
Review of evaluating existing capacity of weaving segments

Mohammad Shoraka¹, Othman Che Puan²

1- Ph.D Candidate, Department Civil Engineering Transportation,
University Technology Malaysia

2- Associate Professor, Department Civil Engineering Transportation,
University Technology Malaysia
shorakamoh@gmail.com

ABSTRACT

Numerous studies have been conducted on freeway weaving sections, and most of these have been efforts to improve procedures in the Highway Capacity Manual. Many of these have produced models for predicting vehicle travel speeds within weaving sections. This paper reviews the previous researches about estimation of the capacity freeway weaving segment. Previous researches on weaving areas have focused on many factors that impact the capacity of freeway weaving section, which were found to include the length of the weaving section, the weaving ratio, the percentage of heavy vehicles in traffic stream, driver characteristics, lane widths, lateral obstructions, speed limit differential between freeway and on-ramp and off-ramp, geometric configuration, number of lanes in weaving section and even percentage of contribution of the four traffic movements. The Highway Capacity Manual 2000 provides values for capacity on various weaving segments (Exhibit 24-8) based on sets of conditions (configuration, speed, length, volume ratio, and number of lanes). However, to find capacity for a given set of conditions, an iterative process should be carried out using a properly programmed spreadsheet. This paper presents comparison among these factors and selects the most effective factor that influences in weaving section and closed the reality. Finally the results of study are compared to Highway Capacity Manual 2000 and even it presents shortcoming and overestimate of HCM.

Keywords: Freeway weaving segment, capacity, on-ramp, off-ramp.

1. Introduction

Traffics are important in urban area. They are involving of three basic variables volume or flow rate, speed, and density can be used to describe traffic in urban area. In the 2000 Highway Capacity Manual, weaving is defined as the crossing of two or more traffic streams traveling in the same general direction along a significant length of highway without the aid of traffic control devices (with the exception of guide signs). Weaving sections are formed when a merge area is closely followed by a diverge area, or when a one-lane on-ramp is closed followed by a one-lane off-ramp and the two are joined by an auxiliary lane (Roger, 2004). Weaving areas have long been studied by many researchers, however, only a few studies have directly addressed the estimation of weaving capacity. The procedures of the HCM (HCM 1950 and HCM 1965) for weaving area analysis were developed from data collected by a variety of agencies to estimate speeds at weaving areas. In the 1985 edition of the HCM, improvements from the previous edition were in the estimation method for speeds of vehicles in the weaving areas and the classification of weaving area configurations. In the HCM 1997 edition, the methodology used to analyze the operational performance of weaving areas was still based on the research conducted during the 1970s and 1980s, the only change from the previous edition was that the speeds of weaving and non-weaving vehicles were

used to estimate density within the weaving area. The HCM 1997 still did not provide procedures for estimating the capacity of weaving segments. The HCM 2000 edit for the first time provides capacity estimates for weaving areas. Capacity estimates are based on the assumption that the boundary between congested and uncongested regimes of traffic flow is 27 pc/km/ln for freeway. There is no specific reason presented why these values are appropriate for capacity estimations. The HCM 2000 weaving methodology provides the classification type of weaving areas based on number of lane changing required by each weaving traffic stream as shown in table 1:

Table 1: Configuration Type Based on the HCM 2000

Number of Lane -changing Required by Movement Vw1	Number of Lane- changing Required by Movement Vw2		
	0	1	≥ 2
0	Type B	Type B	Type C
1	Type B	Type A	N/A
≥ 2	Type C	N/A	N/A

The result of this lane-changing activity is often significant turbulence within the weaving section itself. Thus, weaving areas often represent bottleneck locations. Also within weaving section, the maximum number of vehicles that can traverse them is highly dependent upon the contributions from the non-weaving and weaving traffic streams. Also capacity is maximum flow of vehicles that can logically be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway traffic and control conditions. Weaving sections form areas of concentrated turbulence on freeways. Even though there are no fixed interruptions that disrupt the traffic stream (e.g., traffic signals), due to the intense lane changing maneuvers happening in weaving sections, traffic in a weaving section is subject to turbulence in excess of that normally presents on basic freeway section.

The turbulence causes special operational problems, thus its impact must be considered in design. Although the existing state-of-the-art analysis and design of weaving sections provide some basic information regarding the relation between geometric features of weaving and some traffic characteristics, some basic questions about the mechanism of weaving are yet to be explored. For example, one might be interested in: the level of traffic at which weaving movement between lanes become hazardous, the effect of various lengths of weaving sections on traffic flow; or the impact of upstream condition on operational condition within weaving sections. Also today there are shortcoming in application of real analysis and evaluation of traffic problems. This problems address capacity in weaving section, high level of traffic turbulence in vicinity of ramps and in general reduction of weaving speed.

2. Factors Influencing Weaving Capacity

Capacity is typically expressed as the maximum rate of vehicles that can be reasonably expected to traverse a roadway facility. In this context, freeway weaving section capacity is a function of numerous factors. Included here are such factors as number of lanes in the

weaving section, length of weaving section, proportion of heavy vehicles in the traffic stream, driver characteristics, lane widths, length of deceleration and acceleration lane, speed differential between freeway and ramp traffic, lateral obstructions, geometric configuration of a weaving section describes alignment of the merge and diverge gores and even weaving ratio (Figure 1). More specifically, geometric configuration dictates lane-changing maneuvers that must be executed by weaving vehicles. It is generally assumed that a geometric configuration that promotes reduced lane-changing activity will provide more capacity than a configuration requiring a high rate of lane changing (Cassidy, 1990,1991-1993).

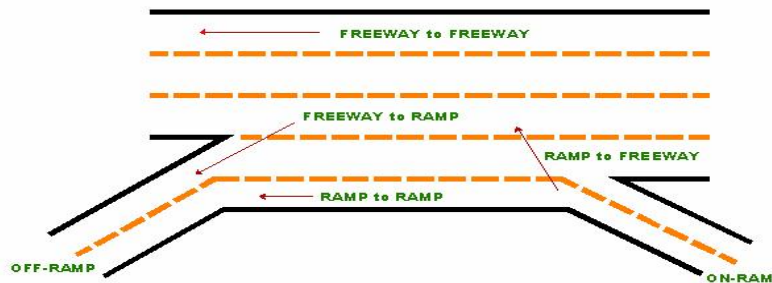


Figure 1: Weaving Area Traffic Movement (Cassidy, 1991,1993)

3. Previous Studies

Research on weaving sections is not new; in fact it began more than half a century ago. Specifically, the HCM procedures can be traced back to the 1940s with the development of the 1950 Highway Capacity Manual, which included one of the first methods for analysis and design of weaving sections. The typical procedures for analysis of weaving sections can be categorized into two groups. One group of procedures estimate the performance of a weaving section and the other group of procedures estimate the capacity of a weaving section. The performance may be measured in terms of the level of turbulence, traffic stream speed, traffic stream density, and/or level of service. Alternatively, the weaving section can be characterized in terms of its throughput capacity. Most of the state-of-practice procedures focus on evaluating a weaving section in terms of its performance. The 1950 Highway Capacity Manual presented one of the first methods for analyzing the operations and design of freeway weaving sections. It was based on the field data collected at six weaving sites in Washington D.C. and Arlington Virginia, area in 1947. This method predicted both capacity and operating speeds. In 1985 HCM, complete definitions and descriptions of type A, B, and C weaving configurations were presented in terms of the number of lane changes that has to be made for successful completion of each weaving maneuver. Weaving capacity was established as 1,800 pcph for type A configuration, and 3,000 pcph for types B and C. 1985 HCM also set the maximum length of weaving sections of 2,000 ft for Type A, and 2,500 ft for type B and C. It was suggested that beyond these lengths, operations should be considered as isolated merging and diverging actions rather than weaving. Cassidy and May (1991) and Wang et al. (1993) analyzed large amounts of empirical and simulation data collected from a number of sites throughout California and evaluated the capacity of freeway weaving sections. They found that the highest concentration of lane-changing activity occurred around the merge gore. The majority of lane changes occurred in the first 500 ft of the weaving area. The

weaving flow rate (the sum of the two weaving flows) was the most significant factor affecting this longitudinal distribution along the weaving area. The capacity of a weaving section in this research was defined as the maximum flow of vehicles that could travel at any point in a single lane. Vermijs (1998) developed a microscopic simulation approach for estimating weaving section capacities that evaluate capacity for several types A major weaves and ramp weaves. Three basic factors, which have impacts on weaving area, (1) weaving section length, (2) weaving flow, (3) the vehicle composition. The results showed that the capacity of the weaving section increased with the increasing of the length, up to a certain length. The length range from 400 to 1000 meters (1310 to 3280 feet) had no significant impact on weaving capacity. In addition, capacity decreases when the weaving flow increases. The HCM 2000 provides lookup tables (Exhibit 24-8) that provide estimates of weaving section capacities as a function of a number of variables, namely: the weaving section type (A,B and C), number of lanes, free-flow speed of freeway, length of weaving section, and volume ratio.

The data bases used to calibrate the weaving procedures in HCM 2000 are very limited in size and quite outdated. Subsequent research has shown that the procedures' ability to predict the operation of the facility is limited. Another disadvantage of the 2000 HCM procedures is that the application range is quite limited. For example, for type A weaving sections with three lanes in the weaving area, the maximum volume ratio (V_R) value that can be analyzed by this procedure is 0.45. But from simulation, operations with V_R values greater than 0.45 is quite possible. Other concerns about the HCM 2000 procedures include lack of consistency in application with other freeway methods, the difficulty of determining the service measure in the field, and the difficulty in comparing the analysis results with the results of simulation models. Kwon et al. (2000) developed an online procedure for estimating weaving section capacities. The study concluded that under free-flow conditions, the most significant factor affecting the speed of diverging vehicles is the geometric conditions of the exit ramp. Second, as the weaving volume increases, diverge vehicles tend to make lane changes earlier within the weaving section, while the ramp-to freeway vehicles tend to travel a short portion on the auxiliary lane before merging into the mainline. Third, vehicles tend to use a limited portion of the auxiliary lane and that the length of the auxiliary lane utilization increases with increased weaving flows.

Lertworawanich and Elefteriadou [2001,2003,2004,2007] proposed a methodology to estimate the capacities of Type B weaving areas based on gap acceptance and linear optimization. In order to use this methodology, firstly, traffic related parameters, traffic demand, and speeds of traffic on each lane should be collected. Secondly, maximum possible lane changes are calculated by using probability functions. Finally, the linear optimization problem is solved to get the capacity on the rightmost three lanes at the core weaving area. Also they provided a procedure to estimate the expected number of lane changes based on gap acceptance theory. The expected number of lane changes at a weaving area can be considered as the utilization of main traffic stream gaps by merging vehicles. It is a function of the length of the weaving area. Rakha and Zhang et al.(2005,2006) present a very simple analytical model for estimating the capacity of weaving sections. The model includes three independent input variables: the weaving section length, the weaving section volume ratio, and weaving ratio [$W_R = V_{FR} / (V_{FR} + V_{RF})$]. The procedures developed in this study define a number of critical issues. First, the capacity of a weaving section reverts to the bottleneck

capacity if the weaving volume ratio is set to zero irrespective of the length of the weaving section. Second, the weaving section capacity reverts to a merge section capacity when W_R is zero. Similarly, the weaving section capacity reverts to a diverge section capacity when W_R is 1.0. The paper demonstrates that the proposed model capacity estimates are consistent with field data. Furthermore, the study demonstrates that the HCM 2000 procedures tend to overestimate weaving section capacities significantly (errors in excess of 100% in some instances).

Roess and Ulerio (2000) wanted to remove the issue of configuration from the weaving analysis process. The new model was proposed in this paper, as a part of NCHRP Project 3-75, in order to calculate capacity of weaving area based on total lane-changing activities and speeds within the weaving section. It was modified from the equation used for estimating capacity of basic freeway segment by an additional factor, which reflects the impact of weaving vehicles. Chulsu (2009) developed analytical weaving models based on gap acceptance theory for the development of managed lanes weaving and access guidelines. In addition Awad (2003,2004) mentioned alternative and convenient procedure for estimating capacity on weaving segments. Two capacity prediction models are developed using linear regression (LR) and neural network (NNT).

4. Existing Models

Computer simulation is a very powerful tool for traffic operational analysis. However, there were only a few articles found which directly discussed the capacity of weaving areas using simulation. The findings from these are summarized below. VISSIM (2007) is a microscopic, stochastic, time-step simulation model developed to model operation of freeway weaving area. VISSIM is a traffic simulator. The traffic simulator is a microscopic traffic flow simulation model including car-following and the lane changing logics. VISSIM requires a lot of information to calibrate the model. Also it does not have a traditional node structure. The lack of nodes provides the user with the flexibility to control traffic operations (e.g., yield conditions) and vehicle paths within an intersection or interchange. VISSIM Inputs is including: Network Geometry Coding, Vehicle Types and Traffic Compositions, Vehicle Inputs and Routing, Lane Change Model, and Car-Following Model. Also outputs from VISSIM included in the calibration process are link evaluation and data collection because the results can be used for simulation calibration and a capacity estimation model for the weaving area.

INTEGRATION (Aerde,1995 & Rakha,2003) is a microscopic traffic simulation and assignment model that can represent traffic dynamics in an integrated freeway and traffic signal network. VanAerde, et al (1995) explained the weaving logic of the INTEGRATION simulation model and subsequently used the model to estimate capacity of weaving areas. The model performs simulations by tracking the movement of individual vehicles within a transportation network every deci-second. There are two different models used when modeling weaving area, 1) car-following model, and 2) Lane-changing model. The car-following logic involved the use of a microscopic speed selection rule to match speed-density relationship, which requires calibrations. INTRAS (Wicks ,1980 & Rakha,2009) is microscopic, stochastic and employs a time stepping procedure for moving discrete vehicle through the freeway. INTRAS has been developed for studying freeway incident detection and control strategies. In field, as total weaving flow rate increases, motorists traveling from

freeway to ramp tend to execute required lane changes over shorter traveled distances. INTRAS, however, was unable to replicate these subtle motorists' responses to varying flow conditions.

Table 2: some of the existing simulation models of weaving section

Model	Author	Type of Model	Description Implementation	Weaknesses
INTRAS	Wicks (1980)	Microscopic	freeway and surface street network model, freeway weaving analysis-grade-horizontal curve- include lane-changing & car-following -queue discharge algorithm	motorists traveling from freeway to off-ramp lane changes over shorter traveled dis.- length of section
FOSIM	Bullen (1982)	Microscopic	determine capacity of freeway weaving area and on-ramp- lane-changing & car-following	couldn't evaluate influence on-ramp on weaving capacity
KRONOS	Michalopoulos- Panos (1984)	Macroscopic	Simulation for freeway urban areas, with 20 on-ramps & 20 exit ramps in freeway	geometric e.g only one auxiliary lane
WEAVSIM	Zarean (1987)	Microscopic	modeling traffic flow through weaving section- effect of grade- lane-changing	Geometric-only 3 lanes for freeway, 3 vehicle type
RFLO	Ross- Paul (1988)	Macroscopic	simulate of weaving section in freeway	volume is not separated into weaving & non-weaving- desired speed & capacity are reduced against weaving
FRESIM	Halati-Henry (1991)	Microscopic	Simulation of complex freeway geometric-lane changing calculate by deceleration rate	requires a large number of calculations, calibration parameters are not easily obtained from field data
INTEGRATION	VanAerde (1995)	Mesoscopic, Microscopic	include car-following & lane-changing, model signals at the entry of on-ramp and at the terminus of off-ramps	does not have the interface to view & edit network data
VISSIM (4.3)	Wiedmeyer (2007)	Microscopic	Operational of freeway weaving area- analysis traffic-include lane-changing & car-following	requires a lot of information to calibration - don't consider grade
CARSIM (Ver 8)	Benekohal 1988-2009	Microscopic	stand-alone simulation of a car-following model, Active Traffic Management, 3D Road Enhancements, designing, testing, and evaluating active safety technologies	couldn't evaluate influence on-ramp on weaving capacity

The model was recently used to successfully generate design alternative for improving the operation of existing weaving sections. Also it is limited a range of weaving section length, number of auxiliary freeway lane and ramp links. Vermijs and Schuurman (1993) outlined the need for a simulation model to determine capacity of weaving areas and on-ramps. Since the HCM 1985 could not provide accurate capacity estimate of weaving areas and were not

comparable to those measured in the field. They used a simulation model called FOSIM to calculate capacities of weaving areas and on-ramp. Driving behaviors that affected capacity of weaving areas were categorized into two stages, 1) lane-changing maneuvers, and 2) car-following behaviors.

The WEAVSIM program (Zarean et al. 1987) is a microscopic freeway simulation program designed for the sole purpose of modeling traffic flow through weaving sections. The WEAVSIM model advances discrete vehicles through the simulated traffic network by processing their positions and speeds at each one second intervals. FRESIM is the microscopic for freeway traffic simulation. The geometry of the freeway more involve for urban streets since on-ramps, off-ramps and weaving segments are modeled as well. It is composed of two models namely; car-following model and lane-changing model. Since FRESIM models lane-changing behavior in detail. It requires a large number of calculations. Additionally, some of the calibration parameters are not easily obtained from the field data. The KRONOS model is macroscopic (i.e., it pertains to density, speed, and volume of traffic without dealing with individual vehicles). The program can simulate a freeway system ten miles long and six lanes wide. It has the capability to use 20 entrance ramps and 20 exit ramps with the option of an auxiliary lane between them. The shortcoming is limitation of the number of ramps and length of freeway. Table 2 mentioned some of the existing models for simulation of weaving section.

5. Conclusions

This paper presented a proposed approach for evaluating the capacity of freeway weaving section that the major findings of this research are as follows:

- The highest concentration of flow and the highest rate of lane changing in a weaving section occur near the merge gore; also weaving capacity was defined as a function of vehicle activity within the first 75 m of the weaving section in the two lanes adjacent to the merge gore (Cassidy,1993). Functional value of capacity has been identified as the sum of all vehicles occupying all or any portion of a lane segment within critical region. This functional value of weaving capacity was found to be 5,900 pcph.
- The 2000 HCM provides lookup tables (Exhibit 24-8) that provide estimates of weaving section capacities as a function of a number of variables, namely: the weaving section type (A,B and C),number of lanes, free-flow speed of freeway, length of weaving section, and volume ratio. The studies demonstrate that the HCM 2000 procedures tend to overestimate weaving section capacities significantly (even excess of 100% in some instances).
- In terms of practical design guidelines, the travel time reliability criterion on the freeway sections investigated here would require that the length of deceleration lanes should be longer than 200m, the length of acceleration lane should be longer than 250m and the weaving length should be longer than 750m (Huizhao, 2006).
- Studies from California (Thanh, 2007 & Ghasemi, 2008) showed that average speed appears to be rather insensitive to flow up to 1,600 passenger cars per hour per lane (pcphpl). They strongly suggested that average travel speed is not a good measure of effectiveness for freeway weaving area. Simulation is the key element and the VISSIM

model was calibrated using data collected in San Antonio to assure that the model behavior reflects observed traffic in the field. Calibration is important because no single simulation model is expected to have the ability to equally represent all possible traffic conditions.

- The investigations of the two weaving bottlenecks (Cassidy, 2009 & Skabardonis, 2010) revealed that the bottleneck activations were initiated by disruptive F-R lane changes. F-R lane changes became disruptive: i) When there were increased concentrations of F-R lane changes near the on-ramp merge triggered by reductions in on-ramp flows; or ii) When there were simply too many F-R lane changes, independent of the ramp flows. The investigations further revealed that changes in the spatial distributions of mandatory lane changes, especially for the F-R maneuvers, also led to variations in bottleneck discharge flows. When the F-R maneuvers were concentrated near the on-ramp, they became more disruptive and resulted in discharge flow reductions.

Also there are many factors Influencing Weaving Capacity therefore it needs to evaluating weaving section capacity by simulation model that it considers many aspects. Such results suggest the need for further exploration of capacity evaluation for weaving section of Malaysian roads and assess the applicability of the HCM method to predict capacity of Malaysian conditions.

5.1 Recommendation for Future Work

The main goal of this study is to review previous studies and existing models about weaving section. But, based on most of researcher's findings the existing tables - for analysis of capacity and level of service at weaving are provided by HCM (2000) are not accurate and are overestimated. Therefore, a simulation model is needed to improve this shortcoming. Outcome of this research will be a proposed software which is more reliable than the HCM 2000 manual and serves the duties like capacity analysis of on-ramp on weaving area, assessment of lane-changing and analysis of acceleration/ deceleration lane. The model should be capable of representing and investigating traffic operations at or near capacity and presenting the influence of length of weaving section and the characteristics of on/off ramp on weaving section capacity.

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Nomenclature

HCM Highway Capacity Manual

NCHRP National Cooperative Highway Research program

TRB Transportation Research Board

LR Linear Regression

NNT Neural Network

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