Statistical Analysis of Day-to-Day Variations in Real-Time Traffic Flow Data

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In the absence of intelligent vehicle-highway system technologies, commuters tend to select their routes through a congested network primarily on the basis of expected average link travel times. For this average to be representative of the current day, it is essential that the traffic conditions be relatively similar each day. However, if the traffic conditions vary considerably from one day to the next, the historical information will be insufficient for commuters to find the optimum routes through the network, and the provision of real-time traffic information could provide major benefits. Furthermore, simulation is becoming an important tool in evaluating different traffic control strategies. As a result it has become more and more important not only that the average typical traffic conditions be established but also that the upper and lower bounds of these average conditions be estimated. Consequently, two related issues are examined: the spatial and temporal magnitude of the variability in traffic conditions during typical nonincident conditions, and the magnitude of this variability during incident conditions. It was shown that in the absence of incidents, the temporal and spatial variations in traffic conditions were very similar for weekdays but varied considerably relative to the typical conditions during weekends. Major incidents, however, were found to alter drastically the average recurring conditions, thus creating a window of opportunity for achieving travel benefits by using dynamic data in real time.

The main objective of most advanced traveler information systems (ATIS) is to provide drivers with accurate real-time information on traffic conditions. Drivers can select optimum routes to their intended destinations based on this information. Various studies have investigated the potential benefits of ATIS (*1,2*).

In general, the benefits of such ATIS have been shown to depend on the level of market penetration and on the relative accuracy of the information provided to the equipped vehicles when compared with the accuracy of the historical data available to nonequipped vehicles.

Furthermore, as simulation becomes an important evaluation tool, it is important that one calibrates these simulation models to the existing traffic conditions.

Therefore, various questions remain. For example, how large must typical day-to-day variations in weekday traffic conditions be before they provide a sufficient window of opportunity for benefits to be accrued through the provision of real-time data to equipped vehicles? By how much do traffic conditions typically vary from day to day? By how much do incidents increase the window of opportunity for achieving benefits through the provision of real-time data?

This paper attempts to address most of these questions through a qulitative and quantitative analysis of 75 days of freeway management center (FMC) data along Interstate 4 in Orlando, Florida. The specific objectives of this paper are twofold: to investigate the variability in traffic conditions during (*a*) typical nonincident conditions and (*b*) incident conditions.

It is anticipated that the findings will be of assistance to both intelligent vehicle-highway system (IVHS) designers and to those who simulate such systems, as they will be able to perform their analysis based on tangible traffic network statistics rather than on hypothetical ones.

BACKGROUND

As part of the Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE), static prediction models were developed that could be applied to a series of traffic flow data: travel time, volume, and occupancy (*3*). In their model, Shbaklo et al. studied the effect of link type, time of day, day of week, and season on the flow and occupancy measurements for arterial and freeway links. This work was an extension of previous work on travel time analysis on links (*4*).

Shbaklo et al. (*3*), using 5-min loop detector data, for 72 days conducted analysis of variance (ANOVA) tests on freeway data in Chicago. They found the season to be an insignificant factor and the day of the week (2.5 to 9.7 percent of squared error) and time period (50 to 77 percent of squared error) to be significant factors on the flow and occupancy measurements. In their analysis, Shbaklo *et al.* did not examine whether Fridays or Mondays were statistically different from midweek days (Tuesdays, Wednesdays and Thursdays). Furthermore, they did not study the effect of incidents on these typical traffic conditions.

In this paper, the work conducted by Shbaklo *et al.* is extended to investigate variability within weekdays, spatial variability, and the effect of incidents on typical traffic conditions. Furthermore, the temporal and spatial variability in flow, speed, and occupancy measurements about a typical average temporal and spatial surface is investigated in an attempt to estimate statistical bounds to identify a typical weekday traffic conditions.

STUDY DESCRIPTION

Network Configuration

A 16-km (10-mile) portion of the I-4 freeway in Orlando, Florida, was considered in this study. I-4 is a major route that travels across the center of Florida from the southwest (Tampa) to the northeast (Daytona), passing by Disney World. The detectorized portion of the I-4 freeway is located near downtown Orlando, extending from 33rd Street to the southwest and ending downstream of Maitland Boulevard to the northeast.

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Twenty-four loop detector stations along I-4 were numbered from 1 to 25, with no data being provided for Station 10. The spacing of the detector stations ranged from approximately 0.40 to 0.90 km (0.25 to 0.54 mil). There were no major terrain variations along the detectorized section of the I-4 freeway, as Orlando is rather flat. However, at many interchanges with arterials, the freeway was elevated. The entire detectorized section of I-4 was composed of three lanes in each direction.

Data Collection Time Frame

The analysis period included traffic data for portions of 4 months during the winter of 1992–1993. The data included 11 days in November 1992, 29 days in January 1993, 26 days in February 1993, and 11 days in March 1993. This amounted to 75 days of 30-sec data, yielding approximately 10 days of data for each day of the week.

The FMC dual loop detectors measured and logged the flow, occupancy, and space-mean speed for each of the three lanes at 30-sec intervals. These data were aggregated into 5-min data summaries in order to reduce the level of data to be processed while still capturing most of the trends in the varying traffic conditions. Average lane flow, occupancy, and space-mean speed estimates were generated from the individual loop detector measurements for each station. In estimating the average lane speed at a specific station, loop speeds were weighted by the volume on each set of dual loops.

INITIAL ANALYSIS OF FMC DATA

An analysis of the FMC traffic data is presented in order to assess the variability in traffic conditions within weekdays. Subsequently, different weekdays are compared and the effect of incidents on the average typical traffic conditions is assessed. The analysis in this paper defines Saturdays and Sundays to constitute weekend days.

Generation of Typical Weekday Surfaces

Using the FMC data available during the 4-month period, it was possible to generate a surface that represented the average for all the days at a particular station of all the speed, flow, and occupancy measurements at a particular time of day. Equations 1 and 2 demonstrate how an estimate of each observation for the flow and occupancy was generated. In the case of the speed surface, a volume-weighted average was used. Core weekdays were considered to be Tuesday through Thursday, as it was initially not clear if Mondays or Fridays would be consistently similar to Tuesdays, Wednesdays, and Thursdays. There were 33 pure core weekdays during the analysis period. These core weekdays were checked for any abnormal traffic conditions such as vehicle detector failures (indicated as -1) or major incidents, as indicated in the incident data base that was provided by the FMC. The suspected days were removed from the estimated average.

The selection process resulted in 22 weekdays being considered in developing the average eastbound weekdays surfaces ($nd = 22$). The entire 33 weekday were used to generate the average westbound weekday surfaces ($nd = 33$). The resulting average flow surface for the eastbound direction only is presented in Figure 1; the results for the westbound direction were very similar.

$$x_{i,j}^{n} = \sum_{k=1}^{10} x_{i,j,k}^{n} \qquad \forall x_{i,j,k}^{n} \geq 0 \tag{1}$$

$$\bar{x}_{i,j} = \frac{\sum_{n=1}^{nd} x_{i,j}^{n}}{n\text{day}} \qquad \forall x_{i,j}^{n} \geq 0 \tag{2}$$

where

nd = total number of nonincident weekdays;
$n$day = number of good observations ($x_{i,j}^{n} \geq 0$);
$x_{i,j,k}^{n}$ = 30-sec observation on day n at station i, at 5-min time interval j, at 30-sec period k during 5-min interval;
$x_{i,j}^{n}$ = 5-min observation on day n at station i at time interval j; and
$\bar{x}_{i,j}$ = average weekday 5-min observation at station i at time interval j (flow or occupancy; speed was generated as a volume-weighted average).

The typical average spatial and temporal flow variation in the eastbound direction for an entire 24-hr period along the detectorized

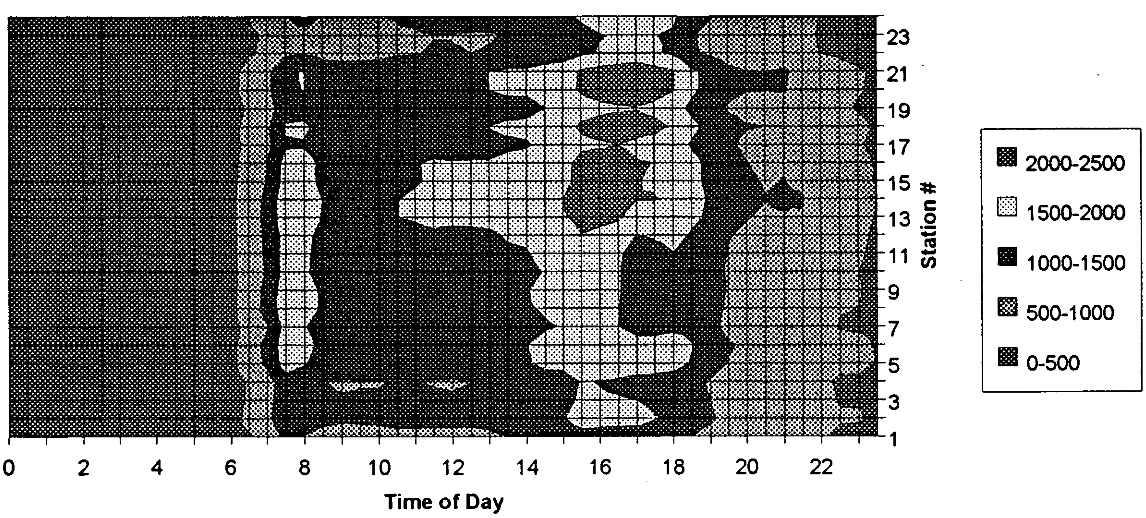

FIGURE 1 Spatial and temporal eastbound flow variation for average weekday [vehicles per hour (vph)].

I-4 section is presented in Figure 1. The x-axis represents the time of day, which ranges from 0 at midnight at the start of the day to 24 at midnight at the conclusion of the day, whereas the y-axis represents the station numbers traversed. The eastbound flow proceeds in the upward direction from Station 1 to Station 25. For each cell combination of time of day and station, the z-axis represents the average hourly lane flow measured.

It can be noted from Figure 1 that the flow increased gradually at 6:00 a.m. along all stations until it reached approximately 2,000 vehicles per hour per lane (vphpl) at 7:30 a.m. along most of the detector stations. The flow increased again during the p.m. peak at approximately 3:00 until 6:30 p.m. at Stations 12 through 22. It appears from Figure 1 that the flow from 5:00 to 7:00 p.m. at Stations 7 through 12 was lower (1,000 to 1,500 vphp). However, after examining Figure 2, it appears that the speed was also low, ranging from 20 to 40 km/hr. Thus the lower flow measurements were most likely due to the presence of congestion rather than to a reduction in demand. It appears from Figures 1 and 2 that a strict analysis of flow contours can be deceiving, as it is not clear whether a reduction in flow is caused by congestion or by a simple reduction in demand.

Single-Factor ANOVA of Weekday Data

To investigate whether the variability in traffic conditions between the different days of the core of the week (Tuesday, Wednesday, and Thursday) was statistically significant, a single-factor ANOVA was conducted using the SYSTAT model (*5*). The ANOVA tested if the root mean square error (*RMSE*) associated with the different day surfaces about the typical average weekday surface was greater than the variation within the samples for each specific day of the week using Equation 3. Table 1 presents the ANOVA results for flow variations in the eastbound direction. These results, based on the 22 observations, indicate that the different days were not found to be statistically different at a level of significance of 95 percent. Similar results were obtained when comparing the speed as well as occupancy in the eastbound direction, as indicated in Table 1. Consequently, the observations in the eastbound direction for Tuesdays, Wednesdays, and Thursdays were grouped together as weekdays.

$$RMSE = \sqrt{\frac{\sum_i \sum_j (x_{i,j}^n - \bar{x}_{i,j})^2}{n\text{obs}}} \qquad \forall x_{i,j}^n, \bar{x}_{i,j} \geq 0 \tag{3}$$

where $n$obs is the number of good observations $(x_{i,j}^n, \bar{x}_{i,j} \geq 0)$.

A similar single-factor ANOVA on the different weekdays in the westbound direction was conducted as presented in Table 1. Again, the ANOVA results demonstrated that there was no statistical difference between the observations for Tuesdays, Wednesdays, and Thursdays at the 95 percent confidence level. Consequently, the data for these days were grouped together as core weekdays.

In order to examine the ANOVA assumption of homogeneity of variance, the variation in residuals as a function of the estimated values (day mean) is plotted in Figure 3. The Studentized residuals were used because it is convenient to reference them against a t distribution. In Figure 3 the residuals for the typical weekdays were all within two standard deviations. It appears from Figure 3 that the residuals are homogeneous as there appears to be no trend to the residuals. Similar trends were found for the residual plots generated for the eastbound speed and occupancy surfaces. Similar trends were also found for the westbound flow, speed, and occupancy surfaces but because of limited space are not presented here.

COMPARISON OF MEAN SURFACES

A typical average core weekday was compared with a typical Monday, a typical Friday, a typical Saturday, and a typical Sunday to determine if the traffic conditions are qualitatively and statistically different. An incident scenario is also compared with the typical average weekday conditions in order to demonstrate qualitatively the relative difference in flow conditions from one day to the next, versus an incident day to a nonincident day.

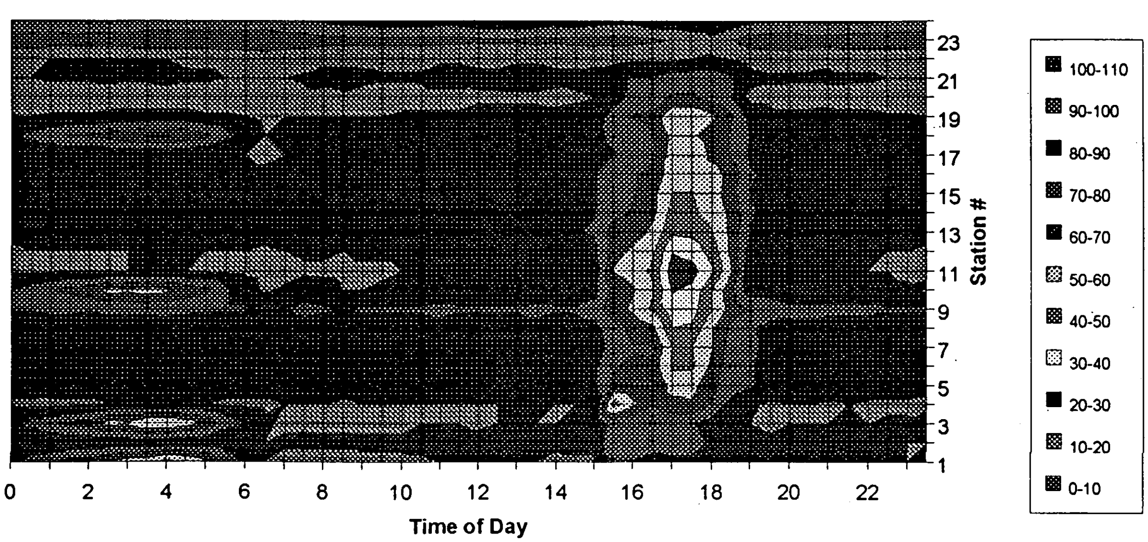

FIGURE 2 Spatial and temporal eastbound speed variation for average weekday (km/hr).

TABLE 1 Single-Factor ANOVA Results

Description	ANOVA groups	DF (within groups)	DF (total)	F	F_{crit}	Sig (95%)
	Tue. vs. Wed. vs. Thur.	19	21	1.16	3.52	No
	weekday vs. Mon.	29	30	5.32	4.18	Yes
Flow (EB)	weekday vs. Fri.	30	31	101.87	4.17	Yes
	weekday vs. Sat.	30	31	682.84	4.17	Yes
	weekday vs. Sun.	32	33	384.79	4.15	Yes
	Tue. vs. Wed. vs. Thur.	19	21	2.76	3.52	No
	weekday vs. Mon.	29	30	2.40	4.18	No
Speed (EB)	weekday vs. Fri.	30	31	101.87	4.17	Yes
	weekday vs. Sat.	30	31	682.84	4.17	Yes
	weekday vs. Sun.	32	33	384.79	4.15	Yes
	Tue. vs. Wed. vs. Thur.	19	21	1.88	3.52	No
	weekday vs. Mon.	29	30	1.20	4.18	No
Occ. (EB)	weekday vs. Fri.	30	31	17.13	4.17	Yes
	weekday vs. Sat.	30	31	16.01	4.17	Yes
	weekday vs. Sun.	32	33	47.25	4.15	Yes
	Tue. vs. Wed. vs. Thur.	30	32	0.85	3.32	No
	weekday vs. Mon.	41	42	7.03	4.08	Yes
Flow (WB)	weekday vs. Fri.	41	42	66.39	4.07	Yes
	weekday vs. Sat.	41	42	1678.67	4.08	Yes
	weekday vs. Sun.	43	44	1668.55	4.07	Yes
	Tue. vs. Wed. vs. Thur.	30	32	0.55	3.32	No
	weekday vs. Mon.	41	42	0.11	4.08	No
Speed (WB)	weekday vs. Fri.	41	42	12.15	4.07	Yes
	weekday vs. Sat.	41	42	22.34	4.08	Yes
	weekday vs. Sun.	43	44	23.54	4.07	Yes
	Tue. vs. Wed. vs. Thur.	30	32	0.62	3.32	No
	weekday vs. Mon.	41	42	0.30	4.08	No
Occ. (WB)	weekday vs. Fri.	41	42	15.98	4.07	Yes
	weekday vs. Sat.	41	42	113.03	4.08	Yes
	weekday vs. Sun.	43	44	208.02	4.07	Yes

Average Monday Surface

The average Monday flow, speed, and occupancy eastbound and westbound surfaces were generated in a similar fashion to the average core weekday surfaces. The eastbound average Monday surfaces were estimated by averaging over 9 Mondays, and the westbound average surfaces were estimated by averaging over 10 days.

The average Monday flow surface was found to be quite similar to the core weekday surface, and thus a typical Monday may qualitatively be considered to be similar to a core weekday. The same trends were found in comparing the occupancy and speed

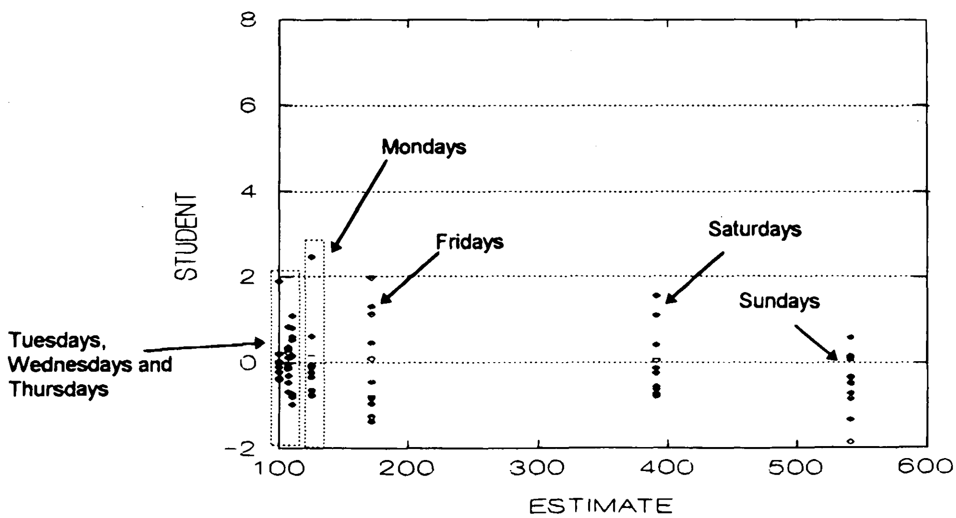

FIGURE 3 Variation in residual error as a function of *RMSE* estimate for eastbound flows.

surfaces. However, the limited space in this paper prevents their inclusion.

To verify quantitatively the similarity or variability between the Monday traffic conditions and the typical core weekday conditions, a single-factor ANOVA was conducted. The results of the ANOVA for the eastbound direction, presented in Table 1, demonstrate that the Monday flow conditions were statistically different from the typical weekday conditions at the 95 percent confidence level. However, the speed and occupancy measurements were not statistically different from the typical core weekday measurements (at the 95 percent confidence level), as given in Table 1. The same trend of results was obtained in conducting an ANOVA for the westbound direction, as indicated in Table 1.

It appears that Mondays are different from core weekdays in terms of flow but not in terms of speed or occupancy. Mondays therefore were not included in the data sample to create an average core weekday. These results were found to be consistent with the homogeneity assumption of ANOVA as illustrated by the residuals in Figure 3.

Average Friday Surface

The eastbound and westbound average Friday flow, speed, and occupancy surfaces were generated by averaging over 10 Fridays. By comparing the weekday and Friday surfaces, it was found that the p.m. peak on Friday started earlier (11:00 a.m. versus 12:00 p.m.) and extended over an extra hour (until 8:00 p.m. versus 7:00 p.m.).

The statistical results were found to verify the preceding qualitative comparison, as given in Table 1. Specifically, the ANOVA results for the eastbound direction indicated that the flows, speeds, and occupancies on a typical Friday were statistically different from the traffic conditions of typical core weekdays at the 95 percent confidence level. The results for the westbound direction were similar, as indicated in Table 1. These results, again, were found to be consistent with the homogeneity assumption of ANOVA, as illustrated by the residuals in Figure 3.

Average Saturday Surface

The eastbound and westbound average Saturday flow, speed, and occupancy surfaces were generated by averaging over 10 Saturdays; the plots are not presented because of the limited space in this paper. For the average Saturday flow surface, the traffic flows increased gradually from 7:00 a.m. until they reached a maximum flow of approximately 1,800 vphpl at noon at Station 15. The flow characteristics for a typical Saturday were very different from the traffic characteristics of a typical core weekday, as might be expected. The ANOVA results for the eastbound direction, presented in Table 1, demonstrate that the Saturday traffic conditions were statistically different from the typical weekday conditions. The results for the westbound direction, presented in Table 1, also demonstrate this trend.

It is noteworthy that in terms of eastbound flow and speed, Saturdays were much more distinct from core weekdays than Fridays. However, in terms of occupancy, Saturdays were different from core weekdays by only as much as were Fridays. In the westbound direction, flow and occupancy were much different, but speeds were not quite so different. These results, again, were found to be consistent with the homogeneity assumption of ANOVA as illustrated by the residuals in Figure 3.

Average Sunday Surface

An ANOVA of the eastbound Sunday traffic conditions and the weekday conditions, presented in Table 1, demonstrates that traffic conditions on Sundays were also statistically different from typical weekday conditions. Similar results were found for the westbound direction, as given in Table 1. As for Saturdays, the results presented in these tables indicate that the flow and speed on a typical Sunday were very different from a typical core weekday for the eastbound direction. The flow and occupancy in the westbound direction were also very different from the core weekday. These results, again, were found to be consistent with the homogeneity assumption of ANOVA as illustrated by the residuals in Figure 3. However, there appeared to be an outlier point, as illustrated in Figure 3.

Incident Effects

During the analysis of the core weekday data, a severe incident that resulted in the total closure of the eastbound direction of I-4 occurred on Thursday, November 5, 1992, as illustrated by the speed surface plot presented in Figure 4. The incident started at approximately 3:20 p.m. and lasted until approximately 5:00 p.m. The incident site was located between Stations 9 and 11 at Robinson Street, as indicated by the stationary frontal shock wave.

Following the clearance of the incident it can be noted in Figure 4 that the traffic proceeded downstream as a continuous platoon, and thus one can observe a surge of low speeds proceeding downstream up to Station 21. The forward-forming shock wave appears to be sloped steeply because the vehicles proceeded to Station 21 within one 5-min analysis period. This incident resulted in a queue that extended as far back as Station 1.

Note that a vehicle entering the system at 6:00 p.m. would experience delay at a location downstream of the incident at a point sometime after the incident was actually cleared.

Summary

In summary, based on statistical comparison of the traffic conditions for various days, the following conclusions can be made:

- Traffic flow conditions within core weekdays appear to be highly similar and consistent.
- Some traffic flow parameters on Mondays are similar to traffic conditions on core weekdays (Tuesday, Wednesday, and Thursday).
- Traffic conditions on Fridays differ from core weekday conditions in each of the three measures. Specifically, it appears that the p.m. peak on Fridays extends further in the day.
- Traffic conditions on weekends differ from traffic conditions on weekdays, and Saturdays differ in flow from Sundays.
- Major incidents can cause significant disruptions to typical weekday traffic conditions.

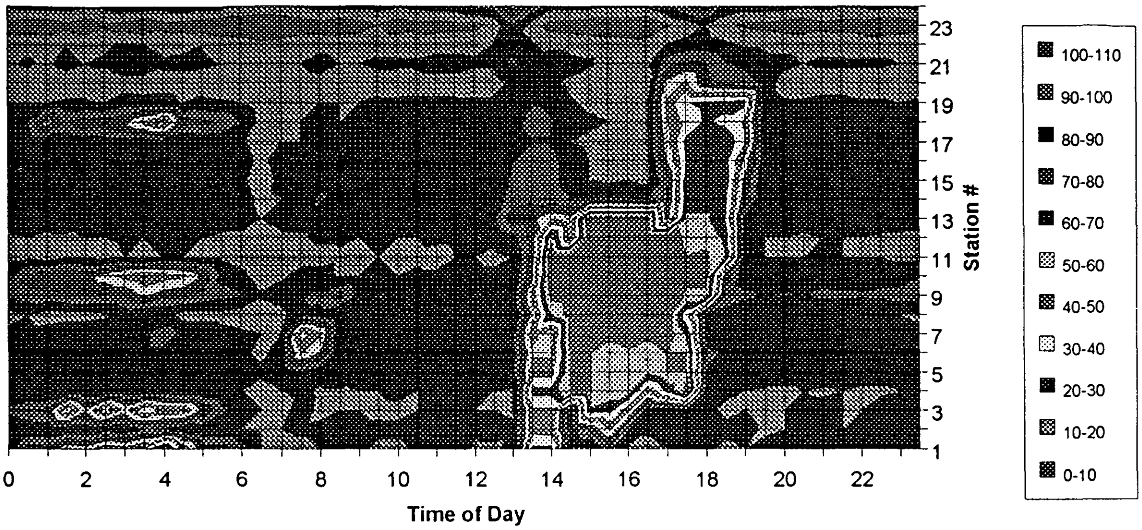

FIGURE 4 Spatial and temporal eastbound speed variation during an incident (km/hr).

OVERALL COMPARISON OF TRAFFIC CONDITIONS

The traffic conditions for each day were compared with the average weekday flow, speed, and occupancy surfaces. Two measures of comparison were estimated. The first was an estimate of the coefficient of determination (R^2) and will be labeled the regression measure. The second measure was an estimate of the number of observations within two standard deviations of the average weekday observation, assuming a normal distribution, and will be labeled the success measure. The findings for each of these measures are discussed in this section.

Regression Measure

A regression measure similar to R^2 was used to compare the traffic conditions for each day. For each day, three matrices of flow, speed, and occupancy observations were generated. These matrices were 288 rows (number of 5-min intervals in the day) by 24 columns (number of loop detector stations). A separate overall mean for the average weekday flow, speed, and occupancy measurements was also estimated, as demonstrated in Equation 4 (mean over all stations and all time periods $\bar{x}$).

For each of these surfaces, the squared error about the average core weekday surface was estimated as the difference for each station and time-of-day combination from the average core weekday surface using Equation 5 (sum of squared errors about the average surface S_1). The sum of squared errors for the flow, speed, and occupancy measurements of each day about their respective overall means was also estimated using Equation 6 (S_t). The sum of squared error, explained by each of the flow, speed, and occupancy average weekday surfaces, S_2, was estimated as the difference between S_t and S_1 using Equation 7. The R^2 measure for each of the three surfaces for each day was calculated as the ratio of S_2 to S_t (S_2/S_t). Thus, R^2 was a measure of the amount of error captured by the average weekday surface. An R^2 of 1 would mean that the average surface explained 100 percent of the squared error, whereas an R^2 of 0 would mean that the average surface did not explain any of the error.

$$\bar{x} = \frac{\sum_{i=1}^{24}\sum_{j=1}^{288}\bar{x}_{i,j}}{nobs} \qquad \forall \bar{x}_{i,j} \geq 0 \tag{4}$$

$$S_1 = \sum_{i=1}^{24}\sum_{j=1}^{288}(x_{i,j}^n - \bar{x}_{i,j})^2 \qquad \forall x_{i,j}^n, \bar{x}_{i,j} \geq 0 \tag{5}$$

$$S_t = \sum_{i=1}^{24}\sum_{j=1}^{288}(x_{i,j}^n - \bar{x})^2 \qquad \forall x_{i,j}^n \geq 0 \tag{6}$$

$$S_t = S_1 + S_2 \tag{7}$$

where

- $nobs$ = number of good observations ($\bar{x}_{i,j} \geq 0$; maximum = 6, 912),
- x = overall average observation (flow, speed, and occupancy),
- S_t = total sum of squared errors about overall mean (flow, speed, and occupancy),
- S_1 = sum of squared errors about average surfaces (flow, speed, and occupancy), and
- S_2 = sum of squared errors explained by average surface (flow, speed, and occupancy).

The variation of R^2 over the 75-day analysis period from the average core weekday flow surface in the eastbound direction is presented in Figure 5. It appears that the R^2 for weekdays exceeded 90 percent and that an R^2 of 30 percent was estimated for the major incident day (November 5, 1992: Day 24). This low R^2 indicated that this incident had a substantial effect on the average traffic conditions. Mondays also had a relatively high R^2 (exceeded 90 percent), except for a Monday that had an incident in addition to a failure in some loop detectors. Fridays had a lower R^2, ranging from 75 to 90 percent. The Saturday and Sunday flow surfaces differed considerably from the weekday average surface (R^2 from 0 to 60 percent). The same trend was found for the westbound direction, but because of limited space, the results are not presented here.

The variation from the average weekday speed surface in the eastbound direction in R^2 during the 75-day analysis period was also analyzed but is not presented because of lack of space. Unlike the flow surface comparisons in Figure 5, the speed variation appeared to be much more scattered. The scatter in the speed variation was probably the result of shock waves proceeding along the detectorized section at different rates, even though the overall flow remained very similar. Interestingly, the major incident did not result in an R^2 worse than nonincident weekdays (Day 24).

The variation, from the average weekday occupancy surface in the eastbound direction, in R^2 during the 75-day analysis period was less scattered than the speed variation. Specifically, the R^2 ranged from 65 to 95 percent for the core weekdays, 45 to 90 percent for Mondays, 60 to 90 percent for Fridays, and 0 percent for Saturdays and Sundays. As was the case for the flow, the R^2 for the major incident day (Day 24) was much lower than the typical weekday R^2 (38 percent).

Success Measure

The original loop detector measurements, which were made at thirty 30-sec intervals, were aggregated into 5-min observations for purposes of analysis. Each 5-min observation was the sum of 10 measurements. Using the central limit theorem, it can be assumed that each of these 5-min observations may become distributed normally because the 5-min observation on one day should not be correlated with the same observation on another day. To verify this assumption, a 5-min estimate of flow for the 22 core days in the eastbound direction were estimated and stratified into bins. The observed probabilities were then tested using a chi-square goodness-of-fit test in order to establish whether the normal distribution assumption was valid, as illustrated in Figure 6. The chi-square type of analysis showed that the observed 5-min flows were not statistically different from the expected outcome of a normal distribution at the 95 percent confidence level. The test was repeated for higher average flows in the range of 1,800 vphpl, and similar results were found. Tests conducted for speed and occupancy 5-min observations had similar outcomes. Thus, it appears that the normal distribution assumption is valid.

The three average weekday surfaces were obtained by averaging each cell of the matrix over the nonincident weekdays using Equations 1 and 2. For each cell of these matrices, the standard deviation of the mean observation was estimated using Equation 8 and upper and lower bounds were estimated assuming a normal distribution using Equations 9 and 10, respectively. The proportion of similar observations was estimated as the ratio of observations within the upper and lower bounds to the total number of good observations using Equation 11. An average proportion of cells within the average weekday confidence limits subsequently was estimated for the weekdays using Equation 12. Using this proportion of successful observations, a lower confidence limit was estimated using Equation 13 (*6*):

$$\sigma_{i,j} = \sqrt{\frac{\sum_{n=1}^{nd} (\bar{x}_{i,j} - x_{i,j}^{n})^2}{(n\text{day} - 1)}} \qquad \forall \bar{x}_{i,j}, x_{i,j}^{n} \geq 0 \tag{8}$$

$$x_{i,j}^{u} = \bar{x}_{i,j} + 1.96 \times \sigma_{i,j} \qquad \forall \bar{x}_{i,j} \geq 0 \tag{9}$$

$$x_{i,j}^{l} = \bar{x}_{i,j} - 1.96 \times \sigma_{i,j} \qquad \forall \bar{x}_{i,j} \geq 0 \tag{10}$$

$$p^{n} = \frac{n_0^{n}}{n^{n}} \tag{11}$$

$$\bar{p} = \frac{\sum p^{n}}{nd} \tag{12}$$

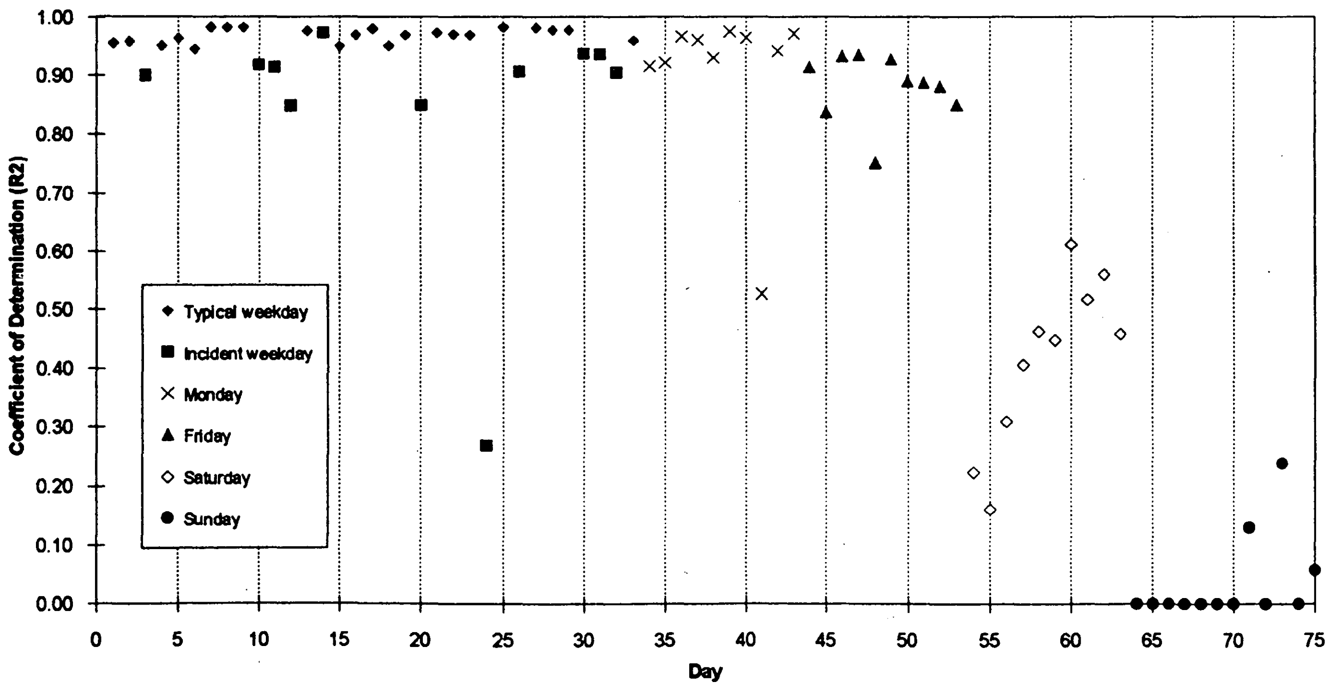

FIGURE 5 R^2 variation for eastbound flow.

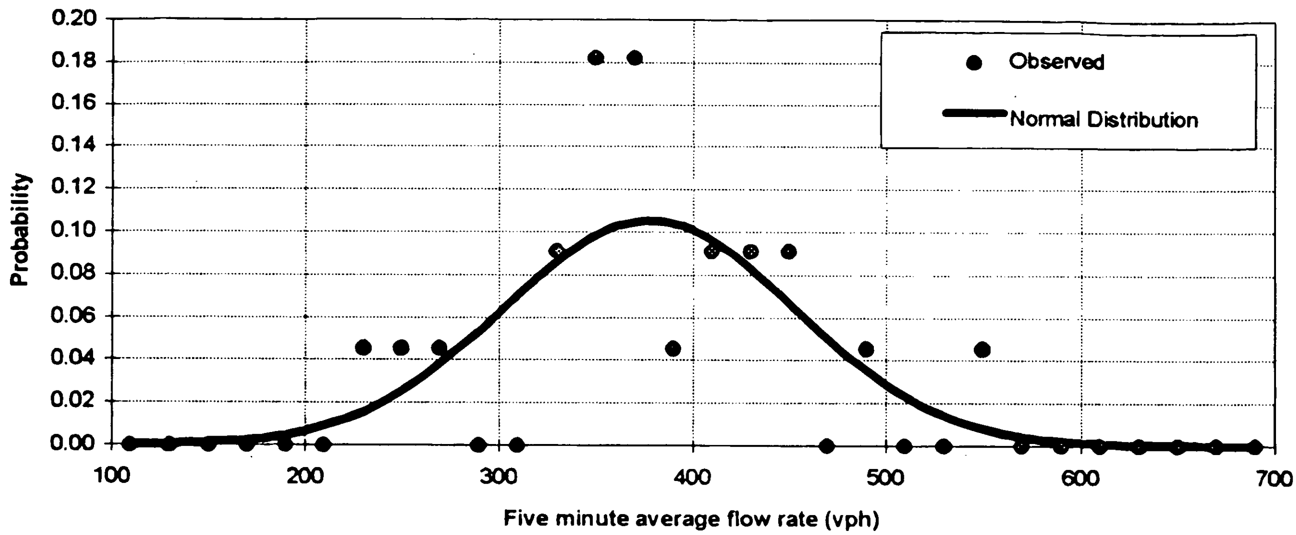

FIGURE 6 Observed and normal distribution 5-min flow rate estimates for 22 weekdays.

$$p^l = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{nobs}} \quad (13)$$

where

- $nobs = 24 \times 288 = 6{,}912$,
- $\sigma_{i,j}$ = standard deviation of 5-min observation distribution at station i at time interval j,
- $x^u_{i,j}$ = upper 95 percent confidence limit of 5-min observation at station i at time interval j,
- $x^l_{i,j}$ = lower 95 percent confidence limit of 5-min observation at station i at time interval j,
- n^n_o = number of observations for day n within confidence limits of average weekday surface,
- n^n = number of good observations for day n (observation ≥ 0),
- p^n = proportion of observations for day n within confidence limits of average weekday surface,
- $\bar{p}$ = average weekday proportion of observations within confidence limits, and
- p^l = lower bound of proportion of observations within confidence limits.

Figure 7 illustrates how flow p^n varied for the different days of the analysis period in the eastbound direction. It appears that most of the nonincident weekdays were within the confidence limit (16 of 22 observations). The high number of observations outside the range occurred because the number of good observations (nonnegative) for these extreme nonincident weekdays was less than *n*obs (used in estimating the confidence limits), and thus the lower confidence limit should have decreased to reflect the smaller number of observations. However, this was not done. The major incident (Day 24) did not have a major influence on p^n, which was 78 percent, indicating that traffic conditions were similar, based on this index, to typical core weekday conditions before and after the effects of the incident were removed. This high p^n resulted because this measure is not affected by how much the observation is outside the confidence limits, and thus the fact that the incident had an extreme effect on traffic flow was not reflected. It is important to note that except for a single incident day, all the incident days fell outside the preceding confidence range.

The Monday flows appeared to be near the borderline of the weekday flows (20 percent of the observations fell within the confidence range). Fridays differed from the weekday conditions, and so did Saturdays and Sundays (0 percent of the days fell within the confidence range). The westbound direction experienced a similar trend in variation of the flow p^n.

Summary

Two methods for distinguishing typical traffic conditions from atypical traffic conditions were investigated. The regression method, which uses the flow and occupancy surfaces, could distinguish typical from atypical weekday traffic conditions. However, the noise in the speed surface was too large to enable the identification of any systematic underlying variations. In the regression method it was not possible to determine any statistical confidence limits, which limits the practical usage of the method.

The success measure of the flow had the advantage of yielding confidence limits in order to distinguish statistically between significant and insignificant variations from the typical traffic conditions. This method could be developed further as an on-line incident detection routine by decreasing the averaging process from 5 to 2 min and estimating a *p*-value on-line for each station. A value outside the confidence limits would indicate a suspicious observation, and a second *p*-value outside the confidence range could set off an alarm. Such an approach to incident detection differs from techniques that detect incidents on the basis of the traffic state at upstream and downstream detector stations (*7*) rather than the deviation of the current observation from some bounds based on time of day.

CONCLUSIONS AND RECOMMENDATIONS

The premise of most equilibrium traffic assignments is that drivers base route selection on the assumption that in the absence of incidents, temporal traffic patterns are very similar from one day to the

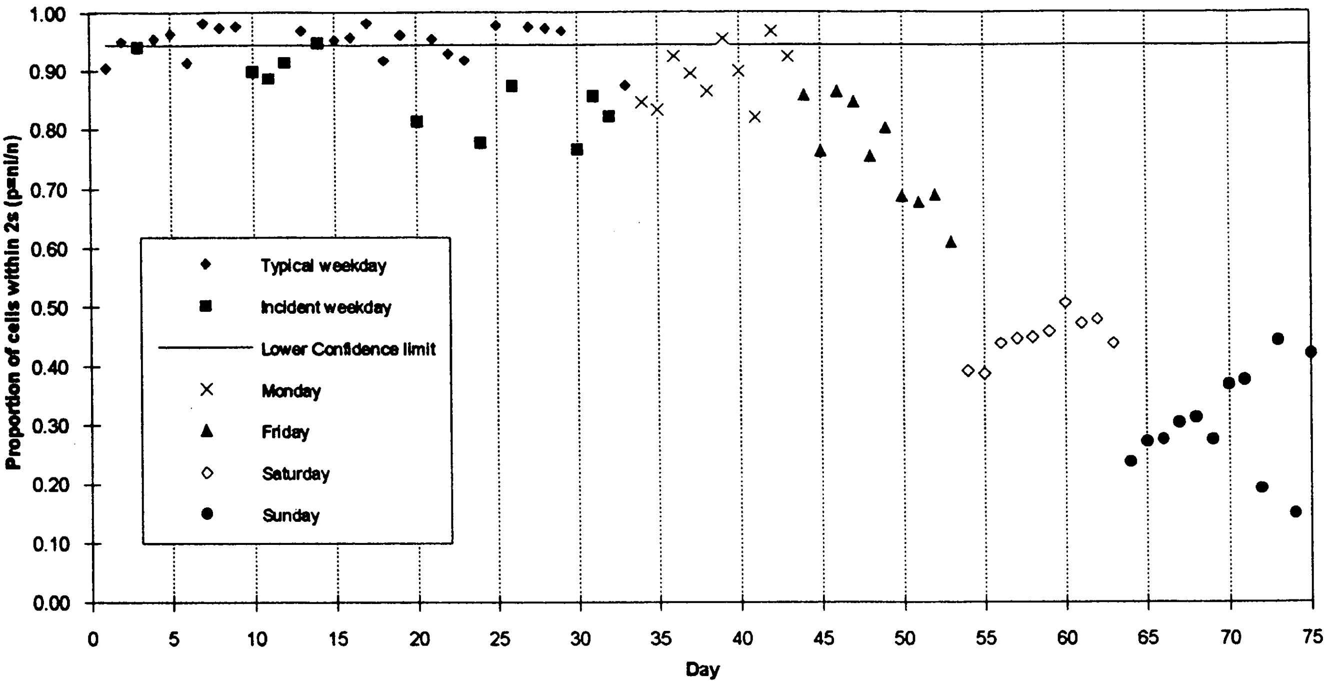

FIGURE 7 Variation of p for eastbound flow.

next. Many IVHS technologies attempt to explore the fact that even in the absence of incidents, traffic conditions on one day may be quite different from a similar previous day. This paper attempted to quantify these similarities and differences, both for incident and nonincident days.

It is recommended that the quantification of these similarities and differences be incorporated directly in any IVHS designs and benefit simulations. The present frequent use of hypothesized similarities or differences of day-to-day traffic may lead to designs or benefit estimates that are not consistent with the actual behavior of traffic. In this paper, such behavior has been quantified for at least one location, and a potential step toward a standardized procedure for analyzing others in a comparable fashion can be adopted.

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