the west and Examiner Avenue to the east. The traffic considered was the eastbound flow (towards Quezon City Hall). The Figure 6 shows a snapshot of the perspective from the video recording equipment at Site 2.

7. RESULTS

Table III shows the results of the paired samples t-test applied to the weaving and nonweaving speeds observed in the field versus the speeds predicted by the HCM model. Mean weaving speeds are very similar for the observed against the predicted values as evidenced by the t-statistics of -0.584 and a significance of 0.563. The standard deviations though are evidently unequal, observed weaving speeds are more spread compared to that of the predicted speeds. Conversely, a significant degree of linearity still exists between the observed and predicted weaving speeds (significance > 0.05).

Based on the t-statistics and significance of 0.001 for the nonweaving speeds, the mean of the observed and predicted speeds are significantly different. Also, the range of the observed values is spread considerably compared to that of the predicted speeds. This observation agrees with the disparity in the standard deviations of the two speeds. Similar to that of the weaving speeds, there is a high degree of linearity (Correlation = 0.555) between observed nonweaving speeds and predicted.

Goodness-of-fit criteria indicate a moderate magnitude of fit for the weaving speed for the HCM model. A large magnitude of fit is shown for the nonweaving speed based on the R2 computed.

The parity plot in Figure 7 is a graph of the observed and the predicted values. The closer the plot of the point for observed and predicted speeds to the 45-degree line ($y = x$), the more accurate the predicted speed. The parity plot also gives a visual description of the relationship between the observed and predicted speeds. If points are located on the left side of the 45-degree line, predicted speeds are generally larger than observed speeds. While predicted speeds are lower if points are located to the right of the line. For weaving speeds, the points are equally distributed on either side of the 45-degree line. Thus, little conclusion can be derived with respect to the relationship between observed and predicted weaving speed from the HCM model. On the contrary, observed nonweaving speeds are higher than predicted nonweaving speeds because generally most of the points in the parity plot are on the right side of the line.

8. DISCUSSION

The result of the t-test for observed and predicted weaving speeds reveal that there is no sufficient statistical basis to conclude that the mean weaving speeds of the observed and predicted values are significantly different. Thus, it can be said that the average mean weaving speed is similar to that predicted by the HCM model. However, the coefficient of correlation showed little significant linearity between observed and predicted weaving speeds. In addition,

Movement		Mean	N	Std. Dev.	Std. Error Mean	Correlation	Sig.*
Weaving	Observed	6.7373	35	0.6272	0.1060	0.308	0.072
	Predicted	6.7965	35	0.2521	0.0426		
Nonweaving	Observed	6.8583	35	0.9137	0.1544	0.555	0.001
	Predicted	6.3693	35	0.1744	0.0295		
		Paired Differences					
		Mean	Std. Dev.		Std. Error Mean	T	Sig.**
Weaving	Obs - Pred	-0.0592	0.5997		0.1014	-0.584	0.563
Nonweaving	Obs - Pred	0.4890	0.8297		0.1402	3.487	0.001
	Observed		Residual			σ^2	R^2
	Std. Dev	Total σ^2	Std. Dev		Error σ^2	Explained	
Weaving	0.6272	0.3945	0.5996		0.3595	0.0351	0.0949
Nonweaving	0.9137	0.8361	0.8298		0.6886	0.1475	0.3078

Note: * For correlation analysis, when significance is less alpha (α), there a significant linear relationship.
** For paired samples t-test, when significance is greater than alpha (α), there is no statistical basis to conclude that the means are significantly different.

Table III. Comparison of Observed and Predicted, Weaving and Nonweaving Speeds

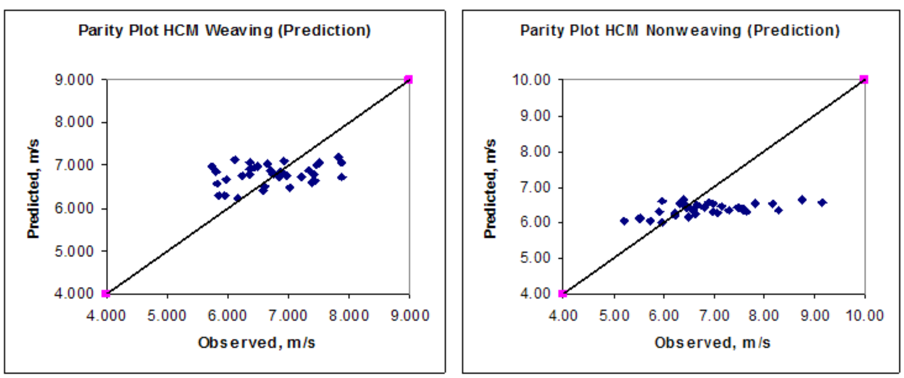

Figure 7. Comparison of Observed and Predicted Weaving and Nonweaving Speeds

the goodness-of-fit R2 indicates small magnitude of fit. As for nonweaving speeds, the means and standard deviations are also significantly different. As a result, the observed versus predicted nonweaving speeds fail the paired samples t-test for equality of means. The mean nonweaving speeds observed are considerably greater than the predicted values. Table IV summarizes the results of the comparison of observed and predicted values for the HCM model and were classified using criteria by Hopkins (2000).

Model	Maneuver Type	Comparison	Correlation	t-test	Goodness-of-fit
HCM Model	Weaving	Obs - Pred	NOT OK	OK	MODERATE
	Nonweaving	Obs - Pred	OK	NOT OK	LARGE

Table IV. Summary of the Test Results for the HCM Model

9. CONCLUSIONS AND RECOMMENDATIONS

Field data were collected from video surveys to test whether the HCM weaving model can accurately predict weaving and nonweaving speeds within an the urban arterial weaving section. A statistical analysis was conducted to test whether predicted speeds were acceptable. The HCM model predicted weaving and nonweaving speeds poorly based on the statistical analysis conducted. Even if the mean of the observed and predicted weaving speeds were very much similar, the goodness-of-fit statistics displayed a poor fit of the model. Thus, use of the HCM 2000 methodology for weaving sections in urban arterials is not recommended. An extensive data collection of arterial weaving sections is needed in order to recalibrate the HCM weaving models for use in arterial weaving sections. In addition, it is further recommended that the physical and operational characteristics of arterial weaving (Section 5) be considered in the development of models for urban arterial weaving sections.

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