The Analysis of Traffic Flow Characterizes for Heavy Highway on Rainy Days

Yingying Tang
School of Highway, School of Science, Chang'an University, Xi'an, China
Email: tangyy@chd.edu.cn

Yong'e Wang, Yanwei Niu, Hong Chen, and Pingming Huang
School of Highway, Chang'an University, Xi'an, China
Email: wangyonge94@126.com.org, niuyanwei@chd.edu.cn

***Abstract*—With the development of economy, highways play an important role in transportation system, especially for heavy highways. In order to learn traffic flow characterizes of heavy highway on rainy days, this study focuses on a heavy highway, Xuanda Highway, in Hebei Province. The research selects traffic data of seven days, collected by weigh-in-motion (WIM) system at Haierwa Bridge, to analyse the effect of rain on traffic flow characterizes, including volumes and speed. Specific issues evaluated that the traffic volumes were not sensitive to little rain, while speed of each time period has different degree of reduction during rainy days. The research further indicates people's willingness to travel. In addition, the study quantifies the speed characteristics for each class, and the relationship between speed and heavy vehicle ratio on rainy days.**

***Index Terms*—traffic flow, heavy load highway, weight-in-motion, rainy, total weight**

I. Introduction

As known, speed, flow and density are three most important characteristics of traffic. Especially, speed is significant affects traffic safety and quality of service. Numerous studies have investigated the relationship between speed and accident [1]. Some of researchers believe in that variance of speed results in accidents, not high speed [2]. Besides, Jian Li *et al.* [3] further modelled the effects of rainfall intensity on the heteroscedastic traffic speed dispersion. Many studies have analysed various factors affecting traffic speed and its coefficient of variation, such as heavy vehicle ratio, rainfall, slope, flow, and so on.

Sungjoon Hong and Taksshi Oguchi [4] investigated the effects of rainfall and heavy vehicles on speed-flow relationship for multilane expressways, finding that the change of rainfall from 0~1mm results the greatest speed deduction, and heavy-vehicle ratio also have influence on it. Babak Mirbaha *et al.* [5] established a prediction of average speed for a two-lane highway, based on its analysis of vehicle speed with different weather condition and traffic characteristics, which can be useful in traffic management plan. As for highway service under rainy days, Nordiana Mashros and Johnnie Ben-Edigbe [6] addressed that light and moderate rainfall resulted in slight qualitative service reduction, while heavy rainfall led to significant reduction in all cases.

Except rainfall, heavy vehicles have a significant impact on highway traffic flows [4]. Typically, the majority of vehicles in traffic flow can be divided passenger cars and others, such as trucks, motorcycle, Jeep, various big vehicles for entertainment and so on. Among them, trucks, large buses and recreational vehicles belong to heavy vehicles, which are large in dimension and have different traffic performance from passenger cars. Therefore, heavy vehicles have a great influence on traffic stream, although they account for small proportion of vehicle traffic. [7] Historically, Karen K. Dixon *et al.* [8] have found that the presence of heavy vehicles did not substantially impact the average speed for low volume rural conditions with heavy vehicle ratio up to 0.3 in generally level terrain. Chang-Gyun R *et al.* [9] indicated that the average speed was stable when HV ratio was range of 0.25-0.45 and recovered after 0.45. Therefore, the impact of HVs on average is not accurate under different conditions, need to further investigate.

Nevertheless, some factors have not been sufficiently clarified, even vary with different combination or conditions. All above focused traffic flow on highway or roads, which did not cover conditions of heavy highway. In order to learn traffic flow characterizes of heavy highway on rainy days, this study focuses on a heavy highway, Xuanda Highway, in Hebei Province. The research selects seven days traffic data, collected by WIM system at Haierwa Bridge, to evaluate the effect of rainfall on traffic flow characterizes. Specific issues evaluated include the change of traffic volumes and speed of each time period during rainy days, to further indicate people's willingness to travel. In addition, the study will quantify the speed characteristics for each class vehicle, and the relationship between speed and heavy vehicle ratio on rainy days.

II. Background

A. Bridge and Equipment

Xuanda Highway, namely xuanhua - datong highway, is one of the main channels for transporting coal from

Manuscript received August 19, 2018; revised November 8, 2018.

doi: 10.18178/jtle.7.1.1-4

Datong to other places in Hebei Province. The Highway is started from xuanhua, via a Shaohua Ying, YangYuan to shanxi provincial boundary, whose total length is 127.8 km. Xuanda Highway is the first mountainous area heavy highway in Hebei province. It is a two-way four-lane highway, with a speed limit range of 90 km/h to 110 km/h.

The Haierwa Bridge (as Fig. 1) is located in the Xuanda Highway in Hebei province, nearly by Xuanhua. The number of the starting mileage pile is K168+ 400, and the terminal pile number is K168+ 612, which total length is 191.6 m, and the bridge width is 24.5 m. It was completed and opened to traffic in December 2000. Bridge design span is combination of 14m+138m+10m+2x8m, which design load is car-20, trailer-120. The main span is composite truss arch bridge with pre-stressed concrete structure. The bridge is two-way four-lane. Especially, lane 3 and lane 4, from Datong to Xuanhua direction, are heavy traffic lanes of the heavy highway, regarded as the research object of the paper.

There is a Weigh-In-Motion (WIM) station setting on the pavement of Haierwa Bridge (as Fig. 2), which is aimed to record traffic information as vehicle pass over its sensors at normal speeds. The traffic information collected by WIM included individual passing time, class designation, speed, spacing between adjacent axles, number of axles, load of each axle, as well as total weight [11].

Figure 1. Haierwa bridge

Figure 2. WIM system

B. Data Collection

Many of previous studies have analysed WIM data [11]-[14]. There was traffic information lasting for three years collected by WIM, about two million vehicle records per year. The paper focused on traffic volumes, speed and total truck weight to analyse heavy highway traffic flow. The writer selected one-week records, from September 7 to September 13, 2015, for two lanes from Datong to Xuanhua. It is noteworthy that the writes defines heavy truck, total weight exceeds 49t, as heavy vehicle in the paper. The ratio of heavy vehicles of Datong to Xuanhua direction was twice as much as other two lanes. It can represent heavy highway better.

In order to analysis effect on above variables on rainy days, the corresponding rainfall data was obtained from National weather service. The rain class is conducted corresponding with rainfall for one hour. Specifically, light rain is 0.1-2.5mm rainfall per hour, called class 1 in the paper. Similarly, moderate rain is 2.6-8.0mm per hour, called class 2, and heavy rain is 8.1-15.9mm per hour, called class 3. The first day and last three days are sunny; pouring rain occurred during 6:00-7:00 on the second day; follow by light rain on the third day, and moderate rain on the fourth. Fig. 3 shows that the traffic volumes declined on third day with light rain and the fourth day with moderate rain, while slight increased on first light rain. After rainy days, the traffic volumes began to recover. The relationship between volumes and rainfall indicated that moderate rain or heavy rain decreased people's willingness to travel, which was not sensitive to light rain or shower.

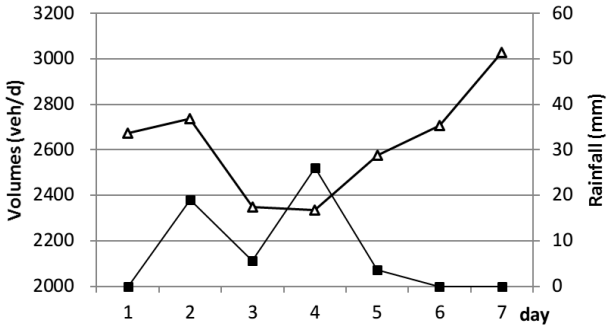

Figure 3. Relationship of volumes and rainfall

III. Characters of Traffic Flow

A. Traffic Volume

The rainfall data was counted for each one hour. There are 129 hours no rain, and 32 hours are light rain. Additionally, 6 hours are moderate rain and only one hour is heavy rain. The part combines all rainy conditions, up to 39 hours, computing the average traffic volumes of each hour for one day. At the same time, the volumes of heavy vehicles were distinguished.

As Fig. 4 shown, the traffic volume distribution of light vehicles for heavy highway belongs to bimodal distribution, similar to ordinary highway. While the heavy vehicles keep stable regardless day or night, even

no matter what rain or sunny. It was deem that the traffic volumes of light vehicles declined result from rainfall during 5:00-21:00. In conclusion, the rainfall decreased light vehicles volumes during the day, but made slightly difference on heavy vehicles.

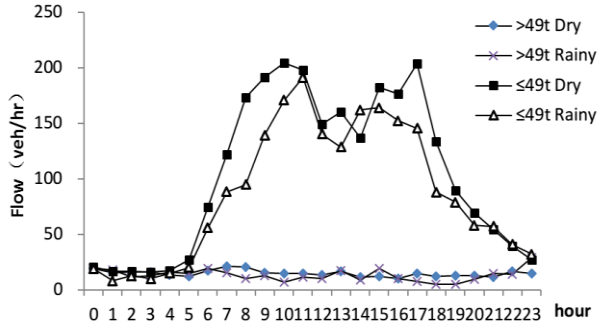

Figure 4. Distribution of traffic flow

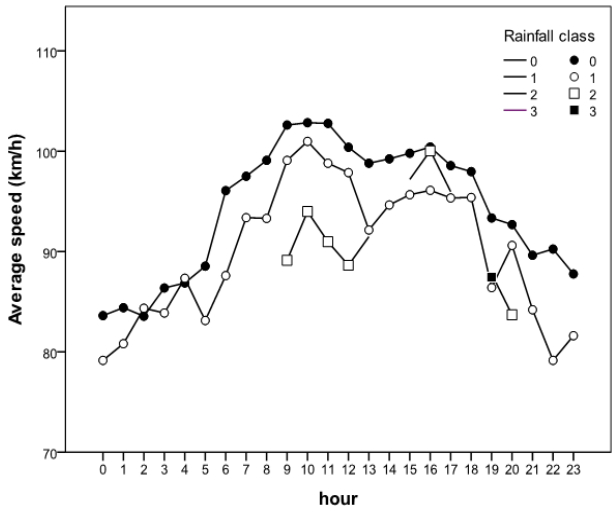

Figure 5. Daily speed distribution on different weather

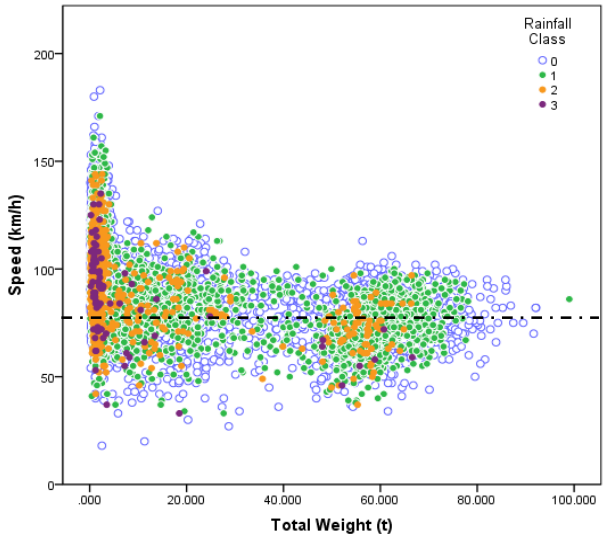

Figure 6. Speed-Total weight

B. *Traffic Speed*

It is certain that rain have a significant impact on road traffic, especially on traffic speed. It can also be applied to heavy highway as Fig. 5. Rainfall class 0~4 means no rain, light rain, moderate rain and heavy rain respectively. The average speed distribution was generally represented by central tendency distribution. The average speed was range from 82km/h to 103km/h during sunny days, while range from 79km/h to 100km/h when rain. Due to the time of moderate rain and heavy rain is only 7 hours, the speed change is unrepresentative. The writer focused on the speed reduction result from the light rain. It is shown that rainy days average speed decrease by 2-10km/h than sunny days during 5:00-1:00 (the second day) in Fig. 5, but still belong to central tendency distribution.

C. *Speed of Different Weight of Heavy Trucks in Free Flow*

For different total weight vehicles, speed reduction is different under different rainy class. The scatter diagram shows individual speed distribution of different weight vehicle as Fig. 6. The total weight is range of 0~30t and 50~80t. Among them, the total weight of passenger cars centralized less than 10t. With the increase of rainfall, the speed of passenger cars centralized to lower value. The maximum individual speeds respectively were 183km/h, 171km/h, 144km/h, 135km/h, corresponding with rainfall class 0~3. The average speed of 0-10t vehicles can also confirm it in Fig. 7. 10~40t and exceed 60t vehicles were not sensitive to light rain. Moderate rain have an impact on vehicle speed with weight range of 40~60t.

It is important to note that there were only 81 traffic records under heavy rain conditions. Because most vehicles weigh lower than 10t, what differences heavy rain made on vehicles was not accurate. On the other hand, all points of heavy vehicles are under the dotted line in Fig. 6, also proved heavy rain may impact on speed of heavy vehicles.

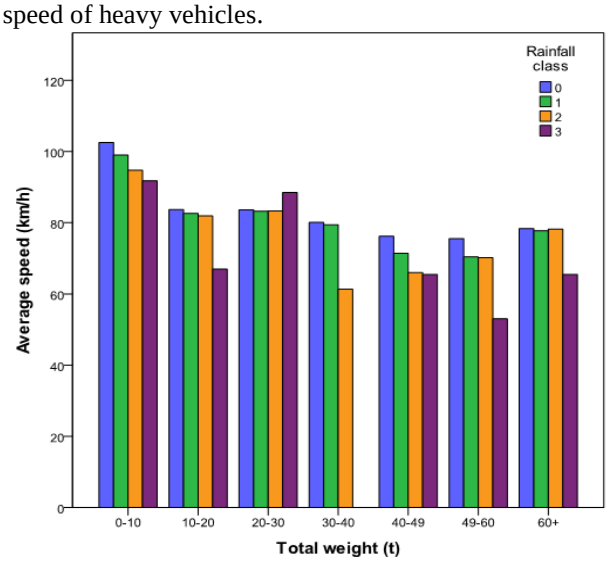

Figure 7. Average speed-Total weight class

D. *Speed-Ratio of Heavy Truck on Rainy Days*

When there was no rain the average speed decreased as the proportion of heavy vehicles increases. In case of light rain and moderate rain, the average speed tendency was similar to sunny days. As shown in Fig. 8, it is important to note that most of average speed of rainy

days was lower than that of sunny days, when the heavy vehicles ratio range of 0~25% and exceeds 45%. In other words, the influence of rainfall on speed was more prominent at low or high heavy vehicles ratio.

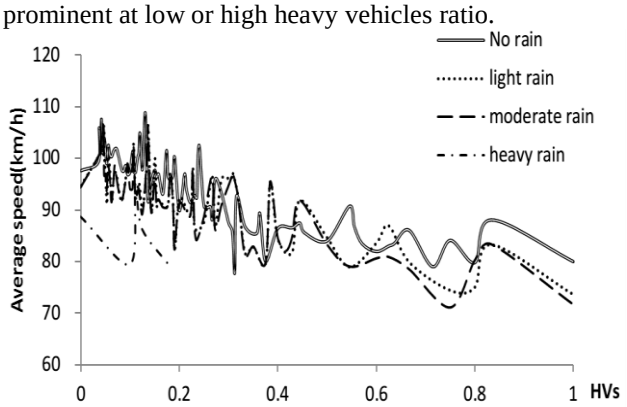

Figure 8. Relationship of average speed-heavy vehicles ratio

Although there were few records for heavy rain condition, its speed reduction is obvious, and the reduction value more than that of light rain and moderate rain. In general, the average speed declined as rainfall stronger and heavy vehicles ratio went up, which was similar to ordinary highway.

IV. Conclusions

The data were obtained using the WIM system at Harerwa Bridge and got from National weather service. The objective of the research was to analyse the traffic flow characterizes for heavy highway on rainy days. Rain has a significant impact on road traffic. The conclusions are as follows:

1) The moderate rain or heavy rain decreased people's willingness to travel, which was not sensitive to light rain or shower.
2) Regard of the vehicle designation, the rainfall decreased passenger cars volumes during the day, but had slightly effect on heavy vehicles.
3) The average speed declined as rainfall and heavy vehicles ratio went up, which was similar to ordinary highway. The speed reduction was more sensitive to rainfall for passenger cars less than 10t. Besides, speed reduction was more prominent when the heavy vehicles ratio less than 25% or more than 45%.
4) The average speed daily distribution is a central tendency distribution no matter what rain or not.

According to previous traffic data analysis for three years, Harerwa Bridge traffic flow is hardly to be congestion. Therefore, the paper is based on free-flow of heavy highway, while congested traffic flow needs further investigation.

Acknowledgment

This study is supported by the National Natural Science Foundation of PR China (51208056), and the Fundamental Research Funds for the Central Universities (310821161013).

References

[1] L. Aaets and I. V. Schagen, "Driving speed and the risk of road crashes: A review," *Acc. Anal. Prev*., vol. 38, no. 2, pp. 215-224, 2006.
[2] C. A. Lave, "Speeding, coordination, and the 55 mph limit," *J. Am. Econ. Rev.*, vol. 75, no. 5, pp. 1159-1164, 1985.
[3] L Jian, *et al*., "Modeling the effects of rainfall intensity on the heteroscedastic traffic speed dispersion on urban roads," *J. Transp. Eng*., vol. 142, no. 6.
[4] S. Hong and T. Oguchi, "Effects of rainfall and heavy vehicles on speed-flow relationship for multilane expressways in Japan," *C. Transportation Research Board 86th Annual Meeting*, 2007.
[5] M. Babak, *et al*., "Predicting average vehicle speed in two lane highways considering weather condition and traffic characteristics" in *Proc. C.IOP Conf. Series: Materials Sci. and Eng*., vol. 245, 2017.
[6] M. Nordiana and B. E. Johnnie, "Determining the quality of highway service caused by rainfall," *J. institution of Civil Eng.*, 2013.
[7] A. Al-Kaisy, "Passenger car equivalents for heavy vehicles at freeways and multilane highways: some critical issues," *J. ITE.*, pp. 40-43, 2006.
[8] K. D. Karen, *et al*., "Posted and free-flow speeds for rural multilane highways in Georgia," *J. Transp. Eng.*, vol. 125, no. 6, pp. 487-494, 1999.
[9] R. Chang-Gyun, *et al*., "Impact of heavy vehicles on highway traffic flows: Case study in the Seoul Metropolitan Area," *J. Transp. Eng. Part A: System*, vol. 143, no. 9, 2017.
[10] H. Tabatabai, H. Titi, and J. Zhao, "WIM-based assessment of load effects on bridges due to various classes of heavy trucks," *J. Engineering Structures*, vol. 140, pp. 189-198, 2017.
[11] W. S. Han, J. Wu, *et al*., "Extra-heavy truck load features and bridge dynamic response based on long-term traffic monitoring record," *J. China Journal of Highway and Transport*, Feb. 2014.
[12] J. Eugene and B. E. Obrien, "Using weigh-in-motion data to determine aggressiveness of traffic for bridge loading," *J. International Journal of Pavement Research and Technology*, vol. pp. 202–213, 2016.
[13] A. N. M. Faruk, W. T. Liu, S. I. Lee, *et al*., "Traffic volume and load data measurement using a portable weigh in motion system: A case study," *J. Bridge Engineering*, vol. 18, pp. 232-239, 2013.