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Analysis of Effects of Heavy Vehicles on Urban Freeway Capacity: Highway Capacity Manual Estimations vs. Observations in Seoul, Korea

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ABSTRACT

Highway Capacity Manuals (HCMs) typically estimate the highway capacity by considering various factors including the heavy vehicle (HV) ratio. HVs are generally believed to impact the highway performances negatively and HCMs reflect such impacts by using the daily average HV ratio for deterministically estimating the highway capacities. However, the breakdown flow rate that triggers the congestion does not always occur with the same demand levels and the deterministic approach needs to be carefully examined. Image detectors that are installed throughout the urban freeways in Seoul, Korea by the Seoul Civil Highway Management Center are used for collecting traffic data including volume, speed, occupancy, and vehicle type. Three study sections of urban freeways that are often prone to the bottleneck phenomena are chosen for the data collection. The data collected in September 2009 on typical weekdays that are free from unusual weather or accidents are used to test the appropriateness of using Korea Highway Capacity Manual (KHCM) on urban freeways in Seoul. Based on the statistical analysis on Maximum Pre-breakdown Flow Rate, Break Flow Rate, and Queue Discharge Flow Rate with varying HV ratios, it is found that KHCM's deterministic estimates on the highway capacity are often significantly different from the observations and this calls for the need of majorly improving the KHCM

Key Words: Heavy vehicles, Highway capacity manual, Passenger car equivalents

INTRODUCTION

The performance of urban freeways is majorly evaluated based on their capacities above which congestions start to occur. In order to efficiently manage the operation of the freeways, it is essential to understand the relationship between the capacity and other factors including speed limit, road width, and ratio of heavy vehicles (HVs). Highway Capacity Manual (HCM) typically uses such factors as inputs for predicting highway capacities. Korea Highway Capacity Manual (KHCM) is a modified version of HCM which is customized for Korean highways that captures locally unique features for better capacity predictions. KHCM categorizes level of service (LOS) where the LOS of E refers to the maximum traffic flow while the next LOS of F starts to experience the breakdown or congestions. The boundary of LOS of E and F can roughly be considered as the highway's capacity. The main concern of using the deterministic approach of HCM or KHCM is that even when all the factors remain intact, the highway capacity is a random variable in real-life. In addition, urban freeways are different from typical highways because they are subjected to different operating environments and there is an academic research gap which is to validate the usage of HCMs for urban freeways.

Seoul Civil Highway Management Center has installed image detectors throughout the urban freeways in Seoul, Korea. This paper uses the data from the detectors for analyzing the actual traffic capacities against the estimated capacities from the KHCM. The objective of this paper is statistically testing the feasibility of using HCM-based capacity predictions on urban freeways in Seoul, discussing the causes of the differences between the observations and estimations, and suggesting how the HCM can be improved.

LITERATURE REVIEW

There are different measures of highway capacity as defined by Elefteriadou (2003) that are Maximum Pre-breakdown Flow Rate (MPBFR), Breakdown Flow Rate (BFR), and Queue Discharge Flow Rate (QDFR), and. As a traffic flow builds up, before any signs of congestions start to occur, MPBFR is a maximum traffic flow observed which occurs within the LOS category of E according to the HCM. As more vehicles are introduced to the highway, the traffic flow "breaks down" experiencing the lower flow rate of BFR while the LOS worsens from E to F. The traffic flow when the traffic flow "recovers" while the LOS switches from F to E, is known as QDFR. KHCM does not provide capacity estimation methods that are specific to urban freeways. Unlike typical highways, urban freeways often contain sections that restrict access to HVs and the HV ratios are significantly lower than the highways. In addition, speed limit, average trip distance, and ramp metering strategies are also different on urban freeways. It is an academic question of determining the appropriateness of applying HCM based current methods for urban freeways.

By analyzing the data collected from Queen Elizabeth Way located in Mississauga, Ontario, Canada, Hall and Agyemang-Duah (1991) find that the maximum traffic flow rate decreases once a queue forms. They conclude that the capacity can only be measured at a bottleneck with a queue. Lorenz and Elefteriadou (2000) confirm that the breakdown occurs not only at the maximum traffic flow condition but also even when the traffic flow is lower suggesting that the breakdown is a probabilistic event. Therefore, they recommend that the static and deterministic approach of HCMs for estimating the capacity needs to be replaced with a random model that involves probabilities of the breakdown. Elefteriadou (2003) categorizes the traffic flow into

MPBFR, BFR and QDFR as mentioned earlier. He defines the breakdown as a condition when average traffic speed is below 90 km/h for longer than certain duration of time. (5 min or 15 min depending on the analysis time periods) Yeon et al. (2009) analyze traffic capacities based on the detector data collected at different sections on the southern stretch of US-202 near Philadelphia, USA, that convey different physical characteristics. Figure 1 shows different traffic flow related measures they focus on. They find that physical characteristics of the sites significantly affect the traffic flows. They also find that there are significant differences between the morning peak and after noon peak capacities while the day of week, does not play a significant role. However, other factors such as weather and HV ratios are not considered in their work.

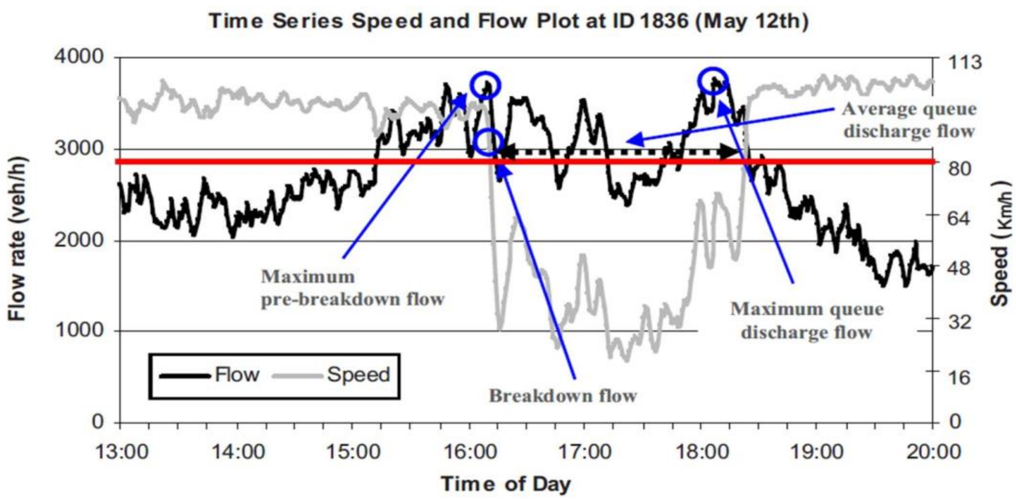

Figure 1 Traffic flow rate and speed graphs [*]

STUDY OBJECTIVE

This paper tests the appropriateness of using HCM based deterministic approach for estimating the capacity on urban freeways by statistically comparing the estimations with observations from the image detectors installed on the freeways in Seoul, Korea. In addition, this paper further utilizes the detectors for determining the HV ratios in order to analyze the influence of HVs on the urban freeway capacities.

DATA COLLECTION

As Hall and Agyemang-Duah (1991) suggests, urban freeway sections whose upstream demands are higher than the downstream capacities, and prone to forming queues and bottlenecks, are carefully chosen, in order to measure the freeway capacities properly. By analyzing the road network cell map maintained by the City of Seoul shown in Figure 2, four sections are chosen for the study. The road sections are well known bottlenecks in Seoul due to various reasons including, merging of roads, road blockage, and reduction in number of lanes.

Section 1: Gangbyun Bukro Banpo Dongjak Ilsan Bangmyun (Merging of roads)

Section 2: Gangbyun Bukro Hangang Dongjak Goori Bangmyun (Blockage of roads)

Section 3: Dongbu Wolgae Nokchun (Reduction of number of lanes from 3 to 2)

Section 4: Olympic Daero Hannam Banpo Ilsan Bangmyun (Reduction of number of lanes from 5 to 4)

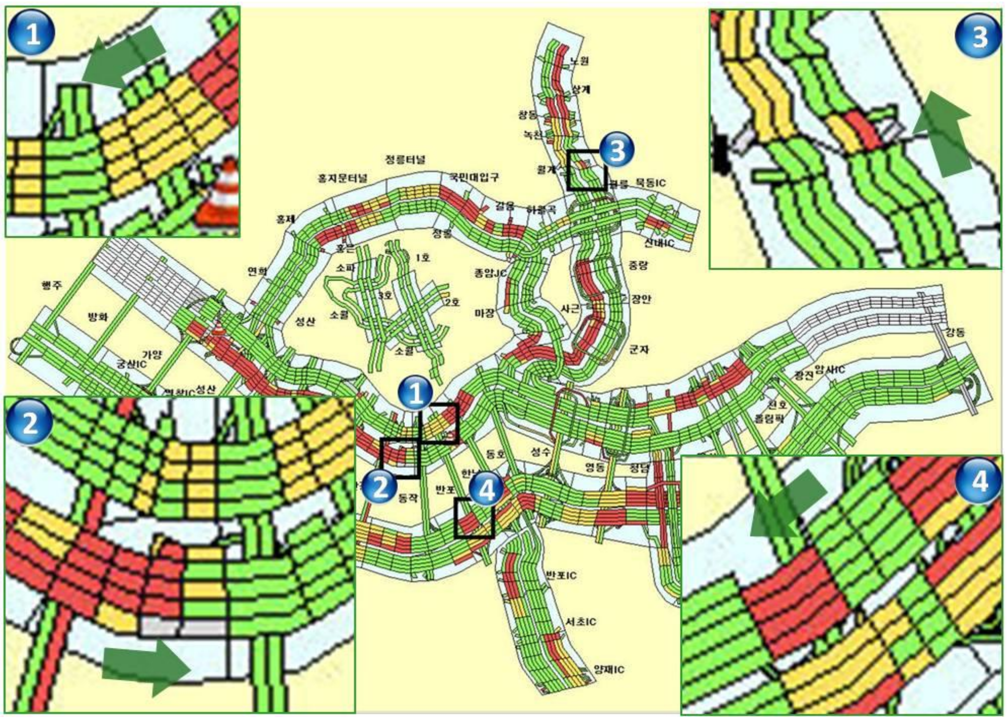

Figure 2 A road network cell map and four chosen urban freeway sections in Seoul, Korea

In order to observe the typical days' data, the data from typical days are collected whose attributes are as in the following.

- Non-cloudy/foggy day
- Non-rainy day
- Weekday
- Days with no major accidents

The data are collected on 7 weekdays in September, 2009 that meets the criteria.

The raw data is collected from an image detector that are installed throughout the urban freeways in Seoul every 30 seconds. The raw data consists of traffic volume, occupancy, density, speed, and vehicle type. The detectors are capable of identifying HVs by detecting the vehicles with the length over 9 meters. Table 1 shows an example of raw data that identifies, small, medium and HVs. The 30 seconds interval-based values are scaled to 15 minute intervals in accordance with KHCM as the peak hour factor (PHF) is usually based on 15 minute interval.

Table 1. Raw detector data Example

DETECT_ID	TTIME	VOLUME	OCCUPANCY	DENSITY	SPEED	SMALL_CAR	MIDDLE_CAR	LARGE_CAR
DD5000381	60000	4	5	0	48	3	1	0
	60030	3	3	0	47	3	0	0
	60100	6	10	0	46	5	0	1
	60130	5	7	0	48	4	0	1
	60200	6	7	0	43	5	1	0
	60230	5	9	0	47	4	0	1
	60300	2	7	0	51	0	0	2
	60330	3	5	0	45	2	0	1
	60400	3	3	0	49	3	0	0
	60430	6	9	0	53	5	0	1

DESIGN OF ANALYSIS

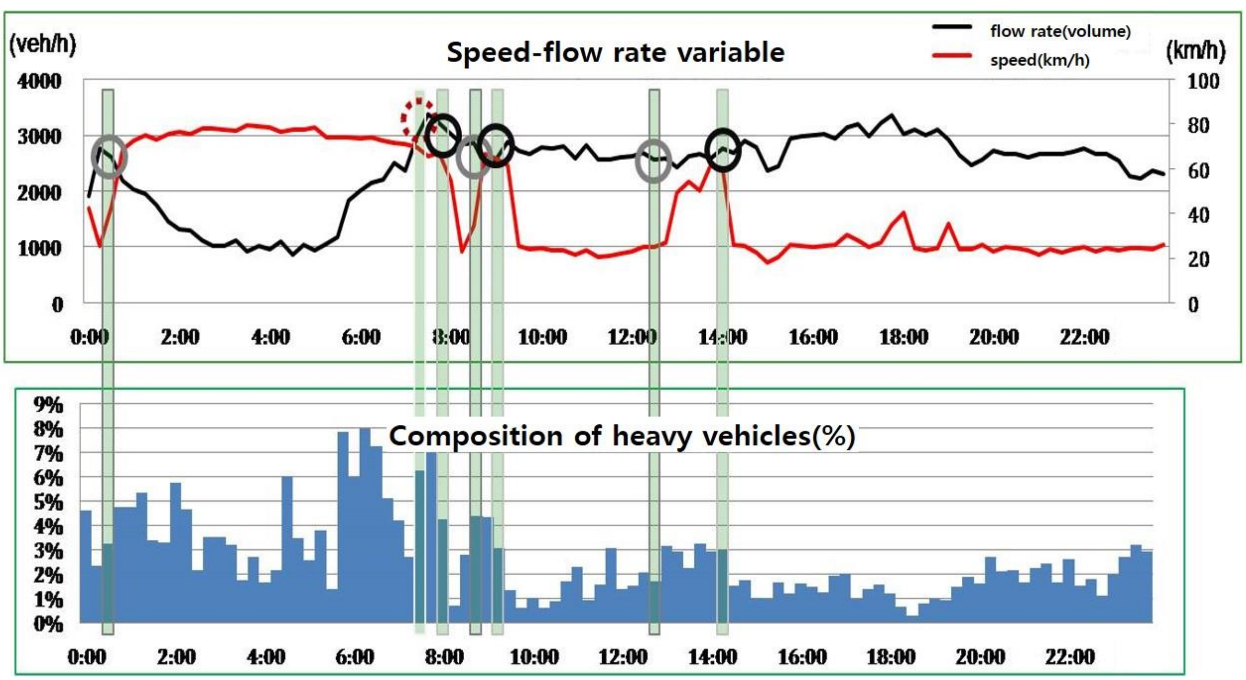

Figure 3. Relationship among flow rate (veh/h), speed (kh/h), and HV ratios

Figure 3 shows an example relationship among flow rate (veh/h), speed (kh/h), and HV ratios. At 7:45 AM, MPBFR occurs as indicated by the dotted circle. Then, at 7:50 AM, as indicated by solid bold circle, the MPFR when the speed drops below 50 km/h. At around 8:30 AM, the speed recovers above 50 km/h and the corresponding grey circle indicates the QDFR. This paper conducts t-test of observed capacities against HCM based predictions and checks if they are significantly different from each other. Then, an ANOVA test is conducted among the 4 sections of the study area that shares the identical physical conditions such as road width, edge (side of the road) width, and designed speed limit, for testing if MPBFR, BFR, and QDFR are significantly different from each other. Finally, an ANOVA test is conducted among the 4 sections of the study area to check if HV ratios significantly affect MPBFR, BFR, and QDFR.

RESULTS

HCM-based Predicted Capacities vs. Observed Capacities

HCM-based predictions are compared with the observed capacities using t-test and the p-values. It is found that HCM-based predicted capacities are significantly larger than observed MPBFR, BFR and QDFR. If the HCM-based predictions are appropriate for current road conditions, the observed values should be similar. However, when the confidence level of 99% is used, except the MPBFR, the HCM-based predictions are significantly larger. This shows that the HCM-based methods needs to be updated in order to reflect the reality.

Observed Capacity Differences among 4 Sections of the Study Area

An ANOVA test is conducted among the 4 different sections of the study area that share similar physical conditions such as road width, edge width, and speed limit. HCM-based predictions would not capture the differences since the 4 sections share the same physical condition related factors. However, the ANOVA test finds that MPBFR, BFR and QDFR are significantly different among the 4 sections of the road even though they share the same physical conditions. The results indicate the HCM-based predictions can not capture the differences among the road sections under identical physical conditions and suggest that the HCM-based methods need to be updated.

Observed Capacity vs. HV Ratios

An ANOVA test was conducted to test if varying HV ratios affect the observed capacities. It is found that MPBFR is not significantly influenced by the HV ratios while BFR and QDFR are significantly influence by the HV ratios.

CONCLUSION

Based on image detector-based observations, this paper statistically tests if HCM based deterministic approach of estimating freeway capacity is appropriate for urban freeways in Seoul, Korea. Different definitions of capacities are analyzed in this paper, That are Maximum Pre-breakdown Flow Rate (MPBFR), Breakdown Flow Rate (BFR), and Queue Discharge Flow Rate (QDFR). In addition, the influence of varying HV ratios on freeway capacities are analyzed. Finally, statistical tests are carried out in order to find out whether different locations with different physical environments play a role in influencing freeway capacities. It is found that current HCM based deterministic capacity estimations are significantly different from observations. It is also found that different road sections, even though they share identical physical conditions according to the HCM's limited categorizations, subjected to additional different physical environments, significantly affect freeway capacities. Finally, except the case of MPBFR, HV ratios are found to be significantly affecting the capacities in urban freeways. It seems that recent performance improvements of modern HVs help the capacities remain intact. In conclusion, for urban freeways in Seoul, the current HCM based approach needs to be improved by considering different definitions of freeway capacities and recent improvements of HVs. Also, specifications of physical characteristics of roads can be inputs to the improved future HCMs that will further improve the accuracies of its estimations.

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