Examination of Fundamental Traffic Characteristics and Implications to ITS

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The purpose of this paper is to study and analyze the essential traffic characteristics of a 5.4-mile stretch of I-64-40 located within the St. Louis metropolitan area. The freeway experiences heavy congestion during peak periods attributed to factors such as exceedingly high traffic volume, conflicting merging and diverging movements, multiple weaving areas, and overall poor geometric design. The freeway volume, speed, and density data were collected on various locations within the study area and the data was translated into a series of graphics including, a speed-volume-time of day chart, a speed-volume chart, a volume-density chart, and a speed-density chart. The numerical result indicated that the capacity, free flow speeds, and critical speeds varied for different lanes. However, it was observed that the critical densities were relatively similar for all lanes at the same location. This indicates that density may be a rather important and more reliable measure than volume and speed in the determination of freeway capacity. This study provides a better understanding of the freeway dynamics. In addition, it forms a comprehensive database for the development and implementation of congestion management techniques utilizing Intelligent Transportation System (ITS). Key words: freeway dynamics, u-q curve, q-k curve, u-k curve, critical density, ITS application.

INTRODUCTION

The purpose of this paper is to study and analyze the essential traffic characteristics of a 5.4-mile stretch of I-64-40 located within the St. Louis metropolitan area. The freeway experiences heavy congestion during peak periods. The congestion is mainly attributed to factors such as exceedingly high traffic volume, conflicting merging and diverging movements, multiple weaving areas, and overall poor geometric design. This study identified and examined the important characteristics of traffic operation, and further, it provided an opportunity for effective exploration of ITS programs.

TRAFFIC VOLUME-SPEED-DENSITY RELATIONSHIPS

The freeway volume, speed, and density data were collected in two different intervals: five-minute intervals when using tube counters and one-minute intervals when using Nu-Metrics Hi-Star counters. However, one-minute counts were derived from the five-minute counts using Poisson distribution random number generation. This

meant that all counts could be treated as one-minute counts for the purpose of analysis (*1*).

The portion of I-64-40 being researched for this study was divided into five sections as shown in Figure 1 (*2*). Data was collected at strategic locations within each of these sections for both directions and for the A.M. and P.M. time periods. The collected data was translated into a series of graphics including: a speed-volume-time of day chart, a speed-volume chart, a volume-density chart, and a speed-density chart (*1*).

Data was collected multiple times for a given location and the aforementioned series of graphics were created for each data collection period. However, in order to gain a better picture of the freeway conditions and relationships, speed-volume (u-q), volume-density (q-k), and speed-density (u-k) charts were created that are composed of all data obtained for a given location within a freeway section. Figures 2 through 4 illustrate these graphics for westbound I-64-40 at the Hanley Road location. From these figures, the capacity and critical density of the freeway section may be determined. It is not necessary to include all of the charts that were generated for each of these locations. Instead, summaries of the results for each section of the study area are shown in Tables 1 and 2 (*1*).

Observing Table 1, we see that the capacity and density of the eastbound sections remain essentially the same at 2300 veh/hr/ln and 50 veh/mi/ln respectively until the Clayton-Hampton section. In this section, the capacity drops to 1950 veh/hr/ln and the density decreases to 45 veh/mi/ln. Unfortunately, counter malfunction did not permit data collection in the Hampton to Kingshighway study area, thus explaining why data is not shown in Table 1 for this section.

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Table 1 Summary of Eastbound Section Information

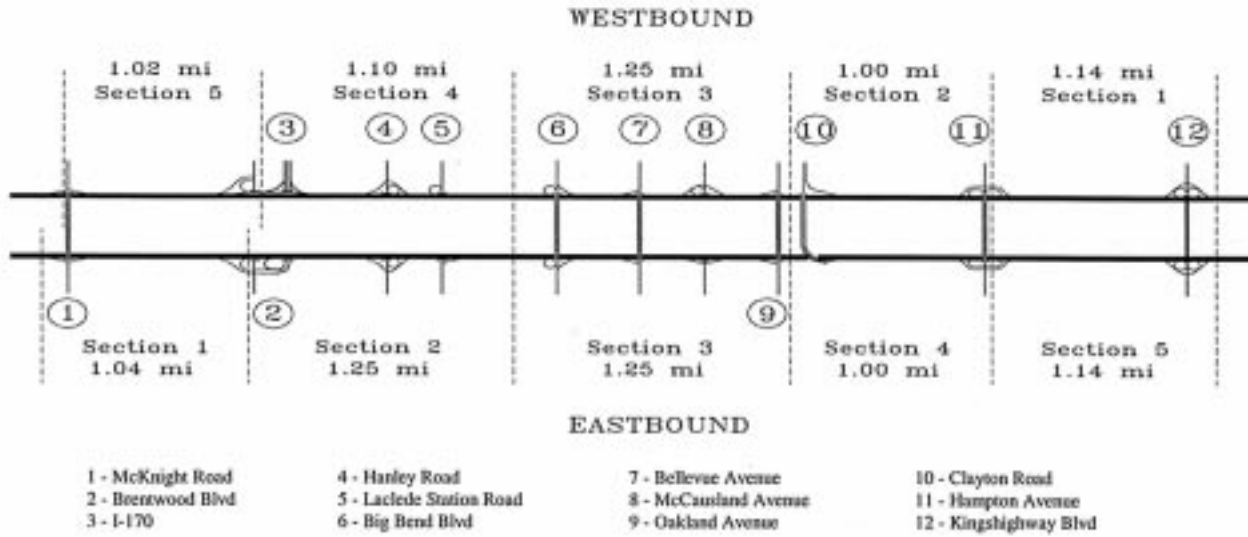|	Section				
	McKnight to Brentwood	I-170 to Hanley	Big Bend to Bellevue	Clayton to Hampton	Hampton to Kings-highway
Capacity (veh/hr/ln)	2300	2300	2350	1950	N/A
Critical Density (veh/mi/ln)	50	50	50	45	N/A

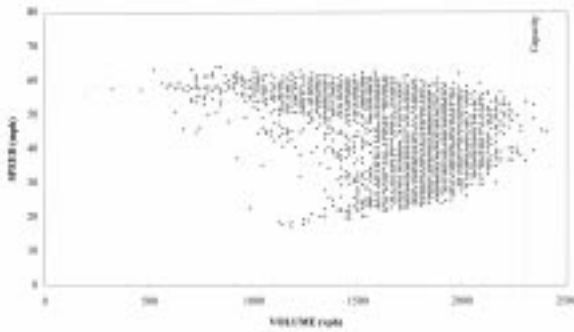FIGURE 1 Diagram of study section.

FIGURE 2 Speed versus volume, I-64 WB at Hanley, 3 lanes.
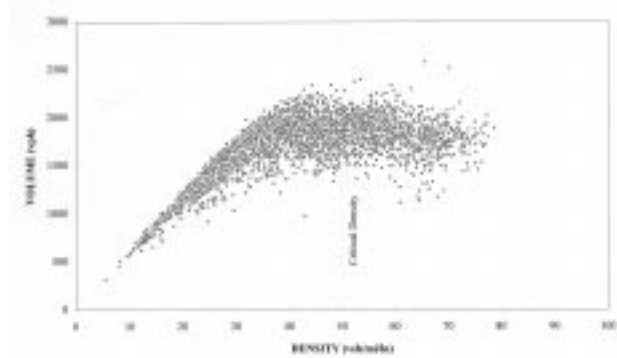

FIGURE 3 Volume versus density, I-64 WB at Hanley, 3 lanes.

Table 2 Summary of Westbound Section Information

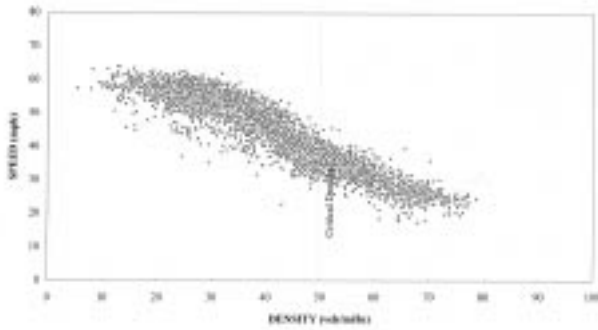|	Hampton to Clayton	Section Clayton to Oakland	Bellevue to Big Bend	Big Bend to Laclede	Laclede to Hanley	Brentwood to McKnight
Capacity (veh/hr/ln)	N/A	2150	2350	2375	2300	2250
Critical Density (veh/mi/ln)	N/A	50	50	48	50	50

FIGURE 4 Speed versus density, I-64 WB at Hanley, 3 lanes.

FIGURE 5 Mean arrival rate.

The characteristics of the westbound sections are more dynamic, as can be seen from Table 2. The capacity increases significantly from the Clayton-Oakland to the Bellevue-Big Bend section. It increases then slightly more, but begins a downward trend from the Big Bend-Laclede to the Laclede-Hanley location. Although the capacity changes for each section, the density appears to remain relatively constant.

To this point, the volume-density relationship has been shown in a relatively macroscopic view. In addition, individual lane traffic characteristics were also observed. Free-flow speeds were analyzed and determined to be significantly different for each individual lane. Free-flow speeds were approximately 55 mph, 58mph, and 63 mph for lane 1, lane 2, and lane 3, respectively. Lane capacities were also identified from u-q curves. The capacities for lane 1, lane 2, and lane 3, were approximately 1700 vph, 1900 vph, and 2100 vph, respectively. The traffic flow in lane 3 tended to move faster than the other lanes and its capacity was the highest. Lane 2 traffic moved slightly faster than lane 1 under uninterrupted traffic flow. The traffic in lane 1, which always has to interact with high truck percentages and ramp merging and diverging activities, showed the lowest free-flow speed and capacity (*1,3*).

Analysis of the q-k and the u-k curves indicated that density had strong relationships with volume and speed until a certain density

range was reached (35-45 veh/mi/ln). When the density was over 40 veh/mi/ln, the relationships were unstable, as volume and speed began to decrease. This phenomenon was experienced for each individual lane.

Due to the different free-flow speeds, the capacities were different by lanes. In a rather conservative way, the critical densities were identified from the q-k curves. The critical density was defined as the density corresponding to the maximum volume that can be accommodated on the freeway. Theoretically, the v/c ratio should be equal to 1 when the density increases from the steady state to the point of critical density (*4,5*). The observed critical densities for lane 1, 2, and 3 seem to be very close to each other, regardless of their observed free-flow speeds. This suggests that density may be a rather important and more reliable measure than volume and speed in the determination of freeway capacity (*2*).

RAMP VOLUME AND ARRIVAL PATTERN

Observing the characteristics of ramp behavior helps to understand freeway traffic flow. Volumes and arrival patterns are two important ramp characteristics that have major impacts on freeway operations. Arrival patterns are patterns of vehicles arriving at the ramp in terms of statistical distributions, mean arrival rates, and standard deviations (*3*). This section examines selected on-ramps with the above traffic characteristics to determine the levels of freeway operations.

In this study, 5- and 1-min volumes were established during certain A.M. and P.M. periods only. The study in this paper analyzes freeway volume, speed and density data collected from detailed 5- and 1-min counts. The periods were determined from critical ranges of previous studies (*2,3*). The main objective of using traffic counts at short intervals was to focus on the arrival rates and patterns of selected ramps during critical traffic periods.

The output of the ramps monitored were all summarized in detailed 1-minute intervals to obtain more precise information, particularly with respect to arrival patterns. The more detailed 1-minute data was also used directly to develop a macroscopic traffic flow simulation model (*1*). Constrained by the memory capacity of the counters, data collected were for four hours and fifty minutes. The selected A.M. range was from 5:00 to 10:00 A.M. while the P.M. range was from 2:00 to 7:00 P.M. Select on-ramp locations in the westbound direction were analyzed. The same analysis can be applied to the entirety of the study section. The chosen locations were on-ramps from McCausland and Hanley.

Both the A.M. and P.M. mean arrival rates were analyzed for the McCausland on-ramp. This ramp was important because it was the location of the ramp metering testing site. For the A.M. period there was a marked increase in mean arrival rate from 6:30 to 7:00. A typical graph generated for is shown in Figure 5, which represents the mean arrival rate at this location during the morning 'rush hour'. It should be noted that this phenomenon was similar to historical data (*2,3*). Since ramp-metering testing was not performed during A.M. periods, the current traffic conditions were not affected with any changes in ramp traffic. The unstable arrival patterns at this location continues to create dramatic impacts on the freeway flow. Converted data indicated an overall arrival rate of 9.63 veh/min. In contrast, the A.M. Peak Average was 11.42 veh/min. The mean arrival rates during the P.M. monitoring period for the McCausland on-ramp show steady mean arrival rates for the data

collection period. After further analysis a normal distribution characteristic for arrival rates was evident. The steady arrival rates may be attributed to the ramp metering installed during the study period. A statistical summary of the arrival rates for the afternoon peak and entire period showed that P.M. peak average was noticeably lower than the A.M. peak average at 7.30 veh/min.

A critical part of the freeway section that is of interest because of its significant traffic congestion is near the Hanley on-ramps. The mean arrival rates for the N.B. Hanley on-ramp were recorded and the expected unstable rates were evident with a marked increase from 7:00 to 9:00 A.M. During this period the highest mean arrival rate reached 14 veh/min. This area poses problems due to the high volume of weaving. At this point, the Hanley on-ramp traffic moving to the mainline traffic begins to conflict with the mainline traffic moving towards the I-170 and Brentwood off-ramp traffic. A histogram of the mean arrival rate indicated a normal distribution. Data observed showed that the P.M. average mean arrival rate at 8.91 veh/min is higher than the overall rate of 7.36 veh/min.

Similar instability in mean arrival rates is observed at the S.B. Hanley on-ramp as that experienced in the N.B traffic. This high volatility is the major cause of inhibition of free traffic flow at this ramp location. In addition, it is worsened due to the percentage of heavy vehicles, 11.73%. Further study of the area concluded that inadequate geometric design at this location added constraint to traffic movement.

Analysis of lane 1 for the entire study section was also made. The density and headway characteristics were observed to determine how the on-ramp and off-ramp vehicle flow affected the mainline traffic. Density for the A.M. peak (7:00 to 9:00) was above average most of the time, as expected. The headways were more stable throughout the morning period, except for the period between 6:00 and 6:30 A.M. where there were large increases in gaps between vehicles. The average density and headway for the morning period were 31.25 vpmpl and 6.26 veh/sec respectively.

The afternoon lane 1 summary of density and headway was also observed. As expected, during the P.M. peak (3:00 to 6:00 P.M.)

density was typically above the average. The headways were consistent throughout the afternoon study period. The mean density was 47.11 vpmpl. The stability of headway is also indicated by the small difference in mean and mode at 2.23 and 2.20 veh/sec. These trends are evidence of the impact that vehicles entering and exiting the ramps have on the mainline traffic.

The above information regarding arrival rates and patterns, combined with volume, speed, and density measurements, form the basis for a freeway traffic simulation model. Information from the ramp metering testing site is also used to provide insight for the ramp metering optimization algorithm. The following synopsis of the ramp monitoring analysis provides more detail on the analysis of ramp metering effects.

RAMP MONITORING ANALYSIS FOR THE TESTING SITE

Part of this research included monitoring the effects of a ramp metering test site, located on the westbound on-ramp from McCausland Ave. Ideally, ramp metering is most effective when all critical ramps on the freeway system, as determined by their impact on the mainline, are metered (*3*). Thus, this single ramp meter on the westbound leg of the I-64-40 study corridor is a somewhat less than ideal condition. However, appreciable changes in the ramp arrival rate and the mainline densities were noticeable.

The densities upstream and downstream of the westbound McCausland on-ramp for the 1996 and 1997 data were compared. The 1996 data was collected prior to the installation of the ramp meter at the McCausland ramp and the 1997 data was collected after installation. Thus, Figures 6 and 7 provide a "before and after" contrast of the density behavior at the selected site. In comparing the data for both years, it is apparent that the 1997 densities are more uniform. Furthermore, spurts in traffic density are less sudden than those present in the 1996 data. Although there are many possible reasons for this phenomenon, it does seem appropriate, given that the ramp arrival rate is more uniform.

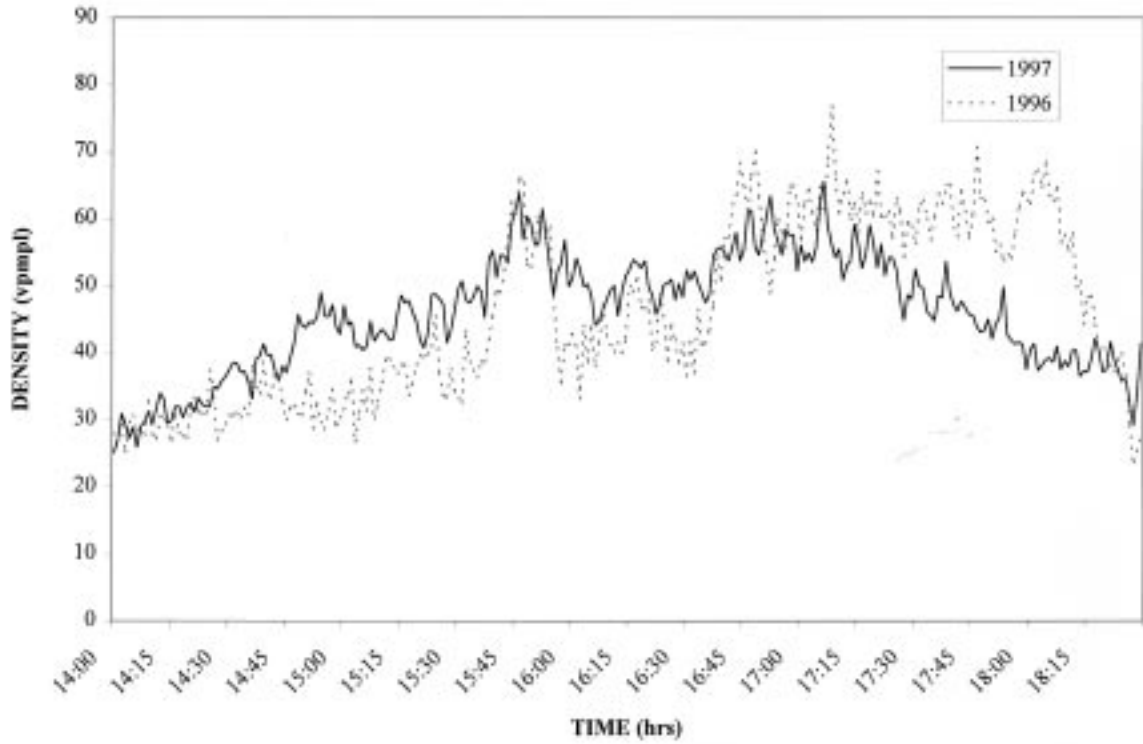**FIGURE 6 I-64 WB upstream of McCausland (all lanes).**

FIGURE 7 I-64 WB downstream of McCausland (all lanes).
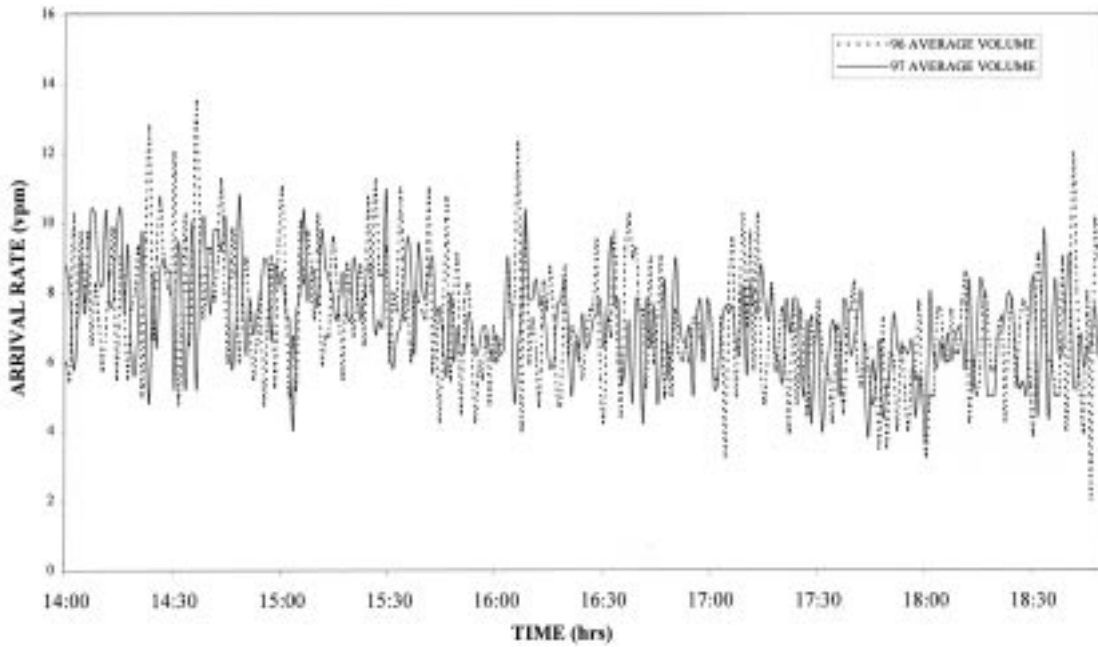

FIGURE 8 Ramp metering effects on mean arrival rates.

Observation of the arrival rate for the McCausland ramp over the P.M. peak period was also performed. A comparison for both years is shown in Figure 8. The 1996 data shows a lack of consistency in the arrival rate. The rate may be large at one point, but significantly lower a short time span later. Now observing the 1997 data, it can be seen that the arrival rate is more uniform due to the presence of the ramp meter. This more uniform arrival rate allows vehicles to enter the mainline traffic stream in a less disruptive

manner. Even though the mainline may be operating above critical density, the resulting effect is more consistent densities on the mainline and therefore less probability of shock wave production.

CONCLUSIONS

Traffic engineers have developed many empirical solutions to the problems of operating transportation systems. Subsequent studies in traffic flow theory have verified that approaches developed by experiment and observation may be the best solution. Speed, volume (flow), and density (concentration) are the three primary measures used for the empirical study of traffic operations. The relationships among these three factors are important in providing the basis for the selection of measures of effectiveness and the definition of level-of-service for freeway segments (*6*). In this study, the numerical results indicated that the capacity, free flow speeds, and critical speeds varied for different lanes. However, it was observed that the critical densities were relatively similar for all lanes at the same location. This indicates that density may be a rather important and more reliable measure than volume and speed in the determination of freeway capacity. It also suggests the critical importance of the study of volume-density relationships in order to understand the characteristics of freeway dynamics. Furthermore, the series of plots provide a clear picture of the dynamics and progression of the traffic stream. In addition, such studies as this one form a comprehensive database for the development and implementation of congestion management techniques utilizing ITS.

Studies of the ramp volumes and arrival patterns are important in locating the trouble areas for freeway corridors. Data observed in these areas allow further analysis of critical traffic flow characteristics that is important in concluding congestion mitigation alternatives. The above studies regarding arrival rates and patterns, combined with the volume, speed, and density measurements provide important information for the understanding of the freeway traffic characteristics. The output of these analyses form the basis of the development of the Advanced Traffic Management Systems (ATMS) programs. Such a large traffic database is important in successfully developing a macroscopic traffic flow simulation model. The input of such comprehensive traffic data into the model improves the accuracy of the dynamics of the freeway's operation, and allows meaningful traffic control such as ramp metering to be implemented.

ACKNOWLEDGMENT

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