TRAFFIC FLOW CHARACTERISTICS OF ISOLATED OFF-RAMPS IN IRANIAN EXPRESSWAYS

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Abstract The purpose of this study was to investigate traffic flow characteristics at off-ramp junctions in Iranian expressways. The study was conducted on the traffic behavior in isolated off-ramp vicinity of 6-lane expressways. The database consisted of traffic flow and traffic speed information extracted from videotapes. The relationship between diverging traffic flow in the right lane of expressway with total expressway and ramp flows was investigated. The 1985 U.S. Highway Capacity Manual, the 1985 HCM, models, and numerical values for isolated off-ramp analysis were evaluated and modifications for Iranian expressway system were suggested. The speed -flow relationship study showed that for a developing country such as Iran, the developed country's transportation engineering and planning manuals such as the 1985 HCM could give misleading results. Highway capacity analysis should be adjusted for a developing country's prevailing traffic composition and driver behavior.

Key Words Transportation Engineering, Traffic Flow Characteristics, Highway Capacity Analysis, Ramp Junction

چکیده هدف این مطالعه شناخت رفتار ترافیک در محدوده خروجی منفرد بزرگراههای ایران است. بانک اطلاعاتی این مطالعه شامل جریان ترافیک و سرعت بوده که از ۶ ساعت فیلم ویدیویی ترافیک استخراج شده است. رابطه جریان خروجی در خط سمت راست قبل از خروج باکل جریان و جریان داخل خروجی ارزیابی گردید. روابط آئین نامه تحلیل ظرفیت ۱۹۸۵ آمریکا برای خروجیهای منفرد مورد ارزیابی قرار گرفته و تغییرات لازم برای استفاده در ایران پیشنهاد شد. این مطالعه نشان داد که برای تحلیل ظرفیت بزرگراهها اعمال تغییرات لازم در مدلهای موجود در آئین نامه های کشورهای پیشرفته رفتار صحیح تری از ترافیک را منعکس می سازد.

INTRODUCTION

Highway capacity analysis is the study of the various types of highway facilities and their ability to carry traffic. The study of highway traffic behavior and operational characteristics permits evaluation of a facility's adequacy and quality of service. To determine the operational characteristics of an expressway, each of its components should be separately evaluated before the overall performance can be assessed. Expressways are made up of three types of sections, namely, basic section, ramp junction and weaving section. Ramp junctions are the sections where vehicles are permitted to enter or leave the expressway. Off-ramps allow vehicles to diverge from expressway into an exiting roadway. The expressway level of service depends directly upon the adequacy of off-ramp that is provided for traffic leaving the expressway. Inadequate off-ramp design and placement can seriously affect expressway operation. Highway capacity analysis procedures do not deal directly with turbulence, but shows its impact on expressway flow in the vicinity of the ramp. The direct measurement and quantification of traffic flow turbulence are complex and difficult [1-3]. Flow lane distribution of ramp junctions is rather puzzling. It is mainly influenced by the total expressway and ramp flows, the number of lanes on the expressway, the proximity and flows on adjacent ramps, and the ramp configuration [4-6]. Isolated off-ramps are far away from any adjacent ramps to be affected by their presence.

Traffic stream parameters fall into two broad categories: macroscopic parameters which characterize the traffic stream as a whole, and microscopic parameters which characterize the behavior of individual vehicles in the traffic stream with respect to each other. A traffic stream may be described macroscopically by six parameters: flow rate or frequency, speed, density, spacing, headway and slowness. Most of these parameters are used extensively in describing highway systems and their level of services. The capacity and level of service of an isolated off-ramp are evaluated on the basis of the expressway and diverge traffic flow rates. Speed is the second parameter describing the traffic behavior in ramp junctions. The traffic stream does not have a single characteristic speed but rather a distribution of individual vehicle speeds in each lane. The highway capacity manuals have not directly addressed the traffic speed characteristics for ramp junctions and have suggested to use the information of basic section for the ramp junctions. This is due to the complexity of the speed distribution among the lanes and during the lane change in ramp junctions. Furthermore, the relative short length of ramp junctions with respect to basic sections makes ramp junction speed study of less concern [2,7].

A diverge point is a location where parts of the traffic flow leave the expressway at the off-ramp. Diverge movements are the main operational features of an isolated off-ramp junction. Diverging involves the separation of traffic into two streams of through and off-ramp traffics. The one and two lane off-ramps are usually constructed on the right hand side of the expressway with or without an auxiliary lane. As off-ramp traffic moves to the expressway right lane, Lane1, to diverge and the through traffic moves toward the outer lanes to avoid conflict with the off-ramp traffic at the diverge point, the lane change intensifies. Downstream of the diverge point, some of the through may change lane back into the right lane. Highway capacity analysis in most of the developing countries is based on the 1965 and 1985 Highway Capacity Manuals [1,3].

STUDY SCOPE

Several developing countries have found that using U.S. highway capacity manuals could give misleading results [8-14]. This is mainly due to the different traffic compositions and driver behaviors in developing countries as compared with those of the U.S. The highway capacity analysis in Iran has so far been based on the aforesaid manuals [15,16]. The ramp junction capacity analysis is carried out using the same numerical values and relationships as available in the manuals without considering the extent to which they are suitable for Iranian conditions. Therefore, the purpose of the study reported here is to gain insight on traffic behavior of the isolated off-ramp junctions for Iranian expressways and to evaluate the validity of the 1985 HCM models and numerical values.

A preliminary observation led to the identification of 6 candidate sites. Of these sites, 2 which had more traffic flow variations were selected. Using more than 2 sites could have enhanced the study results, nevertheless, the limited resources confined the scope of the study to the selected sites. Using a video camera with a timer, the traffic behavior was taped. The sites were single lane isolated off-ramps on 6-lane expressways within the Tehran Greater Metropolitan Area with no adjacent upstream or downstream ramp. The traffic consisted of a commuter population with less than 5% heavy vehicles. For both sites, the expressway geometric design was ideal. The design speed was 110 kilometer per hour, the grade was less than 2%, and the lanes were 3.75 meters with no lateral obstruction within 5 meters. The Iranian geometric design standard requires a taper or deceleration lane for off-ramps. The design specifications are usually similar to U.S. design guidelines [15-18].

The first site, site A, was a parallel type with a length of 125 meters deceleration lane off-ramp connecting Modares Expressway to Hemmat Expressway. The second site, site B, was a 125 meter taper type off-ramp connecting Chamrun Expressway to Hemmat Expressway. For both sites, the video camera was located on Hemmat Expressway overpass that could clearly capture the traffic behavior up to 300 meters upstream for the off-ramp nose. Small markers showing 50 meter intervals were located on expressway shoulders on both sides up to 200 meters upstream from off-ramp nose.

DATA COLLECTION

The data were limited to 6 hours of videotaping. Longer videotaping could have improved the study results, nevertheless, the limited resources confined the videotaping to 6 hours. At each site 3 hour videotapes were taken from 7:00 a.m. to 10:00 a.m. on a weekday. Tehran's weekday peak period usually occurs between 7:00 a.m. to 9:00 a.m. At sites A and B videotaping was conducted on Monday 6 December 1993, and Tuesday 7 December 1993, respectively. During the 6 hour videotaping, no unusual event or traffic incident occurred. Furthermore, no backlog or traffic jam was observed in traffic streams. This showed that the ramp slopes did not have any significant effect on ramp junction operations.

The videotapes were reviewed and information about the traffic behavior was extracted from the display on the television screen. Past studies have used 5 to 15 minutes as the study time interval [1-14, 19]. No matter what time interval is chosen, there is always a shorter interval that could be used that the traffic parameters would show more variation. For this study, shorter than 5-minute intervals could have been statistically unstable. Selection of longer than 5-minute time intervals would have significantly reduced the study sample size. The manually extracted information includes lane flows, lane changing flows and travel times for 5-minute time intervals of the 6 hour videotaping. The flows and travel times were measured by a hand traffic counter, the timer records dubbed to the tape and a hand chronometer with tenth of a second prescision. To reduce measuring error, with a pen marker, the 50 meter shoulder markers were highlighted and laterally connected by a straight line on the television screen. For each 5-minute interval, vehicle travel times for 200 meters upstream of the off-ramp nose were measured. The vehicle travel times were used to compute space mean speed.

The database consisted of traffic flow characteristics for 72 five-minute intervals. For each 5-minute interval, the lane flow information included 200 meters upstream of the off-ramp lane flows, immediately upstream of the off-ramp lane flows, the off-ramp flows and immediately downstream of the off-ramp lane flows in vehicle per hour. The lane changing information includes lane changing flows along 4 expressway sections of 50 meters length upstream of off-ramp nose in vehicle per hour. The speed information includes space mean speed for traveling 200 meters upstream of the off-ramp for each lane in kilometer per hour. Videotaping traffic was a simple and inexpensive way of traffic behavior data collection. It was very invaluable for data review and verification.

FLOW ANALYSIS

The study of traffic behavior reported here consists of flow and speed analyses. The principle operational characteristics of an isolated off-ramp are the expressway and the diverge traffic flows. Transportation planning provides current traffic demand and forecasts of future traffic demands for expressway and off-ramp flows [4-7]. With this information, the 1985 HCM presents two procedures for estimating the diverge flow in the expressway Lane 1 just upstream of the off-ramp. The capacity and level of service of an isolated off-ramp are evaluated based on the expressway and diverge traffic flows.

The first technique of the 1985 HCM uses a multiple linear regression model for a 6-lane expressway. The second technique is more general and can be applied to any ramp configuration. To determine the flow on Lane 1, several mathematical models including the multiple linear regression model of the 1985 HCM were evaluated. These models had the general functional form of Equation 1:

$$V_1 = F\,(V_f, V_r) \qquad (1)$$

where V_1 is the flow on Lane 1 upstream of the off-ramp in vehicle per hour, F is the functional form, V_f is the all across expressway flow upstream of the off-ramp in vehicle per hour and V_r is the ramp flow in vehicle per hour. The functional forms used and evaluated in this study were linear, quadratic, exponential and multiplicative, respectively. The selected model with the smallest root mean square error, RMSE, of 153 vehicle per hour had a linear form and is given by:

$$V_1 = -488 + 0.338\ V_f + 0.179\ V_r \qquad (2)$$

where the variables are defined as in Equation 1. The coefficient of determination, R^2, was 0.94, the t statistics for the intercept, coefficient of V_f and coefficient of V_r were -10.4, 7.6 and 1.8, respectively. The expressway flow, V_f, had a mean of 3478 vehicle per hour, a standard deviation of 1493 vehicle per hour, a minimum of 1620 vehicle per hour and a maximum of 6252 vehicle per hour. The off-ramp flow, V_r, had a mean of 1034 vehicle per hour, a standard deviation of 485 vehicle per hour, a minimum of 408 vehicle per hour and a maximum of 2280 vehicle per hour. The Lane 1 flow, V_1, had a mean of 873 vehicle per hour, a standard deviation of 608 vehicle per hour, a minimum of 168 vehicle per hour and a maximum of 1872 vehicle per hour. The 1985 HCM model given by Equation 3 overestimated the Lane 1 flow and had a RMSE of 537 for the observed data:

$$V_1 = 96 + 0.231V_f + 0.473V_r \qquad (3)$$

where the variables are defined as in Equation 1. The range of V_f was from 100 to 6200 vehicle per hour and the range of V_r was from 20 to 1800 vehicle per hour. The study showed that for the collected data the best functional form was the same as that of 1985 HCM, i.e. linear.

The difference between Equations 2 and 3 was due to two reasons. First, the databases of the two models were different. Equation 3 was calibrated from a 1960 study conducted by then U.S. Bureau of Public Roads using full-hour volumes of a large database. Equation 2 database present a different traffic composition and driver behavior using a limited database of 5-minute interval flows. Secondly, Equation 3 assumed that the off-ramp flow immediately would transfer from Lane 1 to the off-ramp at the point of diverge, where as for Equation 2, vehicles had transferred along the taper or deceleration lane. For the study reported here, the beginning of taper or deceleration lane was taken as the upstream of the off-ramp. Figure 1 shows the average of the lane distribution of the off-ramp flows for the observed flows and that of 1985 HCM. Figure 1 shows that lane changing for the Iranian off-ramp traffic occurred much closer to the off-ramp nose as compared to that of 1985 HCM estimates. For example, the study showed that 150 meters from the off-ramp nose, only 42% and 45% of ramp flows were in Lane 1 for the off-ramp with taper lane and deceleration lane respectively. This traffic behavior was different when compared with the 1985 HCM estimation of all the

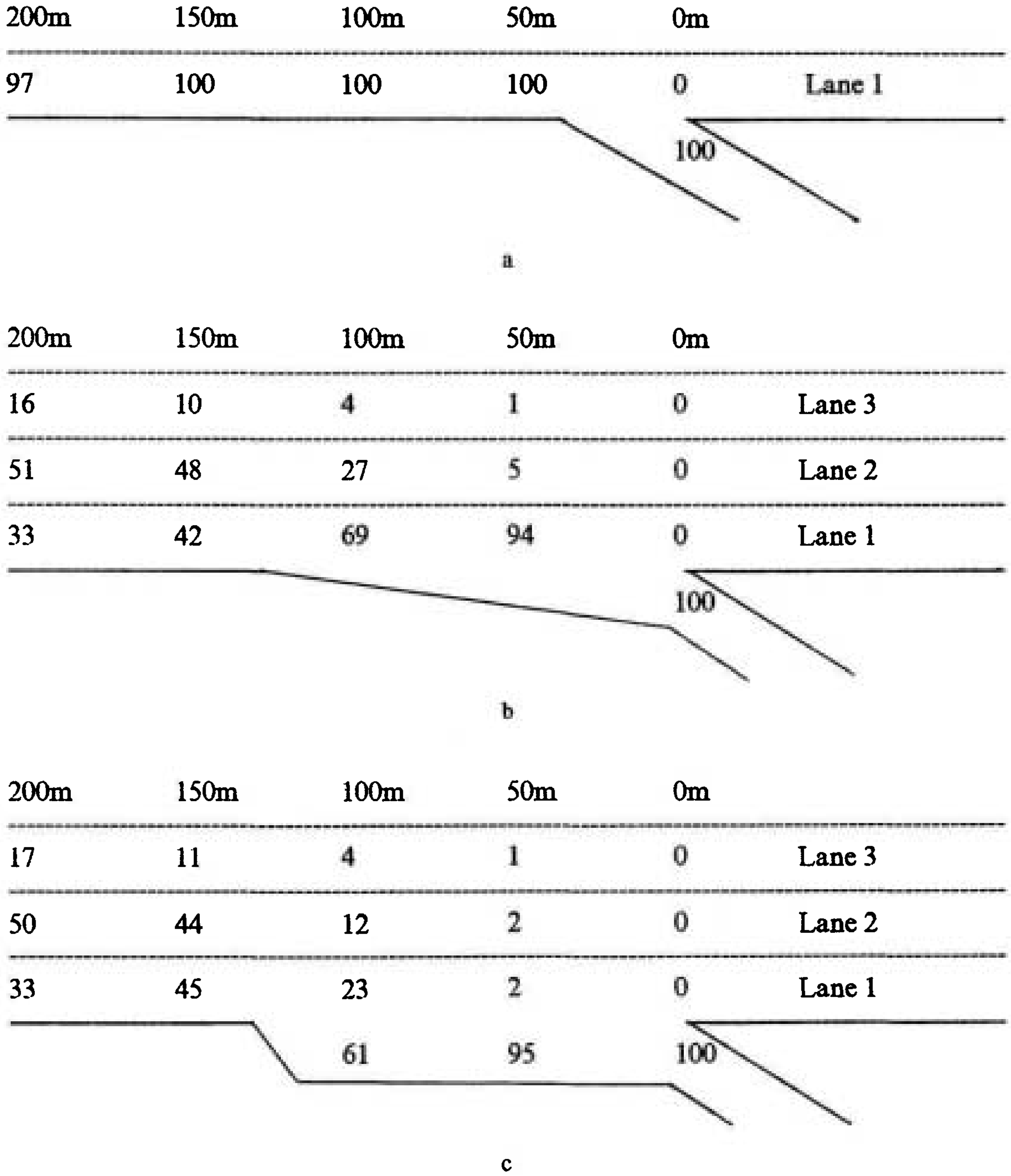

Figure 1. Lane distribution of ramp flow for the study database and the 1985 HCM. **a**) The 1985 HCM percentage of ramp flow in Lane 1 at various distances from the off-ramp. **b**) Lane distribution of ramp flow at various distances from the off-ramp with taper lane. **c**) Lane distribution of ramp flow at various distances from the off-rame with deceleration lane.

off-ramp flow in Lane 1 at 150 meters from the off-ramp nose. Figure 2 shows the average of the lane distribution of the through traffic flows in the off-ramp vicinity. The flow in each lane can be determined if its off-ramp and through traffic components are computed from these two figures. Indeed, this is the second procedure of the 1985 HCM Lane 1 flow estimation. For the observed expressway flows of 1620 to 6252 vehicle per hour and ramp flows of 408 to 2280 vehicle per hour, Figures 1 and 2 could be used to estimate the individual lane flows. The study showed that diverging maneuvers along a taper or deceleration lane were effective in reducing the adverse effects of lane changing. The percentages of a 6-lane expressway through traffic in Lane 1 in the off-ramp vicinity for the 1985 HCM and the observed flows are shown in Table 1. The percentages of the observed through traffic flows in Lane 1 were higher than those of 1985 HCM estimates. Nevertheless, due to diverging along a taper or deceleration lane, the two procedures of the 1985 HCM resulted in overestimation of Lane 1 flows.

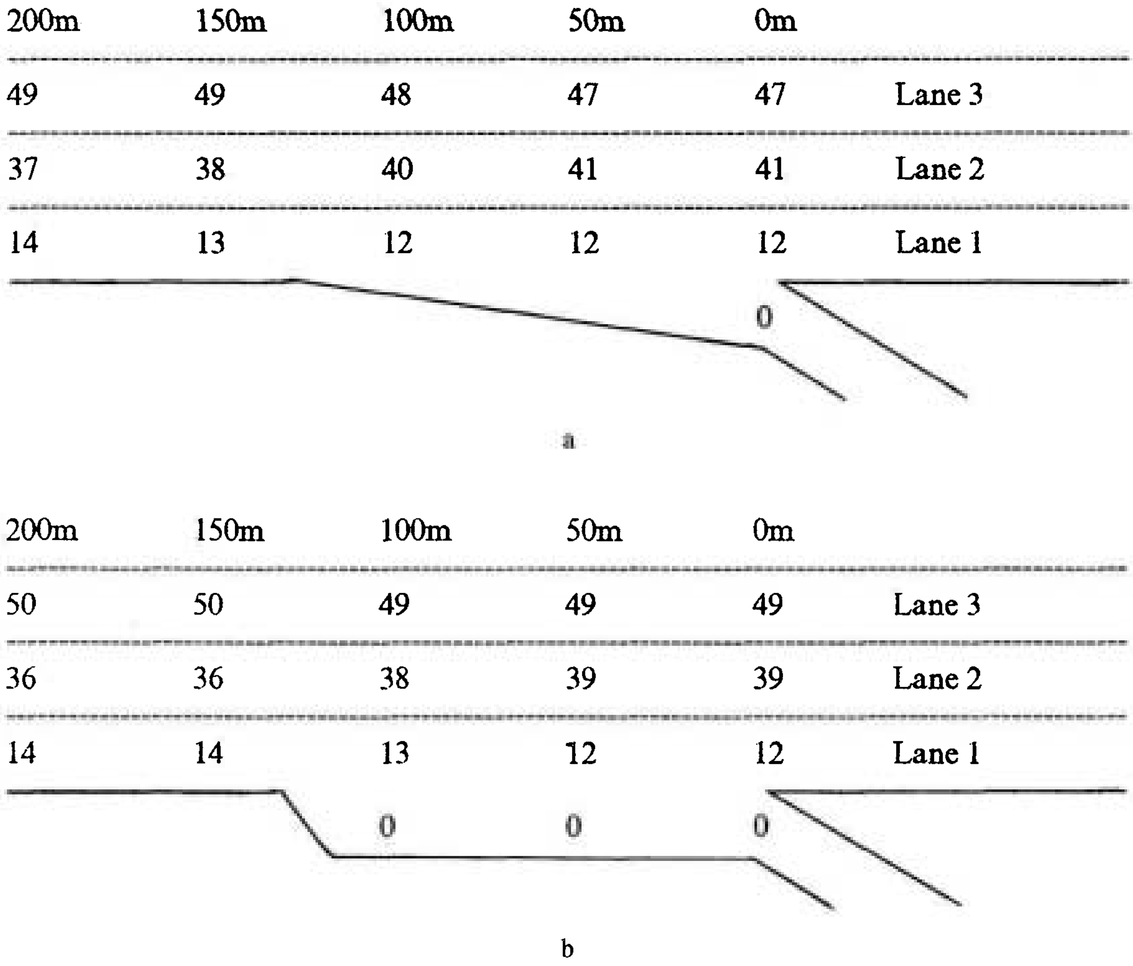

Figure 2. Lane distribution of through traffic flow for the study database. **a)** Lane distribution of through traffic flow at various distances from the off-ramp with taper lane. **b)** Lane distribution of through traffic flow at varous distances from the off-ramp with deceleration lane.

TABLE 1. The Percentage of through Traffic Remaining in Lane 1 in the Vicinity of off-ramps for 6-lane Freeways.

Through traffic in one dircetion in vph	The observed percentage	The 1985 HCM percentage
4000 to 4499	16	14
3500 to 3999	14	10
3000 to 3499	13	6
2500 to 2999	12	6
2000 to 2499	10	6
1500 to 1999	10	6
0 to 1499	10	6

The study showed that the main portion of lane changing for the off-ramp traffic took place within the 200 meters upstream from the off-ramp nose. Furthermore, the study showed that the percentage of the through traffic flow in Lane 1 was higher than that in the 1985 HCM. Provision of the deceleration or taper lane was effective in reducing the adverse effect of the off-ramp traffic lane changing. The lane changing behavior on Iranian expressway, was more intensely closer to the off-ramp nose as compared with that of 1985 HCM estimate. It was expected that the 1985 HCM would underestimated the Lane 1 flow upstream of the off-ramp nose if there was no deceleration or taper lane.

SPEED ANALYSIS

The highway capacity manuals have not directly addressed the traffic speed characteristics for ramp junctions and have suggested to use the information of basic section for the ramp junctions. This is due to the complexity of the speed distribution among the lanes and during the lane change in ramp junctions. Furthermore, the relative short length of ramp junctions with respect to basic sections makes speed measurement of ramp junctions less important for travel time studies [2,7]. Nevertheless, in considering a surrogate for flow rates to reflect the effectiveness for ramp junctions, speed was also investigated.

The speed of expressway lane was calculated based on traveling 200 meters upstream of the off-ramp nose. For each 5-minute time interval, the travel times of 10 randomly selected through traffic vehicles were measured. The calculated space mean speed of each lane for 72 five-minute was then analyzed. Due to the complexity of the observed lane changing maneuvers which often required more than one lane change in the 200 meters upstream of the off-ramp nose, the speed of the lane changing vehicles were extracted for only three 5- minute intervals. The measured speed of lane changing vehicles were found roughly to be 5% less than their through vehicles. Nonetheless, speed of the through traffic was further studied.

The univariate analysis of speed revealed key statistics for speed in each lane. The speed in Lane 1 had a mean of 60.3 kilometer per hour, a standard deviation of 4.6 kilometer per hour, a minimum of 50.1 kilometer per hour and a maximum of 71.2 kilometer per hour. The speed in Lane 2 had a mean of 68.2 kilometer per hour, a standard deviation of 5.1 kilometer per hour, a minimum of 55.3 kilometer per hour and a maximum of 80.4 kilometer per hour. The speed in Lane 3 had a mean of 82.2 kilometer per hour, a standard deviation of 5.1 kilometer per hour, a minimum of 68.1 kilometer per hour and a maximum of 91.4 kilometer per hour. The speed in Lane 3 was on the average 14 kilometer per hour or 20.5% higher than that of Lane 2. The speed in Lane 2 was on the average 8 kilometer per hour or 13.1% higher than that of Lane 1.

To determine the speed-flow relationship, for each lane, the speed-flow scattergram was studied. Figures 3 to 5 show the results for Lane 1, Lane 2 and Lane 3, respectively. The data showed two clusters of moderate and heavy flow levels. For the moderate flows, for a total of 3 lane flow levels below 4000 vehicle per hour, all the three figures confirmed that the speed is insensitive to the flow level. For the

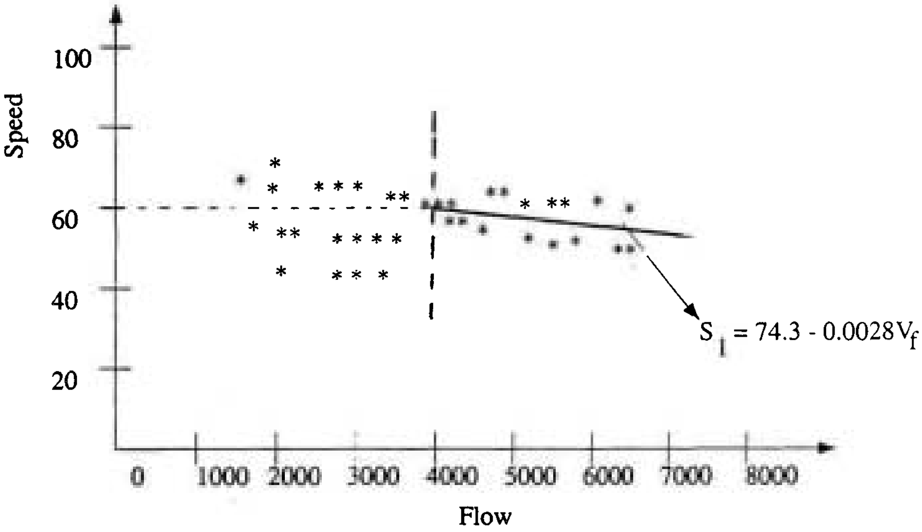

Figure 3. Expressway Lane 1 speed versus total flow.

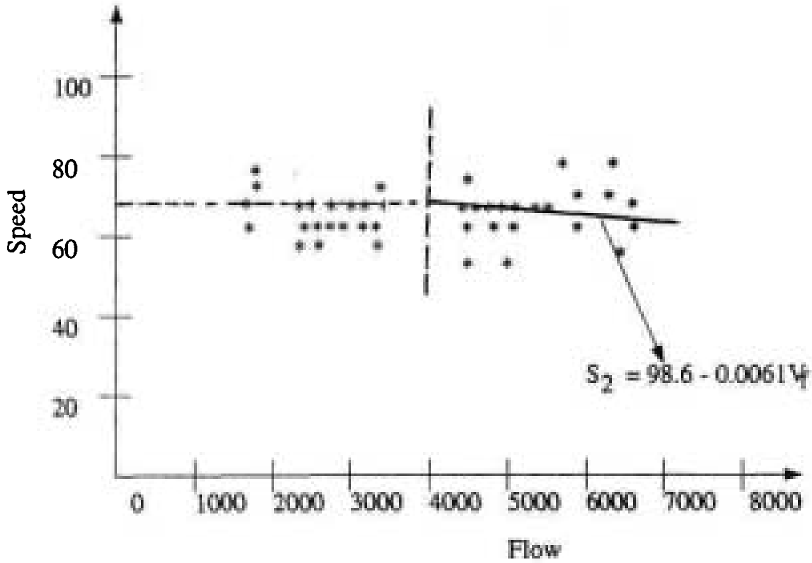

Figure 4. Expressway Lane 2 speed versus total flow.

heavy flows, flow levels above 4000 vehicle per hour, the speed was statistically significantly correlated with the flow. These results were in agreement with the past speed-flow studies which showed that speeds remained constant with increasing flow for considerable range and then started to decrease around two-thirds or three quarters of the maximum flow [8, 10, 19]. To determine speed-flow relationships, several regression models were developed and evaluated for all the flow levels including, the moderate flow levels and the heavy flow levels. For the developed models, the expressway flow, V_f, was the independent variable and the speed in each lane was the dependent variable. The selected models, presented by Equations 4 to 6, were for the heavy flow levels when the flow was above 4000

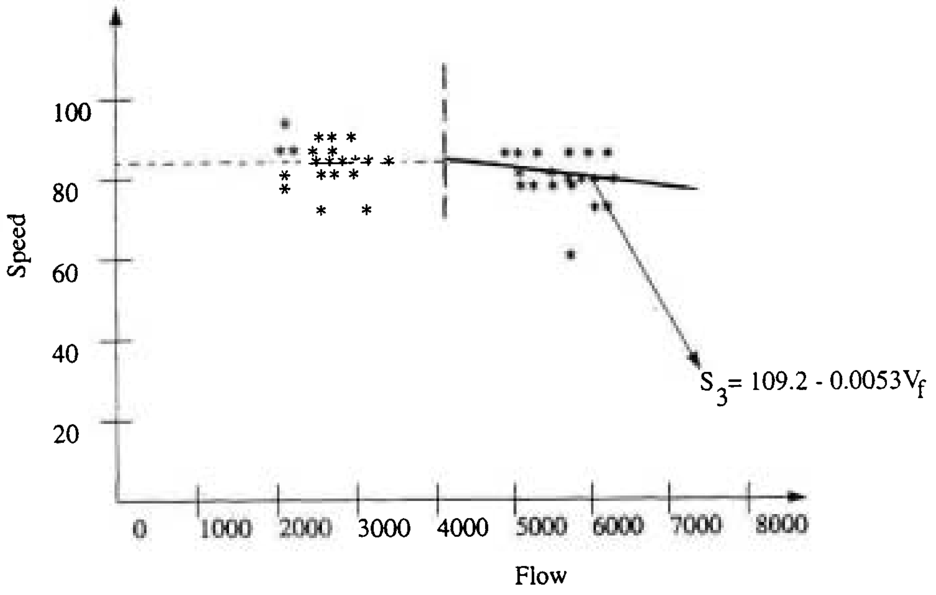

Figure 5. Expressway Lane 3 speed versus total flow.

vehicle per hour:

$$S_1 = 74.4 - 0.0028V_f \quad (4)$$

$$S_2 = 98.6 - 0.0061V_f \quad (5)$$

$$S_3 = 109.2 - 0.0053V_f \quad (6)$$

where S_1, S_2 and S_3 were speeds in kilometer per hour in Lane 1, Lane 2 and Lane 3, respectively and V_f was expressway total flow in vehicle per hour. The coefficients of determination, R^2, for the Equations 4 to 6 were 0.13, 0.37 and 0.31, respectively. The **t** statistics for the intercept for Equations 4 to 6 were 11.7, 14.2 and 15.3, respectively. The **t** statistics for the coefficient of V_f were -2.2, -4.3 and -3.7, respectively. The RMSE of Equations 4 to 6 were 4.2, 4.6 and 6.5 kilometer per hour, respectively. For heavy flow levels, the models showed the effect of expressway total flow, V_f, on Lane 1 speed was less than those for Lane 2 and Lane 3.

CONCLUSIONS

The study of traffic behavior in isolated off-ramp vicinity of 6-lane expressways shed some light on traffic flow characteristics of ramp junctions. Data extraction from videotapes was simple but time consuming. Nevertheless, traffic behavior videotaping was very invaluable for data review and verification. The study showed that the recommended model for Lane 1 diverge flow prediction had the same functional form as that of 1985 HCM. Nevertheless, the model coefficients were modified for the collected database. Provision of the deceleration or taper lane showed to be effective in reducing the adverse effect of the off-ramp traffic lane changing. The lane changing behavior on the Iranian expressway was more intensely closer to the off-ramp nose as compared with that of 1985 HCM estimate. The study showed that speeds remained constant with increasing expressway flow for considerable range of flows and then started to decrease around 4000 vehicle per hour. The speed in Lane 1, Lane 2 and Lane 3 had a mean of 60.3, 68.1 and 82.2 kilometer per hour, respectively. The speed in Lane 3 was on the average 14 kilometer per hour or 20.5% higher than that of Lane 2. The speed in Lane 2 was on the average 8 kilometer per hour or 13.1% higher than that of Lane 1. The study showed that the functional forms and general relationships of traffic flow characteristics for the 1985 HCM for isolated off-ramp junction were similar to the traffic behavior in Iranian expressway. Nonetheless, they should be modified to reflect the influence of the local traffic composition and driver behavior. Using the same methodology, further traffic behavior study is suggested for other ramp junction configurations and weaving sections.

In summary, the study showed that for a developing country such as Iran, the developed country's transportation engineering and planning manuals such as the 1985 HCM could give misleading results. Capacity analysis based on the 1985 HCM should be adjusted for the developing country's prevailing driver, vehicle, and roadway conditions.

ACKNOWLEDGMENTS

Partial funding for this project was provided by the Department of Civil Engineering of the Sharif University of Technology. The author wishes to thank Mr. A. Haydari-Kani for the extensive data extraction process.

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