Systematic Analysis of Weaving Section Capacity

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ABSTRACT

The paper first validates the INTEGRATION model for estimating the capacity of weaving sections. Specifically, comparisons are made to field data and the Highway Capacity Manual (HCM) procedures. Subsequently, the paper presents a systematic analysis of the factors that potentially impact the capacity of freeway weaving sections, which include the length of the weaving section, the weaving ratio, the percentage of heavy vehicles, and the speed differential between freeway and ramp traffic. The study demonstrates some questionable capacity estimates by the CORSIM software and a gap acceptance procedure proposed in the literature. The study also demonstrates that the weaving ratio, which is the ratio of the lowest weaving volume to the total weaving volume, has a significant impact on the capacity of weaving sections. In addition, the study demonstrates that the length of weaving section has a larger impact on the capacity of weaving sections for short lengths and high traffic demands. Furthermore, the study demonstrates that there does not exist enough evidence to conclude that the speed differential between freeway and ramp traffic has a significant impact on weaving section capacities. Finally, the study demonstrates that the HCM procedures for accounting for heavy duty vehicle impacts on weaving section capacities appear to be reasonable.

Key words: Freeway weaving section, Capacity estimation, HCM 2000, and INTEGRATION.

1. INTRODUCTION

The freeway weaving analysis procedures in the 2000 Highway Capacity Manual (HCM) are based on research conducted in the early 1970s through the early 1980s (Roess and Ulerio, 2000). Subsequent researches have shown that the methods' ability to predict the operation of a weaving section is limited (Lertworawanich and Elefteriadou, 2002 and 2004), which is most probably due to the outdated database. As to capacity estimation of freeway weaving sections, some other methods such as the gap-acceptance based methods and simulation based methods have been used as alternatives (Stewart *et al*., 1996; Kwon *et al*., 2000; Lertworawanich and Elefteriadou, 2002 and 2004).

The research effort first validates the INTEGRATION software for estimating the capacity of freeway weaving sections using three sections that are available in the literature (Lertworawanich and Elefteriadou, 2004). Subsequently, the paper utilizes the INTEGRATION software to conduct a systematic analysis of critical variables that impact the capacity of weaving sections. The simulation results are compared to the HCM procedures in an attempt to validate and identify the limitations of the current HCM procedures.

The paper initially presents the state-of-the-art studies on the capacity of weaving sections. Subsequently, the field data that were utilized to validate the INTEGRATION capacity modeling

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procedures are described. Subsequently, the experimental design for the sensitivity analysis is described followed by the results of the sensitivity analysis. Finally the findings and conclusions of the study are presented.

2. STATE-OF-THE-ART WEAVING ANALYSIS PROCEDURES

A limited number of publications were found in the literature that were deemed related to this study. For example, Zarean and Nemeth (1988) utilized the WEAVSIM microscopic simulation model, to investigate the effect of the different arrival speeds on the operation of weaving sections. Subsequently, the researchers developed a regression model for the modeling of weaving sections based on the simulation results. The simulation results demonstrated that the speed differential between the mainline and on-ramp arrivals had a significant effect on the operation of weaving sections, which was not considered in the 1985 HCM procedures (Highway Capacity Manual, 1985) and is not considered in the current HCM procedures (HCM 2000 procedures).

Skabardonis *et al*. (1989) applied the INTRAS microscopic simulation model to evaluate the operation of a few major freeway weaving sections. INTRAS was modified to predict the speeds of weaving and non-weaving vehicles and was applied to eight major freeway weaving sections. Vehicle speeds within the weaving sections were compared to a few analytical procedures that included the 1985 HCM procedure, Leisch's procedure, JHK's procedure, Fazio's Procedure, and the Polytechnic Institute of New York (PINY) procedure. The researchers concluded that the INTRAS speed predictions were closer to the field measurements than the analytical procedure speed predictions. The researchers concluded that simulation tools could be utilized with field data to enhance existing state-of-the-art analytical procedures for the modeling of weaving section operations.

Stewart *et al*. (1996) evaluated the capability of INTEGRATION version 1.50 for the modeling of weaving sections. The study showed that both the 1985 HCM procedure and INTEGRATION offered identical conclusions for a given sample problem. However, the study demonstrated differences between the two approaches on critical design parameters of weaving sections. Specifically INTEGRATION identified the number of lanes in the core area as a critical factor in affecting a weaving capacity, which was not captured in the HCM procedures. Alternatively, while the HCM procedures demonstrated that the length of the core area was critical in the design of weaving sections, the INTEGRATION results demonstrated that this factor was critical for short lengths but was less critical as the weaving section length increased.

Vermijs (1998) reported on the efforts in developing the Dutch capacity standards for freeway weaving sections using FOSIM (Freeway Operations SIMulation), a microscopic simulation software developed in the Netherlands. Specifically, a total of 315 Type A weaving sections with different configurations and traffic factors were simulated. All simulation runs were repeated 100 times using different random seeds. The 100 simulation results for capacity appeared to be normally distributed with standard deviation in the range of 200 ~ 400 veh/h/lane.

Finally, Lertworawanich and Elefteriadou (2002 and 2003) proposed a capacity estimation method for weaving sections based on gap acceptance and linear optimization techniques, which is totally analytical. Readers interested in the specific details of the procedure are encouraged to review the literature. The authors of this research effort believe that the gap acceptance method is too theoretical and makes a number of simplifying assumptions that limit the applicability of the procedures. For example, the procedures do not capture the effect of the weaving section length on the capacity of weaving sections.

3. TEST SITES AND FIELD DATA DESCRIPTION

This section briefly describes the test sites and field data that were utilized for the validation effort. These test sites are described in further detail in the literature (Lertworawanich and Elefteriadou, 2004). The test sites include three weaving sections along the Queen Elizabeth Expressway (QEW) in Toronto, Canada. These three weaving sections include a type B and two type C weaving sections, denoted B1, C1, and C2, respectively. The posted speed limit on the QEW was 100 km/h with a 10 percent heavy vehicle population. The three selected sites operated under congested conditions because of the intense lane changing behavior within the weaving sections.

The section capacities and total traffic demand classified by on-ramp, off-ramp, upstream mainline, and downstream mainline flows were recorded in the data set. The weaving section capacity was computed as the maximum observed pre-breakdown 15-minute flow rate. The data set included 10 days of data for site B1, 10 days for site C1, and 16 days for site C2. Since the Origin-Destination (O-D) demand varied from one day to another, the capacity of each site also varied accordingly.

Due to a lack of type A weaving sections within the original data set, another site, named site A1 was added to the data. Though no field data were available for this site, it was thought helpful to include a type A site for all the sensitivity analyses. The geometric layout and details of these four sites are shown in Figure 1.

4. EXPERIMENTAL DESIGN

As was mentioned earlier, the study utilizes the INTEGRATION software to conduct the analysis. The INTEGRATION software is a microscopic traffic simulation and assignment model that represents traffic dynamics in an integrated freeway and traffic signal network. The model has been successfully applied since the early 1990's in North America and Europe (Bacon, 1994, Gardes, 1993, Hellinga and Van Aerde, 1994, Rakha *et al*., 1998, Rakha *et al*., 2000, Dion *et al*., In press, and Rakha and Ahn, 2004). Earlier versions of the model (version 1.50) were tested and validated against weaving section field data, however, it was deemed essential to validate the 2.30 version of the model since significant changes have been made to the car-following and lane-changing logic. It should be noted that the INTEGRATION 2.30 lane-changing logic was described and validated in an earlier paper (Rakha and Zhang, 2004). This paper extends the previous research efforts by validating the estimates of roadway capacity that are derived from the INTEGRATION software as a result of lane-changing behavior within weaving sections. It should be noted that the user inputs an ideal roadway capacity, however the internal friction within the traffic stream that results from lane-changing behavior, produces reductions in the roadway capacity that varies dynamically as the O-D demand varies.

The first step in this study was to calibrate the model to the three test sites B1, C1, and C2. The calibration of the INTEGRATION software involves the calibration of the traffic demand (O-D tables) and the calibration of the steady-state car-following behavior by estimating four parameters, namely the free-speed, the speed-at-capacity, the ideal capacity, and the jam density. Subsequently, the impact of the random seed on the capacity of weaving sections was investigated because Vermijs (1998) demonstrated that the random seed resulted in significant differences in weaving section capacities in the range of 200 to 400 veh/h/lane.

The analysis considers a number of factors that are hypothesized to significantly impact the capacity and operations of freeway weaving sections. The considered geometric and traffic characteristic parameters that are considered in this study are summarized in Table 1. The HCM 2000 defines the weaving ratio as the ratio of the smaller of the weaving volumes to the total weaving volume. The weaving volume may be viewed as a measure of the distribution of the weaving volume between the mainline and on-ramp flows. However, the HCM 2000 procedures ignore the effect of the weaving ratio on the weaving section capacity. Consequently, the study evaluates the impact of the weaving ratio on the weaving section capacity by maintaining a constant volume ratio (weaving volume/total volume) while varying the weaving ratio, as demonstrated in Table 1.

Another factor that is hypothesized to impact the capacity of weaving sections is the length of the weaving section and has produced differing results across various studies. The HCM 2000 considers the maximum length of a weaving section to be 750 meters for all configuration types and beyond these lengths, the HCM recommends the modeling of merge and diverge sections separately. In this study the impact of weaving length on weaving section capacity for different volume ratios is studied. The study considers weaving section lengths that range from 150 to 750 meters, as summarized in Table 1.The considered volume ratios included the full range that is presented in the HCM 2000 capacity tables, which differ according to the type of weaving sections. For example, for Type A weaving sections, the volume ratio ranges from 0.10 to 0.35, while for Type B weaving sections, the volume ratio ranges from 0.10 to 0.80.

Because of the lower geometric design standards for on- and off-ramps, vehicle speeds on these facilities are typically lower than their speeds on freeways. A number of studies have indicated that the lower speeds of vehicles on on- and off-ramps affect the operation of weaving sections significantly. Consequently, as part of this study the impact of the speed differential between freeway and ramp traffic on the capacity of weaving sections is analyzed in a systematic fashion. Specifically, the speed differential between freeway and on-ramp and the speed differential between freeway and off-ramp traffic are considered separately.

While the percentage trucks within a traffic stream is generally considered an important capacity-impacting element because trucks occupy more space than passenger cars and do not share the same acceleration and deceleration capabilities as other vehicles. The HCM procedures attempt to capture the effect of trucks through the consideration of a heavy truck adjustment factor, as is currently done in many procedures within the HCM. Consequently, the study investigates the impact of different percentages of heavy vehicles on the capacity of weaving sections, as demonstrated in Table 1.

Finally, Lertworawanich and Elefteriadou (2004) suggested that the two configurations of Figure 2 should be modeled differently because they involved different lane-changing behavior although they are both categorized as Type B weaving sections. Specifically, the second confirguration does not require any lane-changing for the weaving vehicles. Unfortunately, the authors did not present any justification for their proposal. Consequently, the study investigates differences in the capacities of both configurations to warrant differentiating both configurations.

5. SIMULATION RESULTS

This section presents the results of a sensitivity analysis that was conducted as part of this study. Initially, the weaving section capacity estimates derived from the INTEGRATION software are validated against field data capacity measurements. Subsequently, the results of the various hypotheses tests are presented.

Based on the conclusions of the sensitivity analysis, all results are averaged over 30 random repetitions. The use of 30 repetitions ensures that the sample standard error is less than 10 veh/h/lane (55/sqrt(30)) given that the standard deviation of data is 55 veh/h/lane (165 divided by 3 standard deviations).

5.1 Model Validation

In order to validate the appropriateness of the INTEGRATION software as a simulation tool for this study, a validation exercise was conducted. The geometric configurations for sites B1, C1 and C2 were input into the INTEGRATION software. In addition, O-D tables were constructed from the observed volume counts on the mainline downstream and upstream the weaving section, the on-ramp, and off-ramp. The simulation runs were executed by increasing the traffic volumes from 70 to 130 percent the field observed capacities. Detectors were located within the simulation model as was observed in the field. The maximum 15-min traffic flow rates were then utilized as an estimate of the weaving section capacity. The validation results for sites B1, C1, and C2 are presented in Figure 3.

The results clearly demonstrate a close match between the simulation and field capacity estimates both in magnitude and temporal variation over the 10, 10, and 16 analysis days, respectively. Two error measures can be used to estimate the mean magnitude of simulation errors. They are called mean relative error (MeRE) and maximum relative error (MaRE) here, which are defined below. Table 3 shows that MeRE for all three sites is below 5% and MaRE for all the sites is below 10%, which is thought to be reasonably good by the researchers.

$$MeRE = \sum_{i=1}^{n} \left(\left| y_i - \hat{y}_i \right| / y_i \right) \Big/ n$$

$$MaRE = \max\left(\left| y_i - \hat{y}_i \right| / y_i \right)$$

Where

$\hat{y}_i$: Simulated capacity

y_i : Field observed capacity

n : Number of observation days for each site

5.2 Sensitivity to Random Seed

Microscopic simulation software model the behavior of individual vehicles in both space and time. Within the INTEGRATION software, the temporal generation of vehicles may be deterministic, fully stochastic (negative exponential inter-vehicle temporal headways), or partially stochastic (shifted negative exponential inter-vehicle temporal headways). In addition, the level of driver aggressiveness may be varied through a random process. Temporal inter-vehicle headways are generated using a sequence of random numbers. The sequence of random numbers may be varied by altering the random number seed.

The results indicate that the maximum variation in weaving section capacity estimates range in the order of 11 percent with a maximum difference of 660 veh/h, which is equivalent to a difference of 165 veh/h/lane. The results that are presented in this study demonstrate a lower level of variability in the weaving section capacity which is less than what was observed in an earlier study (Vermijs, 1998). Specifically, the Vermijs study, which was based on 100 random simulations, concluded that the standard deviation of the weaving section capacity had a standard deviation of 200 to 400 veh/h/lane.

5.3 Model Comparison

Further validation of the model was conducted by performing a sensitivity analysis on sites B1, C1, and C2 using a number of software and analytical formulations. The freeway and on-ramp volume ratios were systematically varied for each of the sites in an attempt to compare the models for a wide range of traffic characteristics. Specifically, the capacity estimates derived by the

INTEGRATION and CORSIM softwares, the HCM 2000 procedures, and a gap acceptance procedure developed by Lertworawanich and Elefteriadou (2004) were compared. The results of the four methods for site B1 are summarized in Table 2 and illustrated in Figure 4. Due to space limitations, the results for sites C1 and C2 are only illustrated graphically in Figure 5 and Figure 6, respectively.

In the case of the B1 site the results of Table 2 and Figure 4 demonstrate that the capacity of a weaving section tends towards the base lane capacity of 2300 veh/h/lane as the weaving volume tends to zero (freeway and on-ramp volume ratio of zero). The results of the HCM procedures and the INTEGRATION simulation results demonstrate that the weaving section capacity decreases consistently as the mainline volume ratio increases. Alternatively, the CORSIM and gap acceptance results demonstrate a slight increase in the weaving section capacity as the mainline volume ratio increases from 0 to 20 percent. These counter intuitive results raise significant concerns about the adequacy of the CORSIM and gap acceptance procedures for the estimation of weaving section capacity because they indicate that the roadway capacity increases with an increase in the mainline weaving volume. As would be expected, the results of the INTEGRATION, HCM, and gap acceptance procedures demonstrate a decrease in the weaving section capacity as the on-ramp volume ratio increases (percentage of on-ramp weaving vehicles increases). Alternatively, the CORSIM results exhibit counter intuitive behavior with an increase in the weaving section capacity as the percentage of on-ramp weaving vehicles increases.

Figure 5 and Figure 6 clearly demonstrate that for each of the three sites, the results from the HCM 2000 procedures exhibit a different behavior in comparison to the other three methods. In general, the behavior exhibited by the INTEGRATION and CORSIM software appear to be consistent for sites C1 and C2. It is interesting to note that the INTEGRATION and CORSIM models demonstrate an increase in the weaving section capacity with an increase in the mainline volume ratio (i.e. by introducing more FR vehicles in addition to the FF vehicles). The reason for this increase in the weaving capacity by introducing the FR O-D demand is caused by the fact that the introduction of the FR demand introduces an additional lane to the freeway vehicles given that the shoulder lane only provides access to the off-ramp. Consequently, the observed increase in weaving section capacity is expected. Unfortunately, the HCM procedures do not capture these intricate effects. It should be noted that Lertworawanich and Elelifftheriadou used paired-*t* tests to compare the shapes of the CORSIM, HCM, and gap acceptance procedures, and concluded that HCM 2000 procedures yields quite different results from the other two methods. Here the different behavior of the HCM weaving procedures and simulation methods are verified once again.

5.4 Impact of Weaving Ratio

As was mentioned earlier, the weaving ratio is defined as the ratio of the smaller of the weaving volumes to the total weaving volume. In this study, the weaving volume on the on-ramp was kept smaller than the weaving volume on the mainline while maintaining a constant total weaving volume. Consequently, the weaving section capacity estimated by the HCM 2000 procedures remained constant given that the weaving volume was held constant throughout the various scenarios, as illustrated in Figure 7.

The simulation results clearly demonstrate that the weaving ratio does have an impact on the capacity of weaving sections even if the total weaving volume remains constant. For example, Site A1 demonstrates an increase in the weaving section capacity as the weaving ratio increases. In the case of Site A1 an increase in the weaving ratio results in a more balanced distribution of the weaving volume between the mainline and on-ramp demands. Since, in the case of Site A1, weaving vehicles are required to make a single lane change to reach their destination, a balanced weaving volume distribution results in a more efficient utilization of the gaps. Alternatively, in the case of Sites B1, C1, and C2, as the on-ramp weaving volume increases, the capacity at the core area decreases. This can be explained by the fact that for a constant weaving volume, more on-ramp weaving vehicles requires more lane change maneuvers within the weaving section and thus increases the turbulence within the weaving section.

5.5 Impact of Weaving Section Length

The effect of weaving section length on weaving section capacity is a controversial issue that has resulted in significant debate over the past years. The study investigates the impact of weaving section length on the capacity of weaving sections using the INTEGRATION software and the HCM procedures, as demonstrated in Figure 8. The results of the two approaches for the four sites demonstrate significantly differing trends. Specifically, the simulation results, unlike the HCM procedures, demonstrate that the impact of the weaving section length on the capacity of a weaving section increases as the traffic demand increases. Clearly, the simulation results appear to be more intuitive.

It is worthy to note that in Figure 8, the simulation results demonstrate that as the weaving volume increases, the weaving section capacity increases initially and then decreases. After a close look at the geometric layout of Sites C1 and C2 in Figure 1 the simulation results appear to be very reasonable. For example, at Site C1, a freeway volume ratio of zero requires that the freeway-to-freeway (FF) vehicles initially travel through a 3-lane segment followed by a 2-lane segment within the weaving section. Alternatively, the ramp-to-ramp (RR) vehicles initially travel on a single lane followed by a 3-lane segment within the weaving section. Consequently, the FF vehicles, unlike the RR vehicles, encounter a bottleneck within the weaving section. Alternatively, if the FF vehicles switch to FR vehicles, the FR are then able utilize a number of the off-ramp lanes and thus travel along a wider roadway segment. Noteworthy is the fact that the HCM 2000 procedures indicate that the weaving section capacity decreases as the volume ratio increases, which does not appear to be reasonable.

Based on the converging lines of Figure 8 we can conclude that, in general, as the weaving section length increases, its impact on the weaving section capacity decreases. For example, the decrease in the weaving section capacity resulting from an increase of 150m for a 150m weaving section is significantly different than its impact on a 600m weaving section.

5.6 Impact of Speed Differential between Mainline and Ramp Vehicles

A number of studies have indicated that the lower speeds of vehicles on on- and off-ramps affect the operation of weaving sections significantly. Consequently, as part of this study the impact of the speed differential between freeway and ramp traffic on the capacity of weaving sections is analyzed in a systematic fashion. Specifically, Sites B1, C1, and C2 are analyzed for three weaving intensities are considered, namely low, medium, and high. In the case of Site B1 the three volume ratios that are considered are 10, 40, and 80 percent while in the case of Sites C1 and C2 volume ratios of 5, 25, and 50 percent are considered. These values were selected based on the maximum recommended values for Type B and C weaving sections for the HCM 2000 procedures.

Statistical analysis of the results (average of 30 simulation runs) using the Kruskal-Wallis test for *K* independent samples revealed that, at a level of significance of 5 percent ($\alpha = 0.05$), there does not exist enough evidence to conclude that the speed differential between the freeway mainline and the on- and off-ramps affects the capacity of freeway weaving sections.

5.7 Impact of Heavy Vehicles

In this section the impact of heavy vehicles on the capacity of weaving sections is analyzed using the INTEGRATION software and the HCM procedures, as illustrated in Figure 9. Figure 9 demonstrates a high degree of consistency between the simulation and HCM results for all four sites, although the simulation results tended to be less than the HCM results. Consequently, the results of this sensitivity analysis demonstrate that the adequacy of the HCM procedures in capturing the impacts of heavy vehicles on the capacity of weaving sections.

5.8 Differentiation between Type B Configurations

According to the HCM 2000 procedures, the two configurations of Figure 2 are categorized as type B weaving sections, and thus would have identical capacities. However, Lertworawanich and Elefteriadou (2004) suggested that these two configurations should be modeled differently because they involve different lane-changing behavior. Consequently, this study investigates whether differences in the capacities of both configurations warrant considering different configuration types.

The two configurations are considered for a weaving length of 600m using an identical O-D demand, with a weaving ratio of 30 percent and an on-ramp volume of 30 percent the total in-coming total demand. The simulation results that are illustrated in Figure 10 demonstrate that the capacity of configuration 1 is typically less than that of configuration 2, especially for high volume ratios. The lower capacity of configuration 1 can be attributed to the fact that freeway-to-ramp (FR) vehicles do not require to execute any lane changes for the second configuration, which is not the case for the first configuration. Consequently, the simulation results verify Lertworawanich and Elefteriadou's suggestion of separating the two configurations into two different weaving section types.

6. FINDINGS AND CONCLUSIONS

The research presented in this paper examined one of the most important aspects of analysis of freeway weaving sections, namely the capacity analysis. The findings and conclusions of the study can be summarized as follows:

a. The study demonstrated the validity of the INTEGRATION software for the analysis of weaving section capacities.

b. The study demonstrated some questionable capacity estimates by the CORSIM software and a gap acceptance procedure proposed in the literature. Specifically, the results demonstrated an unrealistic increase in roadway capacity with an increase in the mainline weaving volume for a Type A weaving section.

c. The study demonstrated that the random number seed resulted in a weaving section capacity standard deviation of 65 veh/h/lane.

d. The weaving ratio, which the ratio of the lowest weaving volume to the total weaving volume, has a significant impact on the capacity of weaving sections. Unfortunately, the weaving ratio is not considered in the HCM 2000 procedures.

e. The length of weaving section has a larger impact on the capacity of weaving sections for short lengths and high traffic demands.

f. There does not exist enough evidence to conclude that the speed differential between freeway and ramp traffic has a significant impact on weaving section capacities.

g. The HCM procedures for accounting for heavy duty vehicle impacts on weaving section capacities appear to be reasonable.

h. The separation of weaving sections requiring no lane changing by weaving flows should be separated from other Type B weaving sections.

i. Simulation is a very useful tool for the capacity analysis of freeway weaving sections.

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Table 1: Geometrical and Traffic Factors

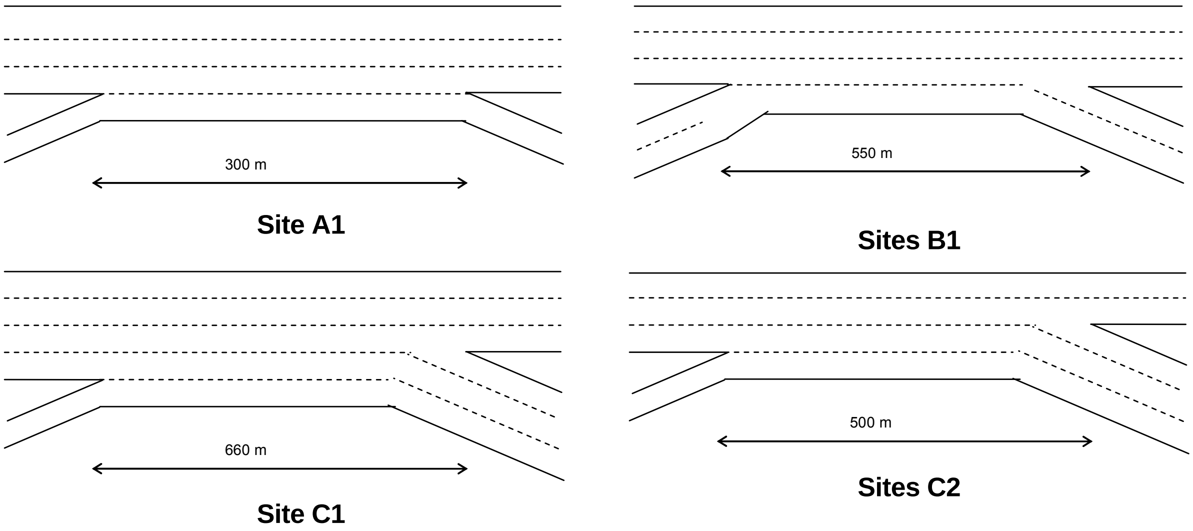
Parameter	Values considered
Weaving section type	Type A, Type B and Type C
Weaving ratio	0.0, 0.1, 0.2, 0.3, 0.4, 0.5
Weaving section length	150, 300, 450, 600, and 750 m
Speed differential between freeway and on-ramp traffic	0, 5, 10, 15, 20, 25, and 30 km/h
Speed differential between freeway and off-ramp traffic	0, 5, 10, 15, 20, 25, and 30 km/h
Percentage heavy duty vehicles	0, 5, 10, 15, 20, and 25%

Table 2: Sensitivity Analysis of Site B1

Methods	Ramp VR	Freeway VR					
		0.0	0.2	0.4	0.6	0.8	1.0
INTEGRATION	0.0	2339	1915	1693	1447	1143	866
	0.2	2125	1884	1642	1396	1103	843
	0.4	1939	1780	1572	1300	1083	803
	0.6	1800	1691	1493	1223	1053	766
	0.8	1674	1611	1464	1229	1050	713
	1.0	1595	1559	1374	1165	952	705
CORSIM	0.0	2213	1957	1703	1371	1125	988
	0.2	1971	1931	1732	1424	1142	984
	0.4	1800	1883	1718	1436	1184	1029
	0.6	1655	1790	1653	1409	1229	1043
	0.8	1560	1692	1602	1422	1206	1038
	1.0	1471	1635	1527	1341	1204	1031
HCM 2000	0.0	2190	2182	2011	1798	1588	1281
	0.2	2190	2175	1936	1734	1479	1190
	0.4	2190	2093	1861	1661	1371	1190
	0.6	2182	2011	1798	1588	1281	1190
	0.8	2175	1936	1734	1479	1190	1190
	1.0	2093	1861	1661	1371	1190	1190
Gap Acceptance Method	0.0	2190	2190	1945	1561	1365	1242
	0.2	1743	1759	1645	1397	1272	1195
	0.4	1688	1712	1602	1318	1165	1071
	0.6	1664	1692	1581	1275	1118	1016
	0.8	1651	1681	1569	1255	1094	983
	1.0	1642	1674	1564	1248	1079	963

Table 3: Validation Statistics of Sites B1, C1, and C2

Site Number	B1	C1	C2
MaRE	8.00%	3.51%	9.42%
MeRE	4.98%	1.61%	3.75%



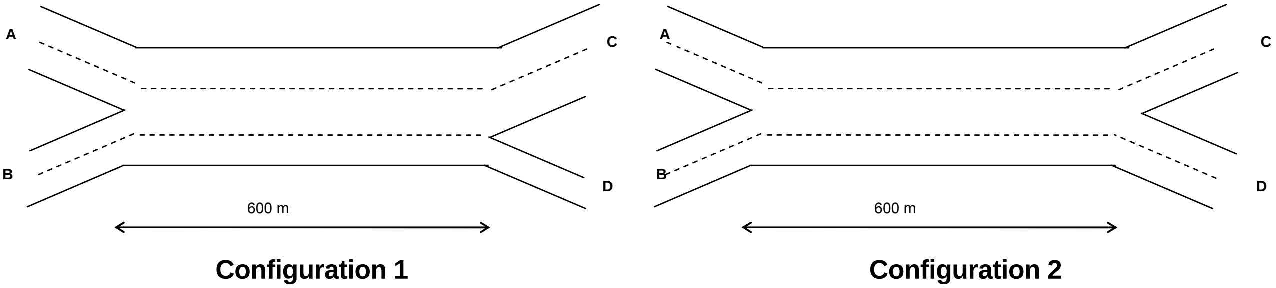
Site A1

Sites B1

Site C1

Sites C2

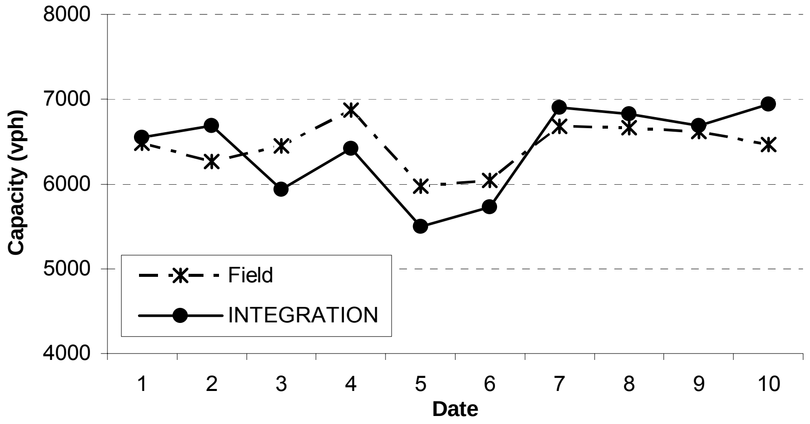
Figure 1: Configurations of Test Weaving Sections



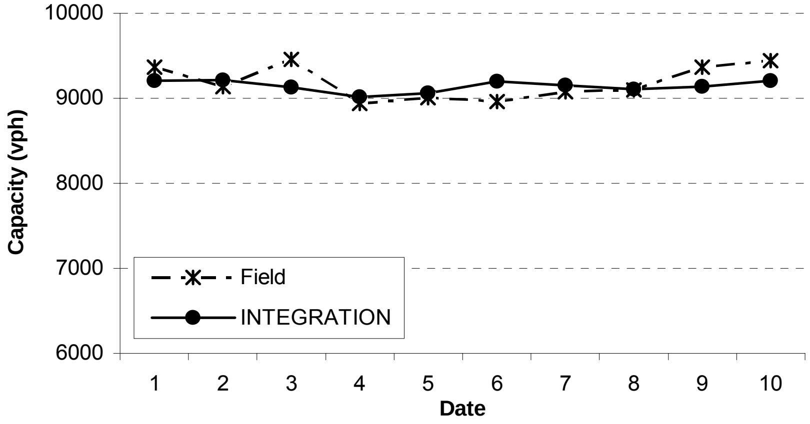
Configuration 1

Configuration 2

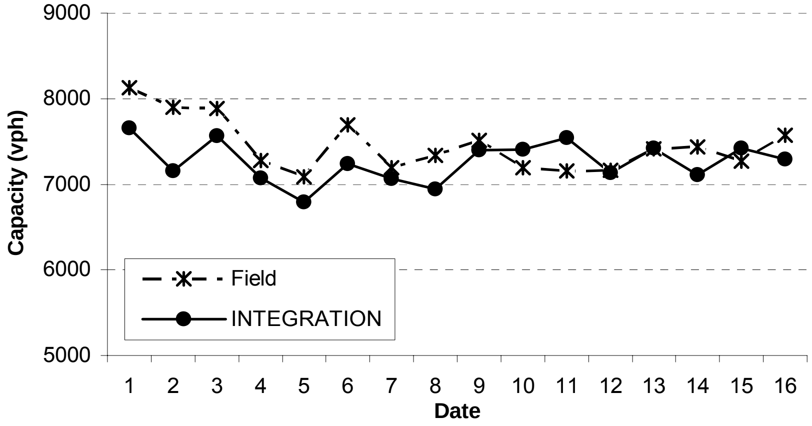
Figure 2: Configurations of Alternative Type B Weaving Sections



Calibration of Site B1

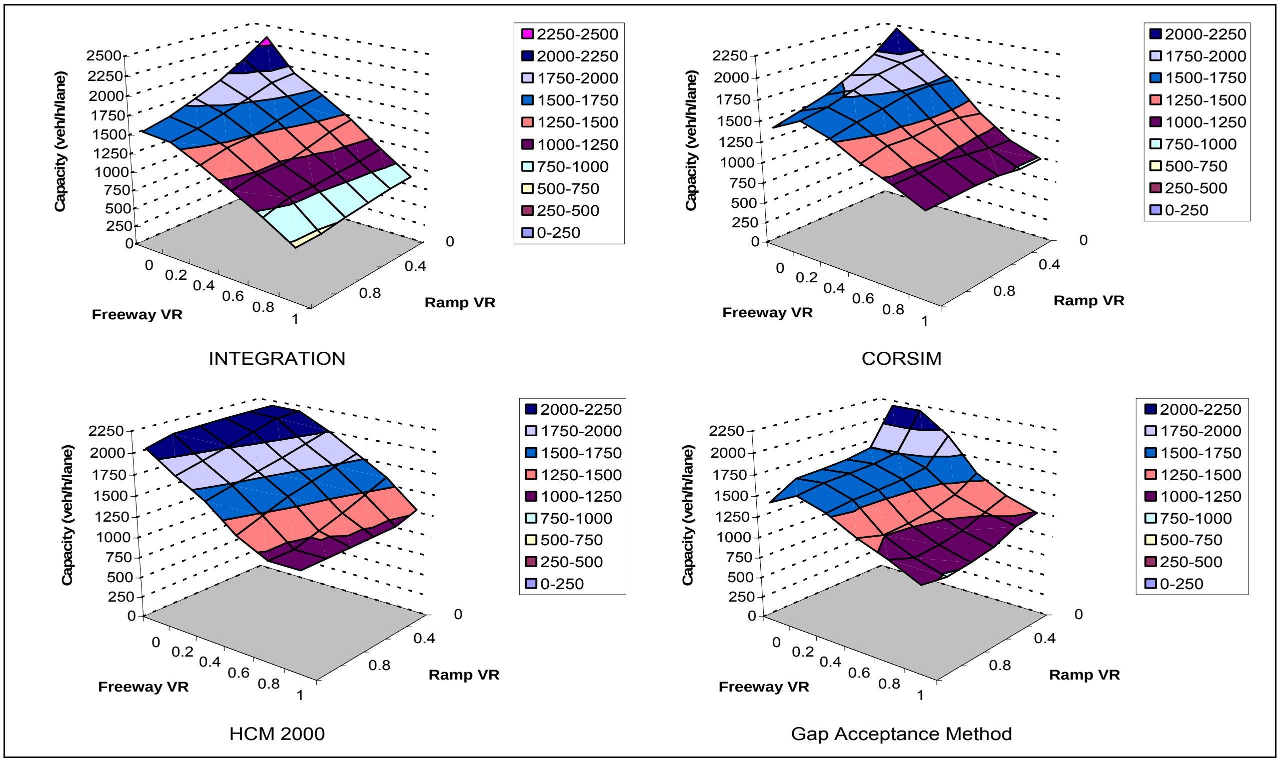


Calibration of Site C1



Calibration of Site C2

Figure 3: Validation Results for Sites B1, C1, and C2



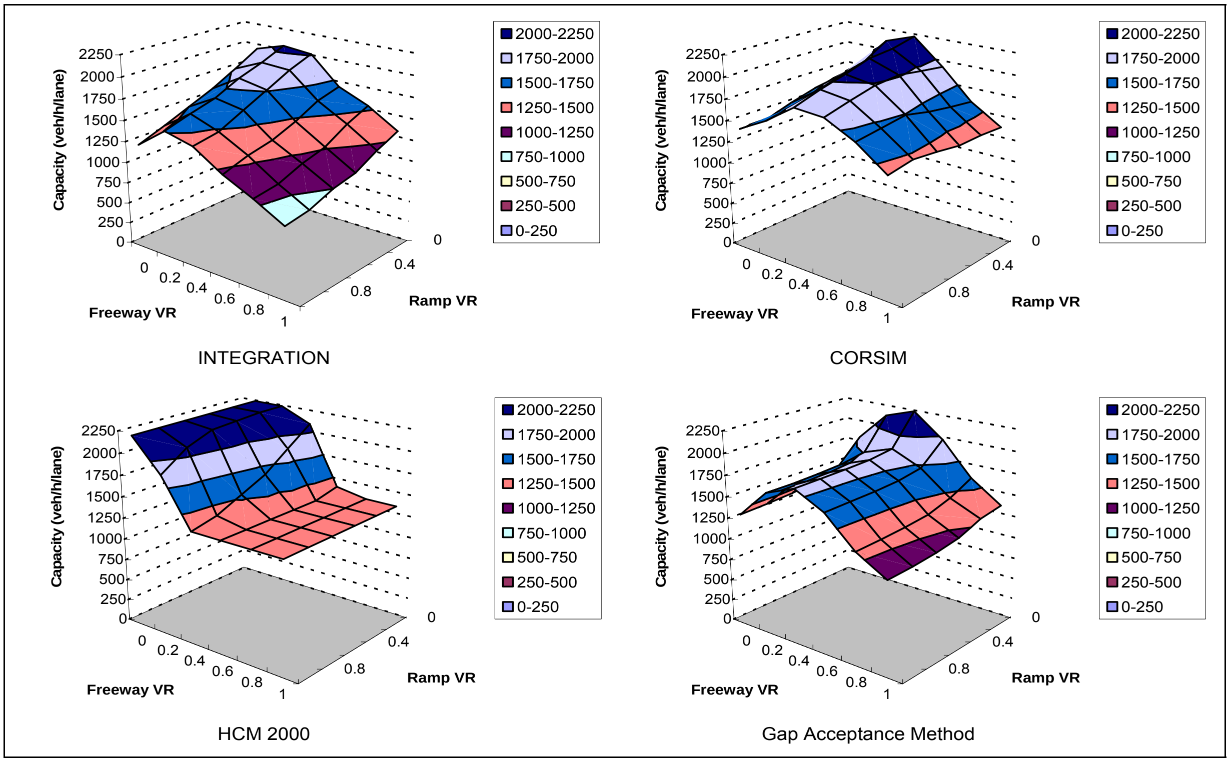
INTEGRATION

CORSIM

HCM 2000

Gap Acceptance Method

Figure 4: Capacity Surfaces for Site B1



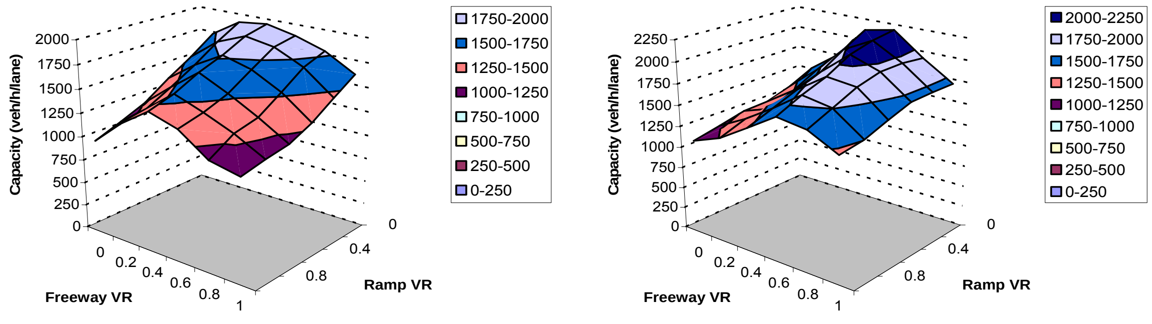
INTEGRATION

CORSIM

HCM 2000

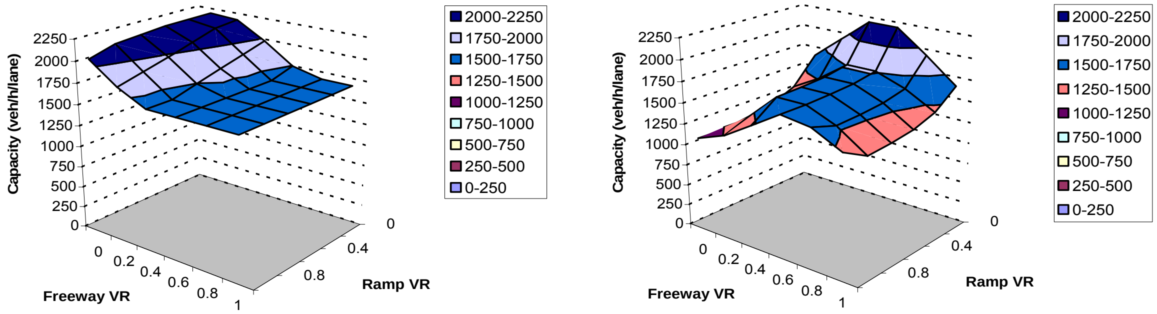
Gap Acceptance Method

Figure 5: Capacity Surfaces for Site C1



INTEGRATION

CORSIM



HCM 2000

Gap Acceptance Method

Figure 6: Capacity Surfaces for Site C2

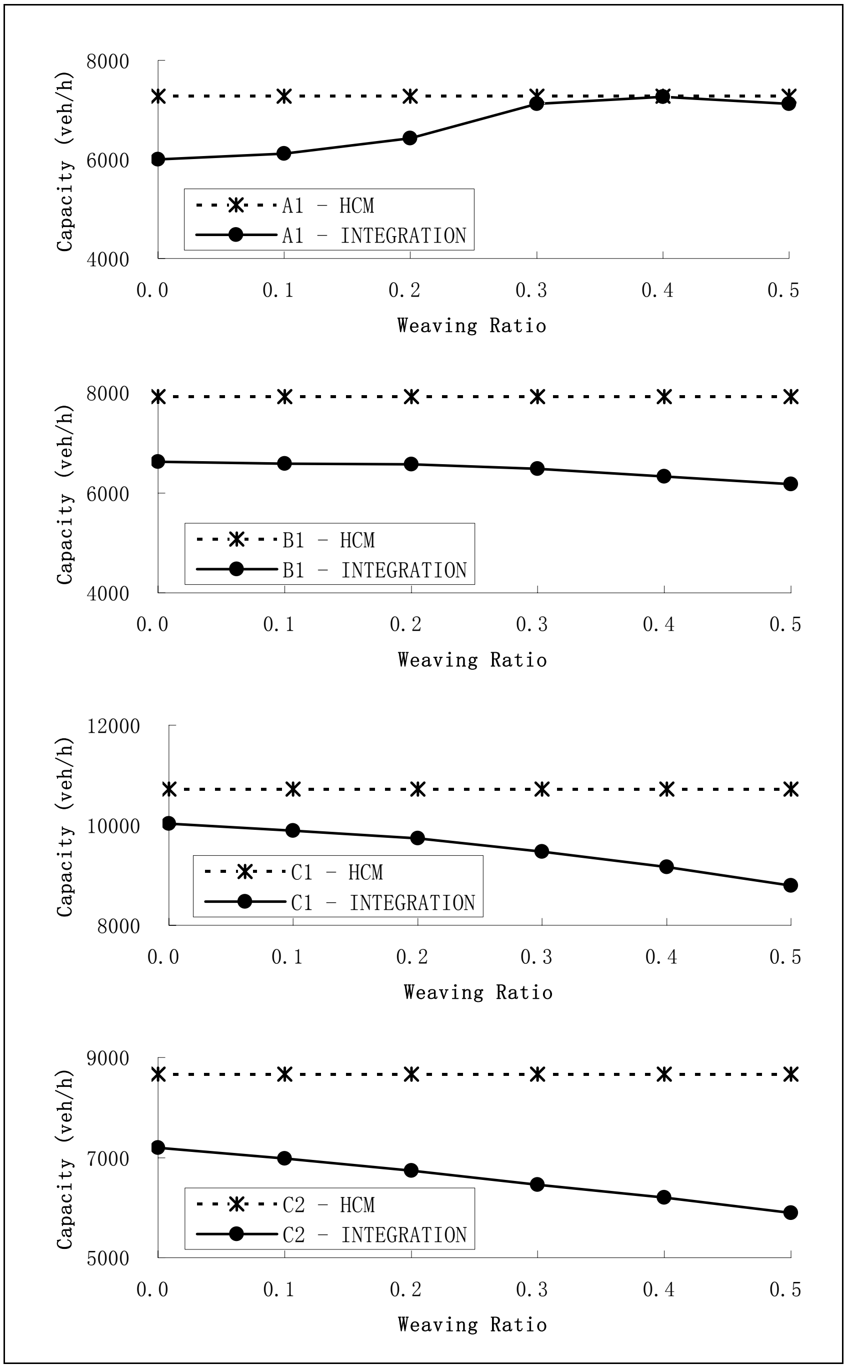
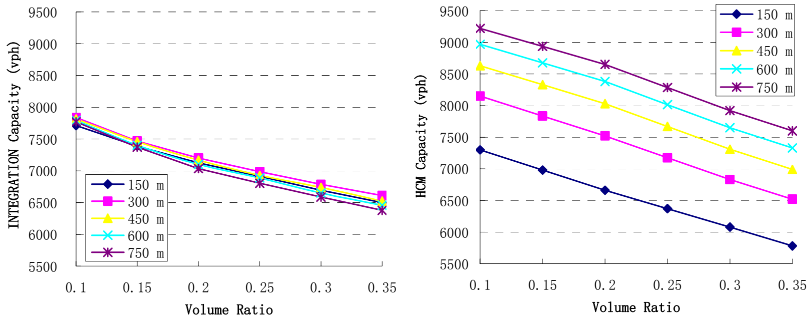
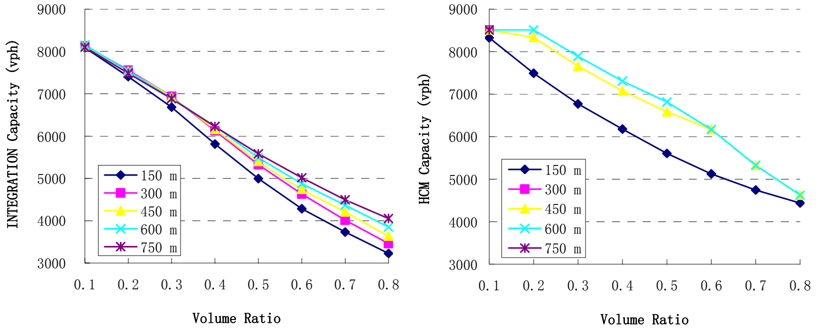


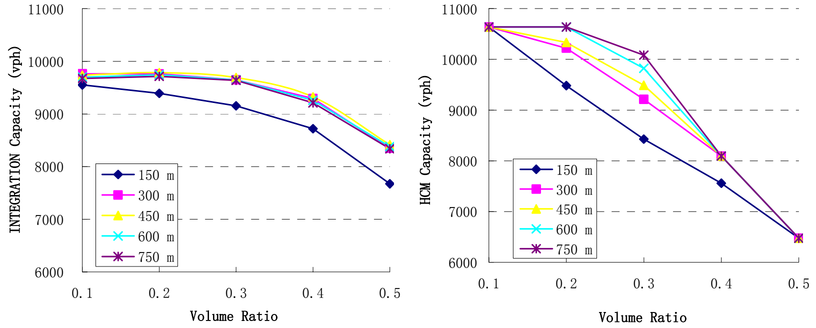
Figure 7: Impact of Weaving Ratio on Capacity



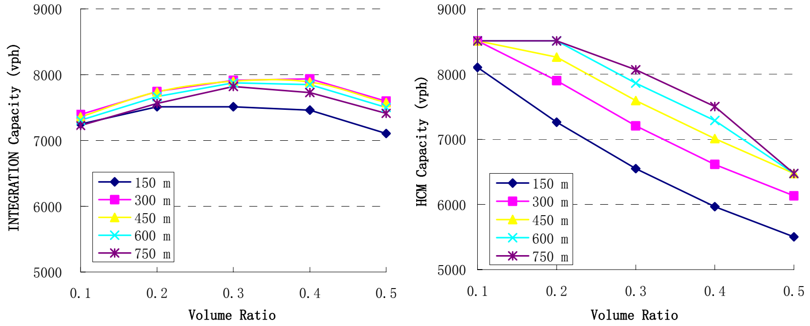
Site A1



Site B1



Site C1



Site C2

Figure 8: Impact of Weaving Section Length on Capacity

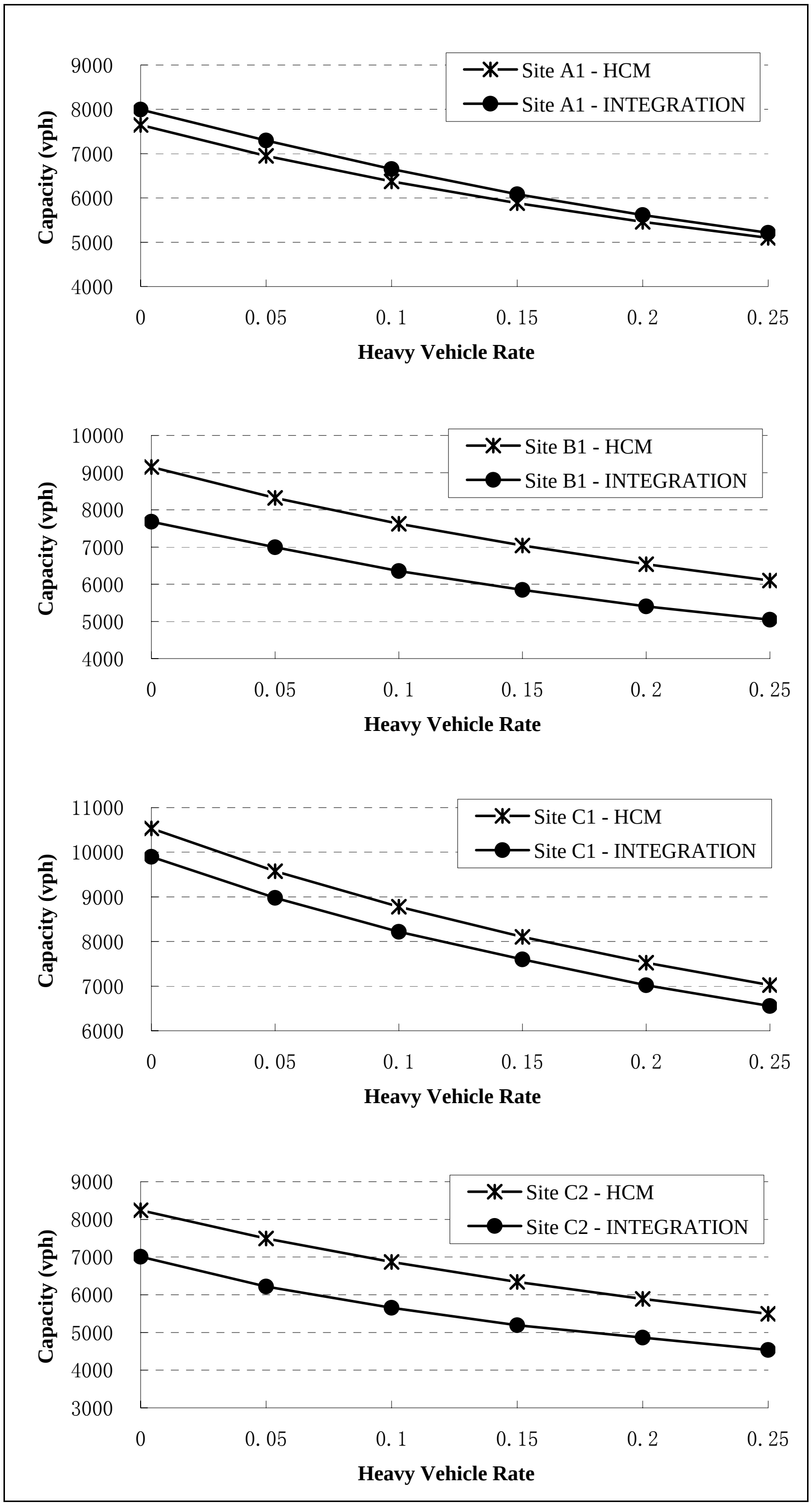


Figure 9: Impact of Heavy Duty Vehicles on Capacity

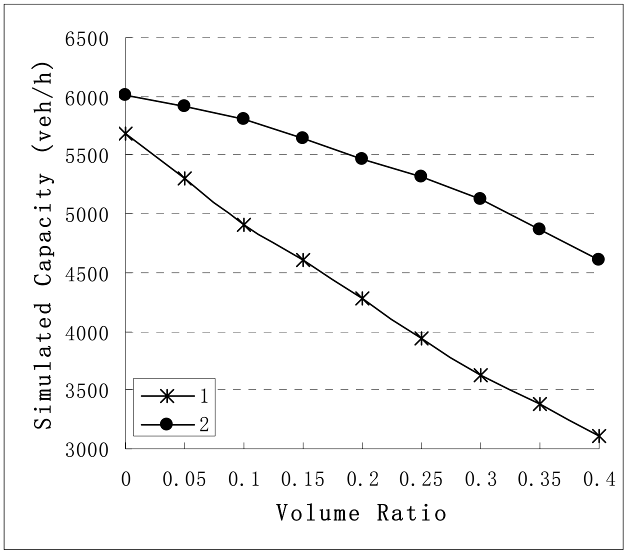


Figure 10: Capacity of Both Type B Configurations