FINAL
CONTRACT REPORT

EXAMINATION OF CORE CONCEPTS IN THE *HIGHWAY CAPACITY MANUAL* PART I: SUBHOURLY VARIATIONS IN TRAFFIC FLOW RATE

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16. Abstract

The rate of flow measures demand on a highway facility and is defined as "the equivalent hourly rate at which vehicles pass over a given point or section of a lane or roadway during a given time interval less than one hour, usually 15 minutes." The *Highway Capacity Manual* (HCM) states that flow rates calculated for periods less than 15 minutes should be avoided since they are "statistically unstable." This assertion is problematic since traffic conditions can change dramatically in the course of 15 minutes.

An investigation of this concept using a large set of data from freeways in the urbanized Hampton Roads region of Virginia led to the following conclusions:

- flow rates may be determined using measurement intervals shorter than the 15-minute interval suggested by the HCM. In some cases, stable flow rates were achieved using measurement intervals of 10 minutes.
- There is not a clear breakpoint in measurement intervals in which the flow rate measure will become significantly more stable. It was determined that in all cases, increasing the measurement interval by 2 minutes resulted in more stable flow rates.

The following recommendations were made:

- VDOT should use the longest measurement interval practical when measuring traffic flow rate to facilitate stability in the measure.
- When measuring traffic flow rate on urban freeways, VDOT should use a minimum of 10-minute intervals when using the values for internal analyses and the provision of public information.

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ABSTRACT

The *Highway Capacity Manual* (HCM) is one of the most widely used traffic engineering guidance documents in the world. It was originally published in 1950, and it has been under constant revision since. Unfortunately, due to past cost and time constraints associated with traffic data collection, much of information in the manual is based on research conducted using relatively small data sets. This calls into question the statistical significance of some of the manual's material.

The Virginia Smart Travel Laboratory is directly connected to operational Virginia Department of Transportation (VDOT) transportation management systems. This gives the laboratory access to unprecedented quantities of traffic data. The purpose of this research was to use these data to investigate a key concept in the HCM: subhourly variations in traffic flow rates.

The rate of flow measures demand on a highway facility and is defined as "the equivalent hourly rate at which vehicles pass over a given point or section of a lane or roadway during a given time interval less than one hour, usually 15 minutes." The HCM states that flow rates calculated for periods less than 15 minutes should be avoided since they are "statistically unstable." This assertion is problematic since traffic conditions can change dramatically in the course of 15 minutes.

An investigation of this concept using a large set of data from freeways in the urbanized Hampton Roads region of Virginia led to the following conclusions:

- Based on very conservative assumptions regarding the definition of stability, stable flow rates may be determined using measurement intervals shorter than the 15-minute interval suggested by the HCM. In some cases, stable flow rates were achieved using measurement intervals of 10 minutes.

- There is not a clear breakpoint in measurement intervals in which the flow rate measure will become significantly more stable. It was determined that in all cases, increasing the measurement interval by 2 minutes resulted in more stable flow rates.

The following recommendations were made:

- VDOT should use the longest measurement interval practical when measuring traffic flow rate to facilitate stability in the measure.

- When measuring traffic flow rate on urban freeways, VDOT should use a minimum of 10-minute intervals when using the values for internal analyses and the provision of public information.

- VDOT should formally transmit this report to TRB for committee consideration as the next version of the HCM is developed.

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INTRODUCTION

The *Highway Capacity Manual (HCM)* is widely used by transportation planners, designers, and operators as a resource of technical information (Transportation Research Board [TRB], 2000). The manual has been revised many times since it was originally published in 1950. These revisions have been based on research conducted throughout North America. Therefore, the quality of future editions is directly dependent on continued research to uncover more knowledge of traffic characteristics. Much of the material in the current manual is based on research conducted many years ago when large traffic data sets were simply not available. This is a serious limitation, as described by Hurdle, Merlo, and Robertson (1997), "relationships [in the *Highway Capacity Manual]* are the result of committee consensus arrived at on the basis of limited data." Therefore, there is a need to revisit many of the concepts and procedures described in the *HCM* using larger, more comprehensive sets of data that will allow for statistically significant conclusions.

The Virginia Smart Travel Laboratory provides an ideal research facility to support the development of enhancements to the *HCM.* The laboratory is directly integrated with Virginia Department of Transportation (VDOT) transportation management systems. Specifically, the Smart Travel Laboratory receives speed, volume, and occupancy measurements from freeway locations throughout Virginia collected using short polling intervals (2 minutes or less). This data has been archived in the Smart Travel Laboratory since May 1998, providing an enormous set of data to use in addressing highway capacity issues.

As a starting point in examining core *HCM* concepts, this project focuses on a fundamental traffic flow concept: subhourly variations in measured traffic flow rates. This area, addressed in Chapter 2 of the *HCM*, "Traffic Characteristics," must be well understood in order to address more complex concepts and procedures, such as speed-flow relationships.

The rate of flow is defined as "the equivalent hourly rate at which vehicles pass over a given point or section of a lane or roadway during a given time interval less than one hour, usually 15 minutes" (TRB, 2000). The rate of flow is a critical variable in the management of traffic in that it measures the demand on a facility. The *HCM* states that flow rates calculated for periods for less than 15 minutes should be avoided since they are "statistically unstable." This assertion is problematic, particularly when real-time transportation management is considered. The traffic flow rate serves as the basis for such fundamental activities as signal timing, transportation planning, and freeway management (such as ramp metering strategies). In addition, in the era of intelligent transportation systems (ITS) and traveler information systems, traffic flow is a key variable used to describe the state of the transportation system to travelers.

Experience has shown that traffic conditions can change dramatically in the course of 15 minutes. As stated by Hurdle et al. (1997), "15 minute data points do not necessarily represent uniform conditions; in some cases the flow may have changed considerably between the beginning and end of a 15 minute period." Clearly, using flows measured over intervals shorter than 15 minutes is desirable. In fact, a number of studies have done just that (from 30-second intervals to 5-minute intervals [Urbanik, Hinshaw, and Barnes, 1991]). In addition, a review of the literature has not revealed any documentation proving the instability of flow at intervals of less than 15 minutes. Therefore, there is a need to study the stability of traffic flow estimates at time intervals shorter than 15 minutes. Given the ability of today's ITS-based traffic control systems to poll detectors at very short intervals (such as every 1 to 10 seconds), it is imperative that the transportation engineering community develop an understanding of the influence of the time interval used in flow measurements.

PURPOSE AND SCOPE

The purpose of this research WAS to investigate the stability of traffic flow measurement using counts taken for intervals less than 15 minutes to support the use of flow rate for operations applications. Given the focus on time-critical operations, intervals longer than 15 minutes were not appropriate for consideration. Finally, it should be emphasized that the study investigated the impact of measurement interval on flow rate and did not seek to identify a new "stable" interval threshold.

METHODOLOGY

The following methodology guided the research effort.

1. *Literature review.* Literature was reviewed to uncover research that addressed highway capacity issues, focusing on the stability of traffic flow estimates.

2. *Data collection and reduction.* Hampton Roads freeway traffic flow data are collected on a continuing basis in the Smart Travel Laboratory. Loop detector stations are installed at 203 locations in the Norfolk and Virginia Beach areas of Hampton Roads. The stations collect, on a lane-specific basis, traffic flow, occupancy, and speed at 2-minute intervals. These data are transferred to the Smart Travel Laboratory and stored in an Oracle database. Data have been collected and are available for all days starting in May 1998 through the present. The purpose of this task is to make use of this resource to provide the data needed to conduct the subsequent analyses.

The following activities were required in this task:

- *Sites were selected for analysis.* The sites were chosen to reflect different traffic conditions, roadway geometry, and traffic control devices. The goal of this step was to select sites that comprise a representative sample of common freeway sections.

- *Dates and times were selected for analyses.* Again, this selection was driven by the goal to develop a representative sample of freeway traffic conditions.

- *The extracted data was examined manually and with software tests developed in the Smart Travel Laboratory to ensure that they were reliable.* Any suspect data were identified based on established data screening rules (Turochy and Smith, 2000) and not used in further analysis.

3. G*raphical testing*. The first component of the graphical testing methodology was to generate plots that compare the average per lane flow rates using different measurement intervals over the course of an entire day to the stable flow rates over the day. In other words, the potentially "noisy" signals (represented by flow rates measured at intervals less than 15 minutes in length) are compared to the true, "stable" flow rate signal (flow rates measured at 15-minute intervals). In essence, this approach provides a visual depiction of the signal-to-noise ratio concept.

Since the Hampton Roads loop detector data are polled at 2-minute cycles, the stable interval used for this analysis was rounded up to a 16-minute time interval (to comply with the *HCM's* requirement of 15 minutes or greater). For each day, the series of flow rates measured at each candidate measurement interval (2, 4, …, 14 minutes) were compared on the plot to the stable signal resulting from the 16-minute measurement interval. In order to minimize bias, each measurement interval was centered as closely as possible on the same collection time period, accounting for the constraint of 2-minute intervals. For example, the intervals used for 10:00 a.m. flow measurements are illustrated in Figure 1.

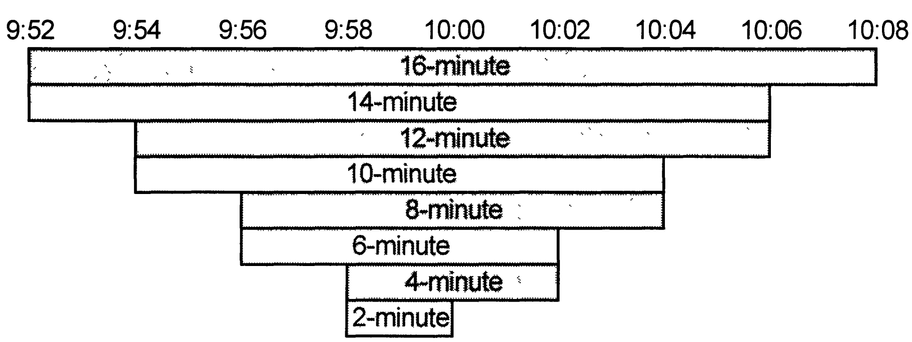

Figure 1. Example of Flow Measurement Interval Periods

The second class of graphs created for the analysis illustrates how the average absolute deviation from the stable per lane flow rate signal (16-minute measurement interval), averaged over an entire day's set of flow rate measurements, was affected by the measurement interval. The average absolute deviation is defined as the absolute difference between the flow rate for a 16-minute time interval (stable signal) and the flow rates for each shorter measurement interval (potentially noisy signals). At each test site, a graph is plotted with the measurement time interval on the x-axis and the average absolute deviation on the y-axis.

4. Statistical testing. Although the graphical tests provide a visual indication of the stability of flow rates at different measurement intervals, there is a need to test statistically the significance of the visually apparent patterns. The first set of "signal-to-noise" graphs provides a visual depiction of stability at different measurement intervals. The second set of average absolute deviations from stable graphs indicate the typical error caused by measurement interval. The two series of hypothesis tests conducted in this section are intended to determine if the trends evident graphically can be verified to some level of statistical significance.

For the first hypothesis test, an assumption was made that stability can be defined to occur when the mean of absolute flow rate deviations from a stable 16-minute flow rate signal over the course of a day is less than 1% of a lane's capacity. Given that the *HCM* defines the capacity of an urban freeway lane to be 2,400 vehicles/hour/lane, a particular measurement interval provides a stable traffic flow rate signal if it results in an average absolute deviation of 24 vehicles/hour/lane or less. This is a very conservative assumption in defining stability. For example, 24 vehicles/hour/lane represents only 3 vehicles passing a location when measuring flow rate at an 8-minute interval.

To test this assumption statistically, the following hypothesis test was conducted for each of the seven stations.

H_0: μ_I=24 vehicles/hour/lane
H_1: μ_I<24 vehicles/hour/lane

Where:
μ_I = mean absolute deviation between the per lane flow rate at the 16-minute measurement interval and the per lane flow rate at a shorter interval, I (I = 2, 4, …, 14 minutes)

In essence, this test was used to determine if there is evidence that the flow rate is stable for interval I, in which case μ_I<24 vehicles/hour/lane and the null hypothesis is rejected. If the test fails to reject the null hypothesis, then there is not sufficient evidence to conclude that the flow rate is stable at interval I.

Given the large number of samples for each station (30 samples per hour, 14 hours per day, 10 days – 4,200 total samples), the distribution of μ_I can be estimated as normal based on the central limit theorem. Using a confidence level of $\alpha = 0.05$, the null hypothesis is rejected when the normalized test statistic is less than -1.645, suggesting sufficient evidence exists to conclude that $\mu_I < 24$, or stability at the measurement interval, *I*. If $z > -1.645$, the null hypothesis cannot be rejected and the traffic flow is considered unstable at measurement interval, *I*.

The second hypothesis test is intended to determine if a significant change in average absolute deviation from a stable signal occurs as one moves from a particular measurement interval to the next longer interval (for example, from a 6-minute interval to an 8-minute interval). The purpose of this approach was to determine if there exists some breakpoint interval at which the stability of flow rate measures degrades significantly.

In this case, the hypothesis test investigates if there is a significant difference between average absolute deviation from stable flow (I = 15-minutes) between two "adjacent" measurement intervals, as described:

H_0: $|\mu_I - \mu_{I+2}| = 0$ vehicles/hour/lane

H_1: $|\mu_I - \mu_{I+2}| > 0$ vehicles/hour/lane

Where:

μ_I = mean absolute deviation between the per lane flow rate at the 16-minute measurement interval and the per lane flow rate at a shorter interval, I (I = 2, 4, …, 14 minutes)

Again, at a confidence level of $\alpha = 0.05$, when the test statistic is greater than -1.645, the null hypothesis is rejected, suggesting a significant difference in the average absolute deviation between the time intervals. If $z < -1.645$, the null hypothesis cannot be rejected and one can conclude that there is no significant difference in flow rate stability between the measurement intervals.

RESULTS

Literature Review

The impact of the measurement interval used in flow rate measurement has been addressed in transportation practice and research. This section examines past experience to demonstrate the need to quantify the impact more definitively.

Highway Capacity Manual

The *HCM* addresses the issue of the impact of the measurement interval on flow rate in multiple sections. First, in Chapter 2, the manual recommends that 15-minute intervals be used for most procedures. This recommendation is supported by the statement: "5-minute flow rates have been avoided, since research has shown them to be statistically unstable" (TRB, 2000).

Unfortunately, a general literature review, and a review of the *HCM's* Chapter 2 references, did not reveal the study or studies that support this statement. Furthermore, the notion of "statistical stability" is vague and no commonly accepted definition of this condition exists.

Later in Chapter 2 of the manual, the measurement interval for rate of flow is again addressed, this time in the context of describing speed-flow relationships, "in measuring the speed-flow relationship, it is important to use appropriate time intervals, since they strongly influence the form of the curve, especially around capacity flow and in the congested region. Five-minute intervals are recommended as the shortest time base for practical purposes." Therefore, one will note that this statement contradicts the earlier recommendation of the manual and seems to encourage transportation engineers to use measurements that are "statistically unstable." This conflict makes the need to quantify the impact of the measurement interval quite clear.

Transportation Research

Many transportation researchers have commented on the issue of the time interval impact on traffic flow measurement. Particularly, there is a great desire to use rather short time intervals in order to better capture the dynamics of traffic flow through time. For example, in their work investigating the speed-flow relationship on freeways, Hurdle et al. (1997) state that "15-minute data points do not necessarily represent uniform conditions; in some cases the flow may have changed considerably between the beginning and end of a 15-minute period." For this reason, they conclude, "any conceptual difficulties of dealing with short-interval data are a small price to pay for the information these data provide."

As a result of this ambiguity, researchers have used a number of measurement intervals when determining traffic flow for various investigations. For example, in a study of flow characteristics in freeway work zones, Polus and Shwartman (1999) measured flow rates using 1-minute measurement intervals. They contended that this measurement interval was suitable "because of the sustained coherent flow conditions in the lanes (of the work zone) that remained open." In a paper investigating characteristics of congested flow, Banks (1999) compared the results of his work, using a measurement time interval of 30 seconds, to those of Kerner's empirical flow modeling work, which used 1-minute data. Banks acknowledged the significance of this difference in the statement, "this difference is potentially significant because 30-second data are considerably noisier than 1-minute data and the effects of random variations must be considered in interpreting the results." The potential for "noise" was also noted by Zhou and Hall (1999) in their paper addressing the speed-flow relationship in congested conditions. They stated that, "to reduce random variation inherent in 20-second data, 5-minute averages were used in the analysis." Finally, Urbanik et al. (1991) graphically illustrated the random variations in flow due to small time-interval measurements in flow plots for the same location using 1-, 5-, and 15-minute time intervals. Their contention is that using longer time intervals "smooths the data to allow trends to be seen."

Clearly, there is a common belief, as evidenced in the literature, that short measurement intervals introduce "noise" into the true pattern of traffic flow at a location. This concept of noise originates in the field of communications systems, in which noise is defined to be inescapable random signals introduced to the true signal (Carlson, 1986). The fundamental premise in communication systems is that in order to maintain an acceptable level of performance, one must work to understand the characteristics of the random signal in order to isolate the true signal. For example, the signal-to-noise ratio, or the ratio of the signal power to noise power, is commonly used to quantify the impact of noise (Carlson, 1986). For similar reasons, it is important for transportation engineers to understand the influence of noise that results from relatively short measurement intervals used in measuring traffic flow. Although the literature contains much discussion from a qualitative sense, as discussed previously, there is little quantitative information. In the next section, this is addressed quantitatively using large sets of data from a number of freeway locations.

Data Collection and Reduction

Seven Hampton Roads stations were chosen for analysis in this study. The stations were chosen to provide locations with diverse characteristics, such as different numbers of lanes, proximities to ramps, and geographic locations. Table 1 and Figure 2 describe the locations and characteristics of the stations used in this analysis.

Data collected between the hours of 6:00 am and 8:00 pm were used in this study. Other times were not considered due to the fact that the low flow rates in the evening and early morning made it very difficult to distinguish "noise" from the underlying traffic flow signal. A major problem faced with using the loop detector data was the large number of missing or erroneous values reported by the stations. Given the harsh environment in which loop detectors operate, it is common for freeway management systems to experience this problem. To account for this, the Smart Travel Laboratory's database was queried for 10 "days" of valid data for each station, where a day is defined as a set of data recorded between the hours of 6:00 am and 8:00 pm with no missing or erroneous values. These days were spread throughout the period between March 1999 and March 2000, covering different seasons and different days of the week, excluding weekends. Based on this approach to data collection and reduction, 29,400 two-minute traffic flow rate measurements were available to support the analysis.

Table 1. Station Descriptions

Station	Facility	Station Location (Mile marker)	Location of Nearest On-Ramp (Mile marker)	Location of Nearest Off-Ramp (Mile marker)	No. Lanes
22	I-64 East	285.1	284.2	284.1	4
39	I-64 East	282.5	282.3	282.1	3
71	I-64 East	280.2	279.9	279.8	3
85	I-64 West	279.0	278.9	279.0	3
111	I-64 East	277.0	277.1	277.0	4
185	I-264 East	5.7	6.1	6.0	4
186	I-264 West	6.0	6.0	6.2	4

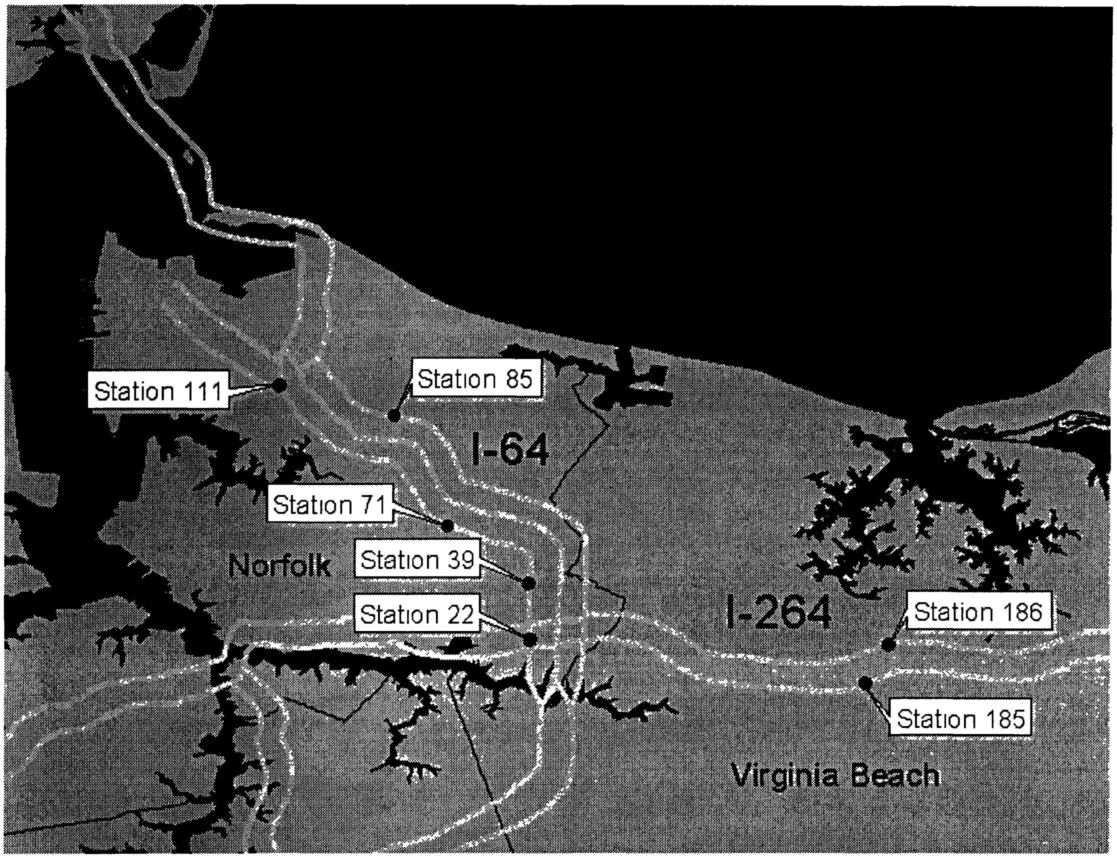

Figure 2. Station Locations

Graphical Testing

Graphs were generated for each day of data, at each location comparing the "stable" flow rate (16-minute measurement interval) to flow rates determined using measurement intervals ranging from 2 to 14 minutes. These graphs clearly demonstrated less deviation from the stable flow rate as the measurement interval becomes longer. However, a distinct "break" from unstable to stable flow measurement is not obvious. Graphs from Station 111 (I-64 Eastbound Mainline) on Friday, September 10, 1999, are displayed in Figures 3 through 9 to provide an example of the larger set of graphs examined for all stations and days. The patterns and trends in these figures are representative of the results as a whole.

The second component of graphical testing involved examining the average absolute deviation from the "stable" flow rate (16-minute measurement interval) for each day at each station, by measurement interval. Most of the graphs demonstrated the same pattern as the samples provided in Figures 10 through 12. Although a slightly larger negative slope is generally apparent in the measurement interval range of 2 minutes to 6 minutes, one will note that overall, no discernable break point exists that separates stable from unstable measurement intervals. Finally, to summarize this element of the testing, Table 2 is presented that summarizes

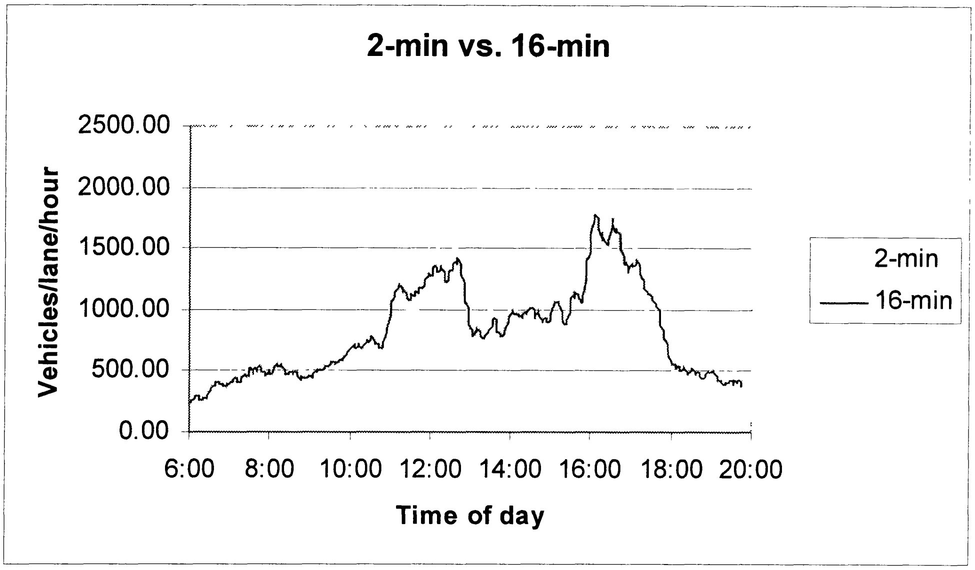

Figure 3. Two-Minute Flow Rates – Station 111, September 10, 1999

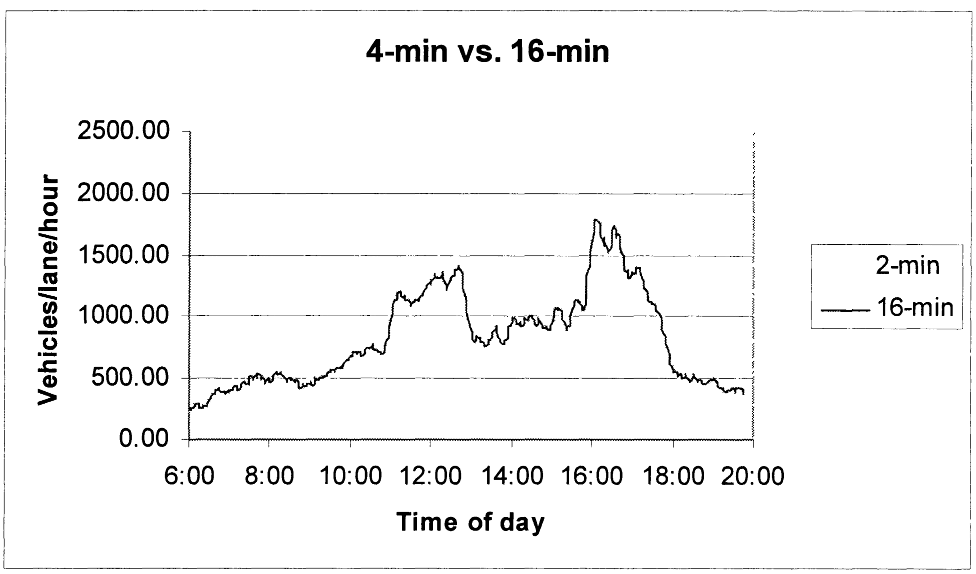

Figure 4. Four-Minute Flow Rates – Station 111, September 10, 1999

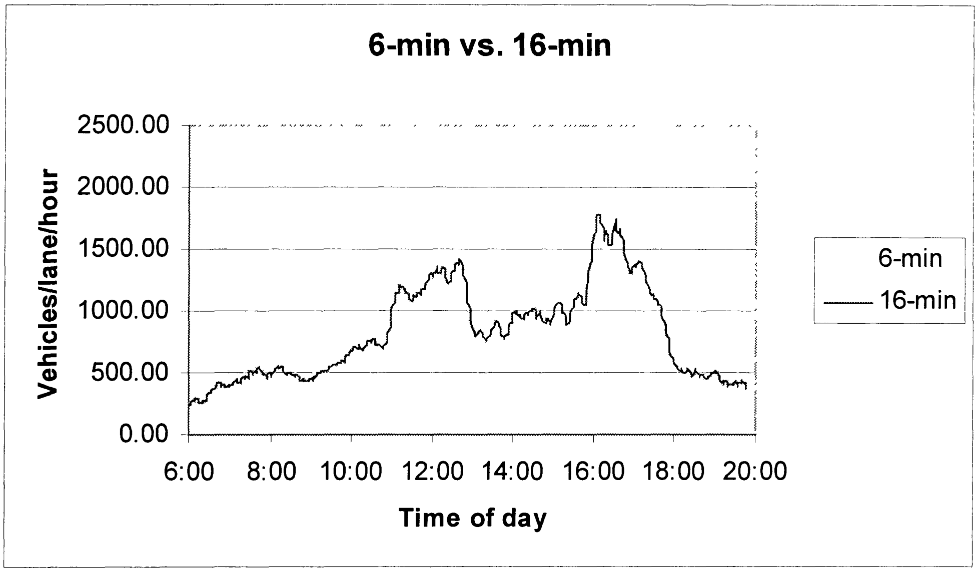

Figure 5. Six-Minute Flow Rates – Station 111, September 10, 1999

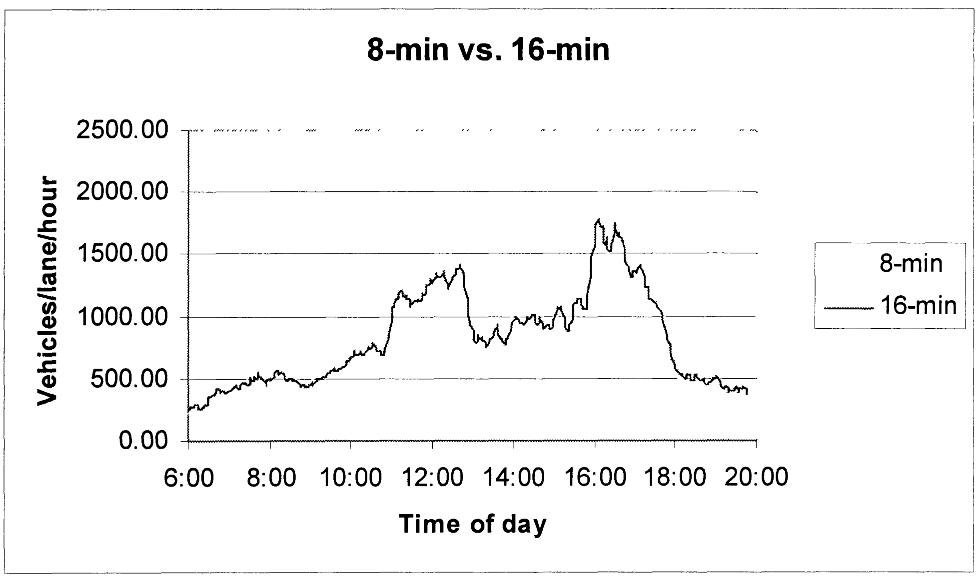

Figure 6. Eight-Minute Flow Rates – Station 111, September 10, 1999

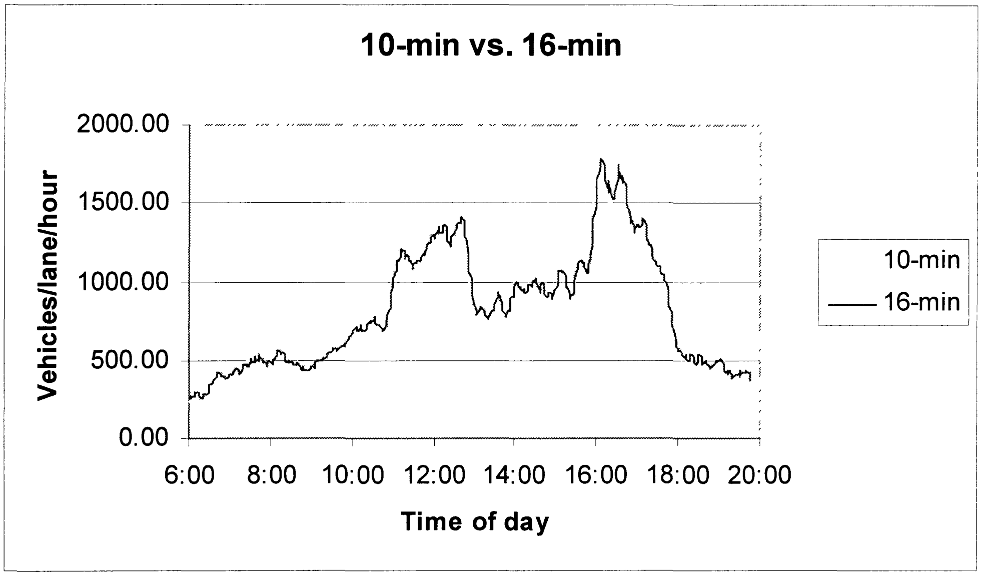

Figure 7. Ten-Minute Flow Rates – Station 111, September 10, 1999

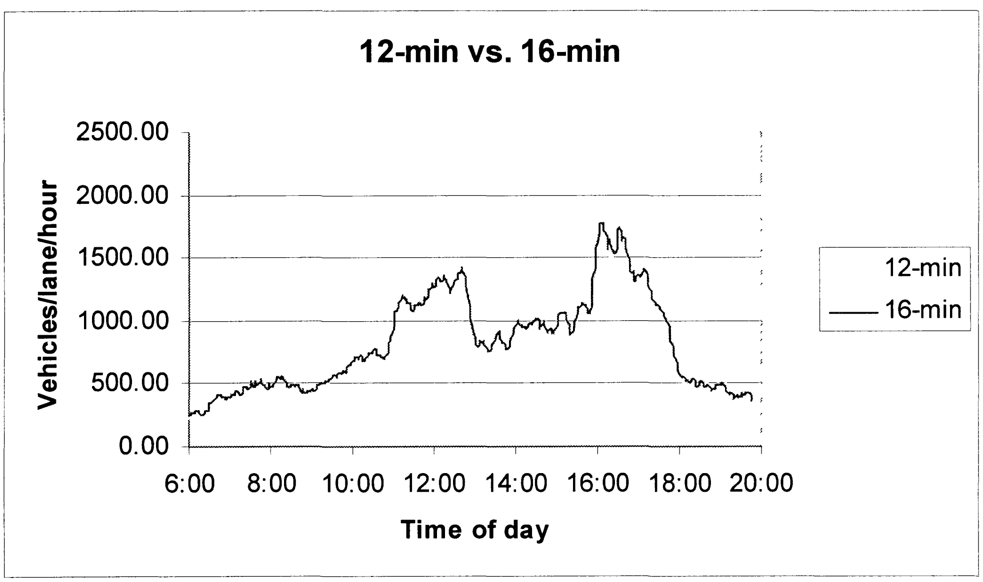

Figure 8. Twelve-Minute Flow Rates – Station 111, September 10, 1999

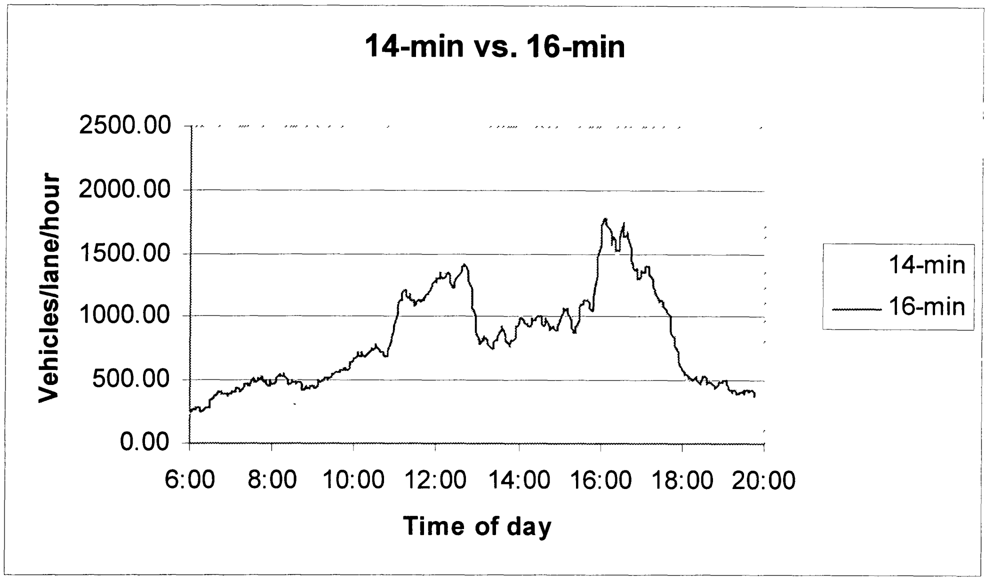

Figure 9. Fourteen-Minute Flow Rates – Station 111, September 10, 1999

Table 2. Average Absolute Deviation from Stable Flow Rate (vehicles/hour/lane)

Station	Measurement Interval						
	2 min	4 min	6 min	8 min	10 min	12 min	14 min
22	57.69	42.05	32.91	26.02	20.46	13.72	10.30
39	99.92	70.74	54.78	42.70	34.34	23.24	17.77
71	117.20	78.64	60.92	47.07	37.84	26.88	19.58
85	84.23	58.66	45.44	34.82	27.49	18.85	14.43
111	87.79	60.84	47.26	36.67	28.74	19.69	14.85
185	64.79	44.53	34.10	26.19	20.94	14.56	10.81
186	67.61	46.53	35.67	27.70	21.90	15.16	11.45

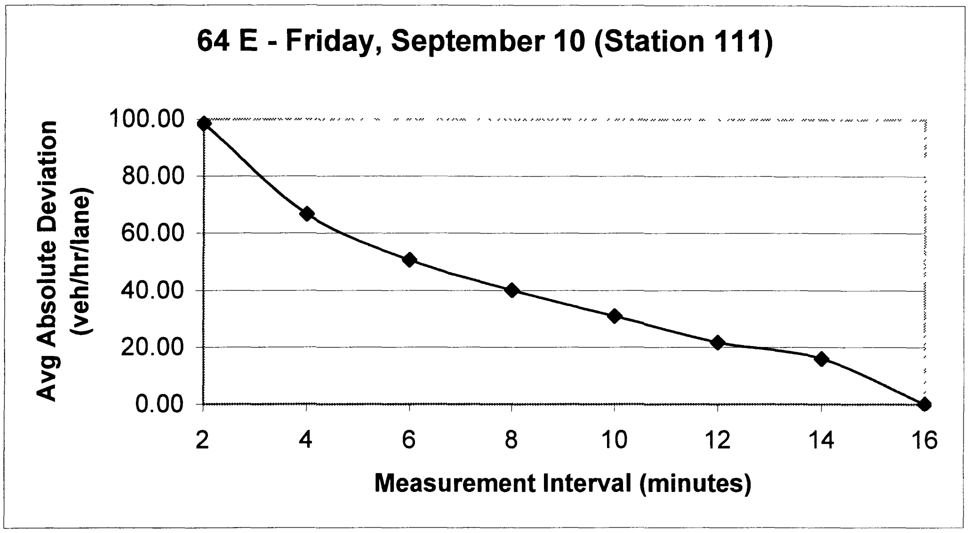

Figure 10. Average Absolute Deviation – Station 111, September 10, 1999

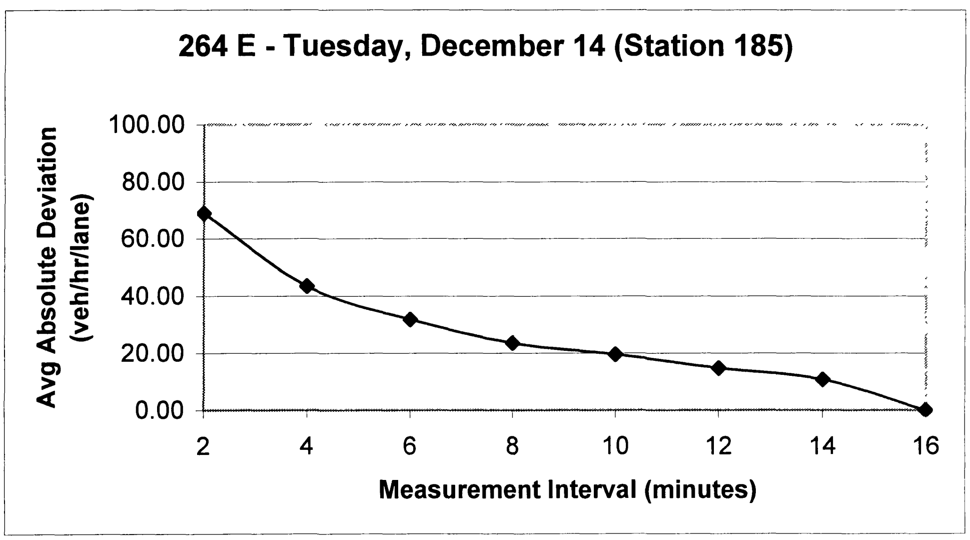

Figure 11. Average Absolute Deviation – Station 185, December 14, 1999

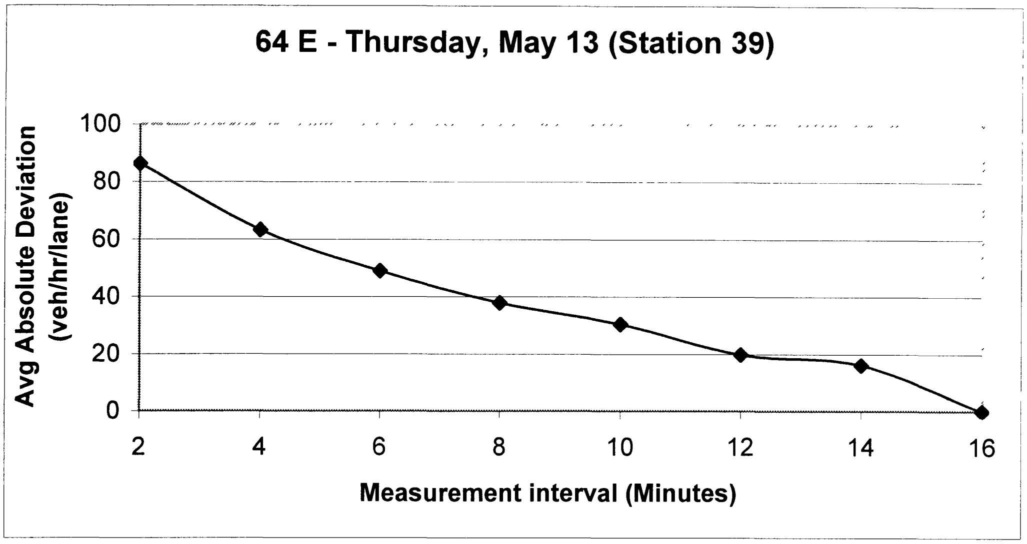

Figure 12. Average Absolute Deviation – Station 39, May 13, 2000

the average absolute deviation at each time interval average over all 10 days of data at each station.

Statistical Testing

The results of the first set of hypothesis tests, conducted to examine the stability of traffic flow rates at various measurement intervals, are presented in Table 3. For each station, the test statistic is presented as well as the conclusion concerning the null hypothesis, $\mu_I = 24$ vehicles/hour/lane. Recall that when the hypothesis is rejected, we can conclude that there is strong evidence to indicate that the mean absolute deviation between the flow rate at the 16-minute measurement interval (the "stable" signal) and the flow rate at the interval in question, I, is less than 24 vehicles/hour – meeting the assumed definition of stability. In other words, when the hypothesis is rejected, we can conclude that flow rate at measurement interval I is as stable as the rate measured at a 16-minute interval. Similarly, in the case that the hypothesis cannot be rejected, we conclude that flow rates at measurement interval I are not as stable as those measured at 16-minute intervals.

Table 3. Results of Stability Hypothesis Tests

	Measurement Time Interval (*I*)						
Station	**2**	**4**	**6**	**8**	**10**	**12**	**14**
22	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Reject	Reject	Reject
z score	13.76141	9.831949	6.003542	1.55976	-4.62066	-19.5606	-33.8998
39	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Reject
z score	19.18955	16.66763	13.94724	11.162	7.66822	-0.99763	-8.95928
71	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Reject
z score	20.37515	16.9159	14.61225	11.80537	8.764237	2.602843	-5.66064
85	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Reject	Reject
z score	18.40552	15.05586	11.95627	7.962381	2.923342	-7.71696	-16.6498
111	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Reject	Reject
z score	17.61467	13.91647	11.12451	8.062233	3.721384	-5.37565	-13.8611
185	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Reject	Reject	Reject
z score	16.37672	11.51588	7.460269	1.893672	-4.09769	-17.3489	-32.6642
186	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Reject	Reject	Reject
z score	16.64272	11.90849	8.036323	3.261272	-2.51244	-15.062	-27.553

Where: Fail to reject indicates instability compared to 16-minute interval

Reject indicates comparable stability to 16-minute interval.

Examining Table 3, one will note that at three of the seven stations, the flow rate becomes "stable" at a measurement interval of 10 minutes, at two of the seven stations, the flow rate becomes "stable" at a measurement interval of 12 minutes, and at the remaining two stations, the flow rate becomes "stable" at a measurement interval of 14 minutes. These results indicate that at relatively small measurement intervals (i.e., less than 10 minutes), there is significant noise in the flow rate "signal" resulting in unstable flow rate measures. Therefore, researchers and practitioners must exercise caution in using flow rates measured at intervals less than 10 minutes. However, the results also indicate that "stable" traffic flow rates may be measured at intervals less than the 15-minute interval suggested by the *HCM.* This finding is significant in that it may allow applications such as capacity studies to use data at a higher temporal resolution than currently recommended.

Table 4 presents the results of the second set of hypothesis tests, designed to determine if a significant change in the "stability" of flow rate occurs between adjacent measurement intervals (i.e., between a 4-minute interval and a 6-minute interval). The results of these tests confirm the trends noted in Figures 10 through 13. In all cases, the null hypothesis was rejected, indicating that in every case lengthening the measurement interval by 2 minutes resulted in a significantly more stable flow rate. In other words, there is no discernable break point at which the measurement interval is no longer influential in flow rate stability. Rather, one can always increase stability significantly by increasing the measurement interval by 2 minutes.

Table 4. Results of "Adjacent" Measurement Intervals Hypothesis Tests

	Measurement Time Interval (*I*)						
Station	**2**	**4**	**6**	**8**	**10**	**12**	**14**
22	Reject	Reject	Reject	Reject	Reject	Reject	Reject
z score	5.073259	3.951426	3.850132	4.087445	6.620814	4.774623	24.62343
39	Reject	Reject	Reject	Reject	Reject	Reject	Reject
z score	5.969845	4.473333	4.38456	3.89282	6.841257	4.706535	25.36309
71	Reject	Reject	Reject	Reject	Reject	Reject	Reject
z score	6.897459	4.336866	4.353664	3.668493	5.722592	5.430717	24.70034
85	Reject	Reject	Reject	Reject	Reject	Reject	Reject
z score	6.319522	4.553489	4.789199	4.269646	6.605996	4.547256	24.35727
111	Reject	Reject	Reject	Reject	Reject	Reject	Reject
z score	5.982389	4.031274	4.064007	3.95135	6.031732	4.502243	22.40539
185	Reject	Reject	Reject	Reject	Reject	Reject	Reject
z score	6.566417	4.714592	4.747079	4.043815	6.496107	5.233722	26.2964
186	Reject	Reject	Reject	Reject	Reject	Reject	Reject
z score	6.446866	4.574631	4.406703	4.113058	6.276466	4.862686	24.7883

Where:

Fail to reject indicates no significant difference in stability between this measurement interval and the adjacent "longer" interval, $I + 2$ minutes

Reject indicates indicates a significant difference in stability between this measurement interval and the adjacent "longer" interval, $I + 2$ minutes.

CONCLUSIONS

The findings of this study indicate that, based on very conservative assumptions regarding the definition of stability, stable flow rates may be determined using measurement intervals shorter than the 15-minute interval suggested by the *HCM*. In some cases, stable flow rates were achieved using measurement intervals of 10 minutes. In addition, it was determined that there is not a clear breakpoint in measurement intervals in which the flow rate measure will become significantly more stable. It was determined that in all cases, increasing the measurement interval by 2 minutes resulted in more stable flow rates.

RECOMMENDATIONS

The results of this research support a number of recommendations for VDOT practice and for further research and analysis in the area of highway capacity. The following specific recommendations are presented to VDOT:

1. VDOT should use the longest measurement interval practical when measuring traffic flow rate in order to facilitate stability in the measure.

2. When measuring traffic flow rate on urban freeways, VDOT should use a minimum of 10-minute intervals when using the values for internal analyses and the provision of public information.

3. VDOT should formally transmit this report to TRB for committee consideration as the next version of the *HCM* is developed.

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