EVALUATION OF WORK ZONE SPEED ADVISORY SYSTEM

Geza Pesti, Patrick T. McCoy, Mark D. Meisinger, and Vijayakumar Kannan

INTRODUCTION

Background

In recent years, numerous new and innovative technologies have been developed to make traffic operations through work zones safer and more efficient. Some of these technologies belong to the category of Advanced Traveler Information Systems (ATIS). Their main function is to disseminate travel-related information to drivers to enhance their decisions regarding the route they choose to take to their desired destination. The system can provide real-time information on travel times, travel speeds, delays, accidents, route closures and detours, and work zone conditions, among others (*2*). The information can be communicated through changeable message signs (CMS), highway advisory radio, Internet, or some other medium.

The effectiveness of CMSs in providing real-time information to drivers about traffic conditions in work zones has been studied in recent years by the University of Nebraska. (*1,3*). The research evaluated the effect of condition-responsive advisory speed messages on vehicle speeds in advance of work zones on a rural interstate highway.

The technology evaluated by this study is called Work Zone Speed Advisory System (WZSAS). The WZSAS is an enroute traveler information system whereby real-time speed advisory information is provided to drivers by means of portable changeable message signs strategically located in advance of diversion points upstream of a work zone. The objective of the WZSAS is to advise drivers of the speed of traffic in advance of a work zone and thereby encourage them to divert to an alternate route when there is congestion in the work zone.

Objective

The objective of this evaluation study was to assess:

- the effectiveness of the WZSAS in encouraging traffic diversion when there is congestion in the work zone, and
- its applicability as a traffic management tool.

LITERATURE REVIEW

A literature review was conducted to find previous research on deploying ATIS to provide information on work zones and the effect travel-related information dissemination had on drivers' route diversion tendencies. Areas of emphasis included the effectiveness of previous systems in encouraging traffic diversion, CMS message display characteristics, driver comprehension of messages, and driver response characteristics.

Effectiveness of Previous Systems in Encouraging Traffic Diversion

McCoy and Pesti (*1*) studied the effectiveness of utilizing changeable message signs to inform drivers of work zone traffic conditions on rural I-80 in Nebraska. A CMS was placed in a location nine miles in advance of a work zone and one mile in advance of a diversion point. Video detection was used to detect congestion in the work zone, and when congestion occurred, the message "DELAYS!! USE ALT ROUTE" was displayed. For this study, data was collected for traffic speed and lane distribution information in advance of the lane closure taper, mainline and exit ramp volumes at the diversion point, and driver surveys. Traffic condition information displayed on CMSs were found to have a statistically significant effect on traffic diversion, accounting for a 4 percent diversion of mainline traffic from I-80 to avoid delays in the work zone. This system is similar to the WZSAS as both utilize CMSs to provide work zone traffic information in an effort to encourage diversion. However, the systems differ in that the WZSAS displays speed advisory information and does not advise drivers to use an alternate route.

Other ATIS systems have been deployed to encourage traffic diversion in various metropolitan areas to relieve recurrent freeway congestion due to peak hour traffic flows. Driver surveys were conducted to study traffic diversion tendencies in the following cities: Chicago, IL (1990), San Francisco, CA (1993), Seattle, WA (1988), London, England (1997), and San Antonio, TX (2001).

The Chicago, San Francisco, and Seattle studies (*2,4*) were conducted when the cities' ATIS systems relied on radio and television information dissemination prior to the deployment of CMSs and traffic information web sites. In Chicago, where quantitative travel time information was provided to drivers via television and radio, 42.5 percent of drivers surveyed diverted from their normal routes to avoid traffic delay. In San Francisco, where qualitative travel time information was provided to drivers via television and radio, the diversion rate was 16.3 percent. In Seattle, where average travel speed and congestion information was provided via television and radio, 5.8 percent of drivers surveyed diverted frequently on home-to-work trips and 13.7 of drivers surveyed diverted frequently on work-to-home trips. This historical information can be compared to diversion percentage information in Omaha where qualitative congestion information is provided via commercial radio and speed advisory information is provided on CMSs by the WZSAS.

The London study (*5*) evaluated drivers' diversion tendencies based on CMS information, and found 24 percent of drivers diverted when faced with delays. The San Antonio studies (6) were conducted after the city's ATIS system was expanded to include radio, CMSs, and informational web sites. In San Antonio, 55 percent of drivers diverted from the freeway when faced with delays. Both of these cities' ATIS systems are compared to the WZSAS and discussed later in this report.

CMS Message Display Characteristics

A common problem with using CMSs is limited space for displaying messages. Typical CMS boards can only display three lines of eight characters, limiting the amount of information that can be displayed at one time. Therefore words in messages are often abbreviated, and CMS boards utilize phasing to display messages that contain multiple pages of information (*7,8*). Each phase of multiple-page messages is presented for a short period of time, typically 1 to 2 seconds. The result is a truncated message that may be difficult for drivers to understand, especially if it is only seen once. For example, the messages used for this study used two phases; the first phase was 1.5 seconds long and read " I-680 Speed Advisory" and the second phase was 1.5 seconds long and read "Average Speed XX mph". This particular message may be difficult for drivers to understand.

If a driver does not see one of the two message phases, the message will not make sense. If only the first phase of the message is seen, the driver will miss the speed advisory information and the message will be useless. If only the second phase of the message is seen, the driver may mistake the speed advisory message for a variable speed limit message and slow down unnecessarily. The message did not indicate to which portion of I-680 the speed advisory pertains because there was not enough display area to convey location information. This lack of location information may cause drivers to misinterpret or disregard the message. In all three cases, the effectiveness of CMS messages are limited due to message display area constraints.

Driver Comprehension of Messages

Previous research by Pesti and McCoy (*3*) indicated message content and message display technique play an important role in driver comprehension. When work zone conditions did not warrant advisory messages, the CMSs were left blank in order to preserve the primacy of messages displayed. Of those surveyed, only 14 percent of drivers who reported seeing any CMSs recalled seeing a blank CMS, and only about 24 percent of drivers who saw a blank CMS understood what it meant. The remaining drivers thought that the CMS was not working or simply didn't know what it meant.

Chaterjee et al studied message interpretation and comprehension in London, England (*5*). As in Nebraska (*3*), London operators also leave CMSs blank when no messages are warranted. Blank signs were understood by 57 percent of London drivers as compared to 24 percent in the Nebraska study. In order to compare the WZSAS study results to the previous Nebraska and London studies, the CMSs were also left blank if no speed advisory messages were warranted. More research is needed to further determine the effects this policy has on driver message comprehension.

In another Nebraska study (*1*), a generic message reading "DELAYS!! USE ALT ROUTE" was used to encourage driver diversion. Results of a driver survey indicated diversion percentages could be increased if diversion messages specified what alternate route should be taken. A large number of the drivers surveyed (over 90 percent) indicated they were from other states and not familiar with local alternate routes.

The results of the same driver survey (*1*) indicated drivers had insufficient time to read the two-phase CMS message "ROAD WORK AHEAD/PLEASE USE CAUTION". For this message, each phase was displayed for 1.5 seconds followed by a blank sign for one second to signify the end of the message. The time for drivers to read this message was about 3 to 3.5 seconds. FWHA's CMS Guidelines (*9*) suggests messages should be displayed twice for drivers to read, which would require message duration of seven seconds. A large percentage of drivers did not see either of the two message phases because it was not displayed for a long enough time.

The message was displayed on a CMS board located 3 miles upstream of the survey location (in a rest area), and 9 miles upstream from the work zone. This resulted in the questioning of its credibility and usefulness by drivers because they did not see any roadwork between the sign and the rest area. Moving the CMS closer to the work zone would increase its effectiveness according to polled drivers.

As these studies indicate, driver responses can vary to CMS information, resulting in lower rates of the desired behaviors that the information is intended to foster, including diversion. (*1,3,5*) Ultimately, driver response is tied to the fundamental comprehension of the messages that are displayed. For this reason, the WZSAS system messages were designed in an attempt to make information presented clear and easy to understand for users.

SITE DESCRIPTION

In 2002, the Nebraska Department of Roads (NDOR) began the reconstruction of the interchange at I-680 and Dodge Street as part of the larger West Dodge Road improvement project in Omaha. The WZSAS was deployed in advance of a work zone on northbound I-680 between Pacific Street and West Dodge Road, which was part of the reconstruction project.

Construction activities in the work zone necessitated the closing one of the three northbound lanes. The posted speed limit in advance of the work zone was 60 mph, and the posted speed in the work zone was 55 mph. The average daily traffic on this section of I-680 in 2001 was about 88,000 vehicles per day, of which 4 percent were trucks. The estimated capacity for the northbound Dodge Street exit ramp was approximately 2,000 vehicles per hour.

Work Zone Geometrics

The work zone studied extended from the beginning of the Dodge Street exit ramp (south of Dodge) to the end of the Dodge Street entrance ramp (north of Dodge). A map of the WZSAS study area is shown in Figure 1. North of the Pacific Street exit ramp, I-680 has three northbound through lanes up to Dodge Street. Construction activity at Dodge Street limited I-680 to two northbound through lanes for the entire length of the work zone. To accommodate construction, the outside lane on I-680 was converted to a single exit-only lane to the Dodge Street exit ramp.

Traffic Concerns

Traffic in the study area became congested during peak hours because of the existence of four separate traffic conflict points adjacent to the work zone as shown in Figure 2. The beginning of the work zone and lane drop coincided with the Dodge Street exit ramp gore, creating the primary conflict point (point A). Here drivers were required to either continue northbound on I-680 on a two-lane section (reduced from three lanes) or exit onto Dodge Street. Just upstream from point A an additional conflict point was created as vehicles exiting I-680 on dodge street and vehicles entering I-680 from Pacific Street had to cross paths in a weaving section in advance of the work zone (point B).

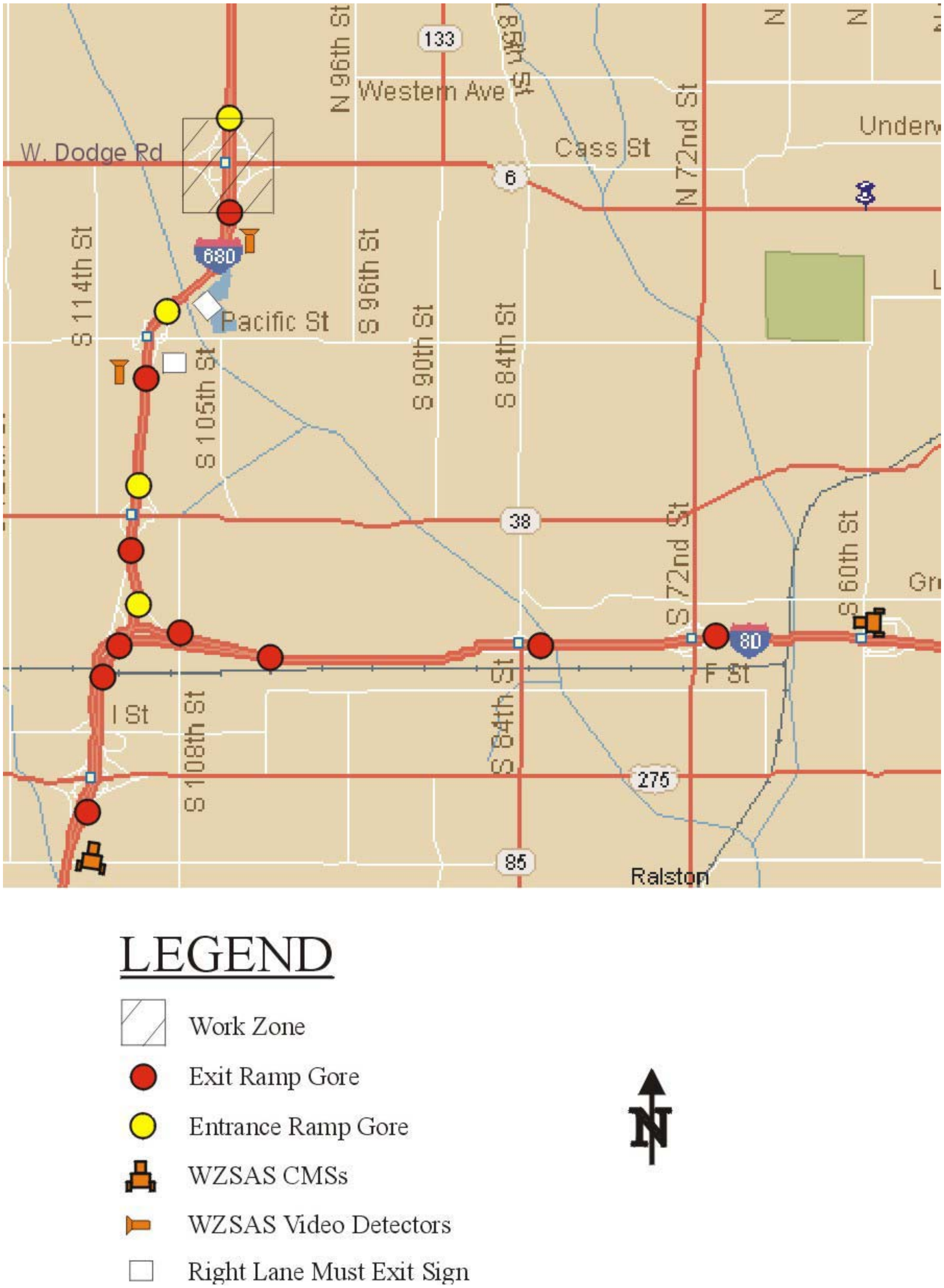

Figure 1. WZSAS Study Area

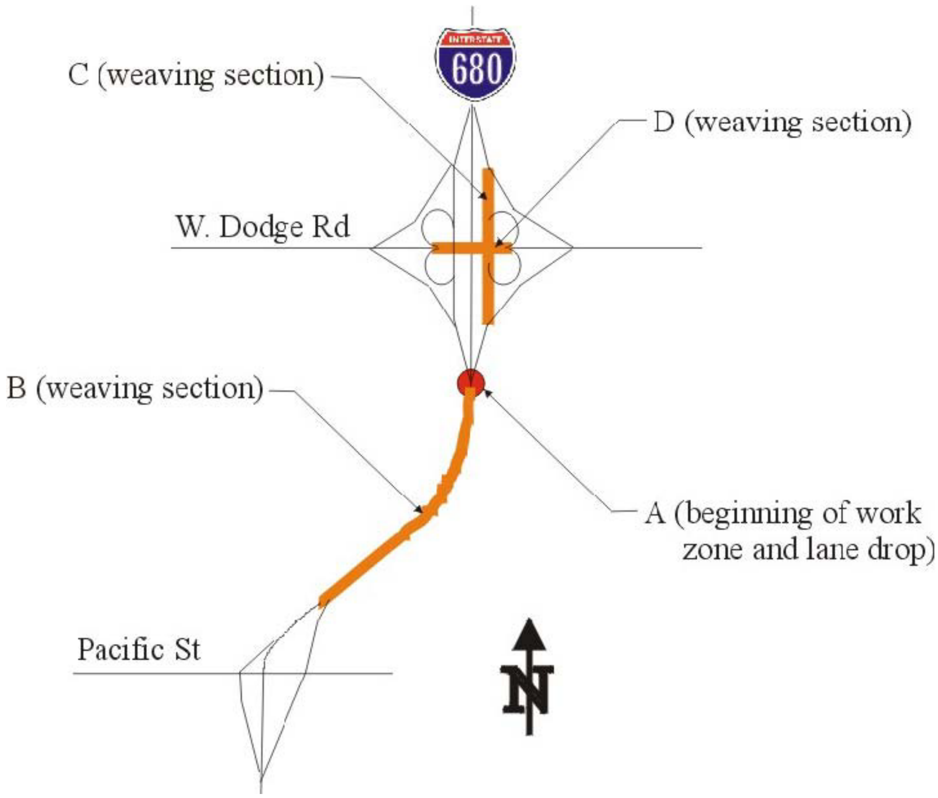

Figure 2. WZSAS Study Area Traffic Conflict Points

Construction activity in the work zone also affected traffic flow in the weaving sections on the Dodge Street exit collector-distributor road (point C) and mainline West Dodge Road (point D), which contributed to traffic congestion in the study area. The construction activity adjacent to these weaving sections would cause delays and congestion during peak hours with queues extending back the Dodge Street exit ramp to the I-680 exit gore.

On-site observations indicated the northbound I-680 Dodge Street exit ramp often became congested at peak traffic hours due to the four traffic conflict points. Queues were observed in November 2001 building up from the Dodge Street exit ramp gore back into the outside lane of I-680. Some queues extended over 2,000 feet upstream past the Pacific Street overpass. At peak hour conditions, the speed of traffic in all three lanes was slowed due to congestion.

Although congestion and queues were observed in November 2001, daily traffic conditions varied. On some days congestion was non-existent; other days half-mile queues were observed. The variance in traffic conditions limited the use of traditional static warning signs and messages. This provided an opportunity to test the WZSAS, which is a dynamic traffic-activated warning system.

WZSAS DESCRIPTION

The WZSAS is comprised of three primary components: (1) a video detection system, (2) two portable CMSs, and (3) a control system. The video detection system was used to measure the speeds of traffic at two selected points in advance of the work zone. Average speeds measured at the two points were displayed on the two portable CMSs which were placed upstream of diversion points in advance of the work zone. The control system, installed on a computer at the NDOR District 2 office, coordinated communications between the video detection system and the portable CMSs necessary to display the appropriate speed messages. NDOR personnel were alerted when speeds dropped below the selected threshold of 15 miles per hour, which enabled them to display incident-related messages when necessary.

A web page was also provided that displayed real-time traffic condition information for the work zone to the public. The system was designed to inform drivers of traffic conditions at the work zone prior to entering the northbound I-680 corridor. This allowed drivers to decide if I-680 congestion at the work zone was severe enough to warrant a route change.

Video Detection System

Two video detection units were installed to collect traffic information at the work zone. Each video detection unit included a camera mounted over the roadway on a sign bridge, as shown in Figure 3, and a controller box on the side of the road. The detection units collected speed, vehicle type, and volume information for each lane. The information collected by the two units was stored on-site and periodically sent via radio to the control system at the NDOR District 2 office. This local storage capability made it possible to downloaded raw data in the field. Each detector unit also included video output jacks for system settings adjustments, and on-site system monitoring.

Figure 3. WZSAS Camera Mounted Above Roadway

One video detection unit was installed in advance of the work zone just south of the Pacific Street overpass. The other unit was installed at the south end of the work zone, at the beginning of the Dodge Street exit ramp. The locations of the video detection units are shown in Figure 4.

The use of two detectors provided two subsections of the roadway to be analyzed simultaneously; one south of Pacific Street ("South") and another north of Pacific Street ("North"). The South subsection begins just after Center Street and ends at Pacific Street. It is approximately one-half mile upstream of the work zone and is the location to which maximum queues extended. The North subsection begins at Pacific Street and ends at the south edge of the work zone, where congestion usually occurred on a daily basis. Each video detection unit collected data from three lanes of traffic on northbound I-680. Figure 4 also shows the locations of changeable message signs, the subsection boundaries, and lane numbering convention.

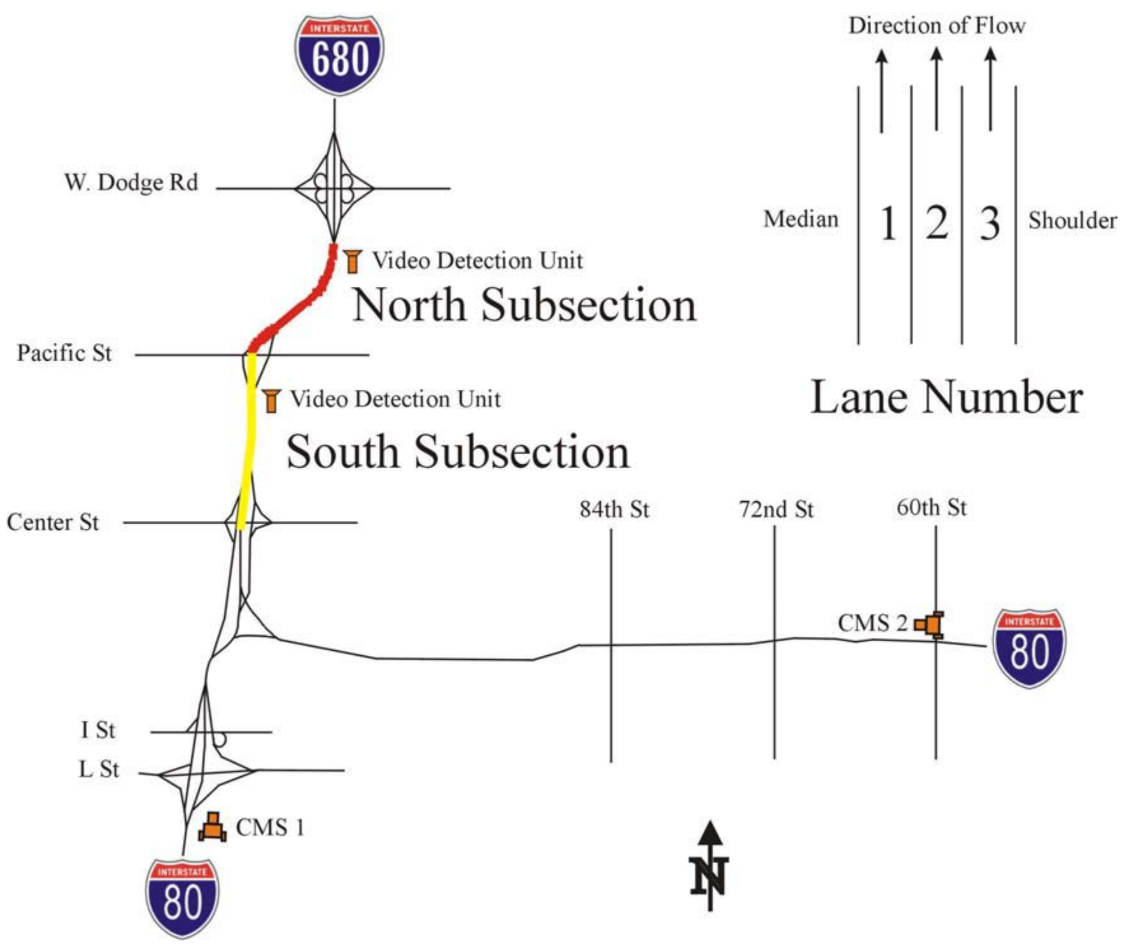

Figure 4. Video Detection and CMS Locations.

Changeable Message Signs

Changeable message signs, pictured in Figure 5, were placed on the roadway shoulders at two locations upstream of the I-680 interchange on I-80 in Omaha. One sign (CMS 1) was located 2,500 feet upstream of the L Street exit gore to serve drivers traveling eastbound on I-80. The other sign (CMS 2) was located on the 60th Street bridge to serve drivers traveling westbound on I-80. The CMS locations are shown in Figure 4. Each CMS was placed far enough upstream of the I-680 interchange to enable drivers to select alternate routes if desired.

Figure 5. Changeable Message Sign

CMS 1 (serving eastbound traffic) was located 4.5 miles in advance of the work zone and 1.6 miles in advance of the I-680 exit gore. Two alternate exits were available for drivers. One was the L Street exit, which was 0.5 miles downstream of CMS 1. The other was the Center Street exit, which was located 2.2 miles downstream of CMS 1 (exit gore located on I-680 ramp prior to beginning of I-680 mainline).

CMS 2 (serving westbound traffic) was located 6.8 miles in advance of the work zone and 3.8 miles in advance of the I-680 exit gore. Three alternate exits were available for drivers to select if desired. One was the 72nd Street exit, which was 0.75 miles downstream of CMS 2. The second was the 84th Street exit, which was located 1.7 miles downstream of CMS 2. The third was the L-Center Street exit, which was located 3.5 miles downstream of CMS 2.

The CMSs were only activated if the average speed of traffic in the work zone was below 55 mph. If the average speed of traffic was 55 mph or greater, the signs were left blank. The two signs were operated as a pair and displayed the same messages concurrently.

The messages used for this study used two phases; the first phase read " I-680 SPEED ADVISORY" and the second phase read "AVERAGE SPEED XX MPH". The phases were shown in a loop until traffic speeds measured in the work zone warranted a message change. The message loop consisted of the display of each phase for 1.5

seconds followed by 1 second of blank sign time to provide a break between messages. Each message loop would require 4 seconds to complete. If a message change was warranted, a new message loop was initiated beginning with the first phase.

The CMS character height was 18 inches, which provided a legibility distance of 900 feet (i.e., 1" character height = 50' legibility distance). At a speed of 60 miles per hour, each CMS would be legible for approximately 10 seconds, allowing at least two messages to be displayed while the sign was in the driver's sight. This conforms to FHWA CMS guidelines, which suggest messages be displayed at least twice for drivers to read. (*9*)

Control System

The information collected by the two video detection units was sent via radio signal to the computerized control system at the NDOR District 2 office. The control system software package was set up to analyze the information collected and select an appropriate speed advisory message based on work zone traffic conditions when necessary. Communications between the video detection system and the portable CMSs were also coordinated by the control system.

NDOR personnel were alerted when speeds dropped below the selected threshold of 15 miles per hour, which enabled them to display incident-related messages on the CMSs. The control system also saved the traffic data and advisory messages in log files, which were reviewed by NDOR personnel to monitor system operations.

Message Selection Logic

As explained in the earlier description of the video detection system, advisory messages were selected based on traffic information collected via video detections for two roadway segments. Each detector collected speed, vehicle type, and volume information for three lanes of traffic. The system software package was set up to calculate an average of vehicle speeds for all three lanes for each segment at one-minute intervals. The most critical subsection (i.e., the one with minimum average speed) was then selected as the basis for the speed advisory message. For example, if the north subsection's average speed of traffic was lower than the south subsection's speed, the advisory message was determined based on the north subsection's speed. Figure 6 shows the message selection logic algorithm utilized by the system software package.

WZSAS Web Site

A web site was created to simulcast the WZSAS traffic information sent to the CMS signs via the Internet. The web site included a home page, a traffic conditions page, and an online survey.

To facilitate a graphical display of traffic conditions in the study area, the WZSAS web site assigned color codes based on the average speed of traffic and traffic flow conditions. Table 1.shows the advisory messages and color-coded alert levels for corresponding traffic conditions.

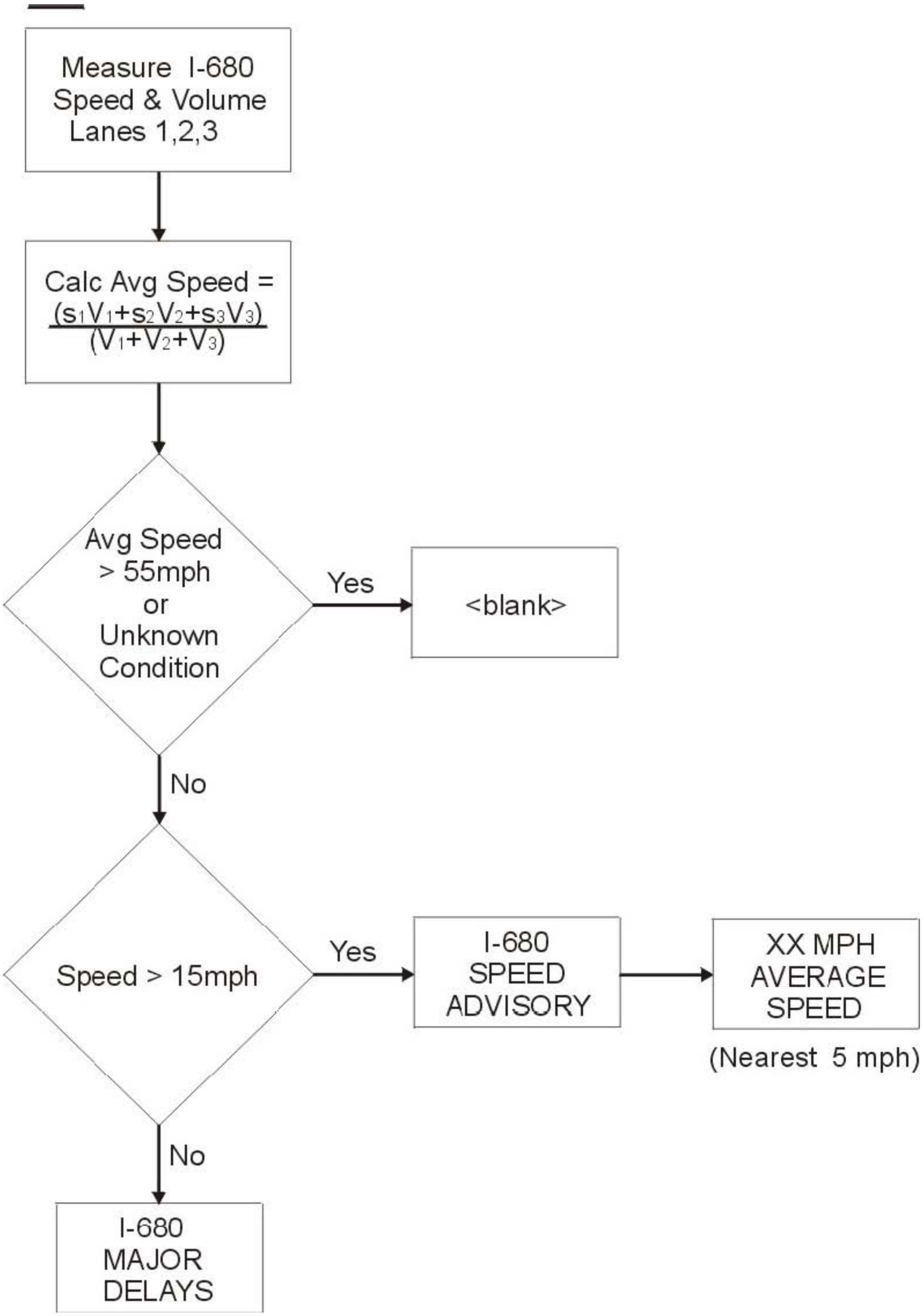

Figure 6. CMS Message Selection Logic

Table 1. WZSAS Web Site Advisory Messages and Alert Levels

WZSAS Speed Advisory Message Characteristics (Northbound I-680)			
Average Speed (mph)	**Traffic Flow**	**Alert Level Color**	**CMS Advisory Message (to nearest 5 mph)**
55 and above 55 to 45 45 to 35 35 to 25 25 to 15 0 to 15 Unknown	Normal Normal Slow Slow Congested Stopped Unknown	Green Green Yellow Yellow Red Red Blue	(blank) I-680 SPEED 50 MPH I-680 SPEED 40 MPH I-680 SPEED 30 MPH I-680 SPEED 20 MPH I-680 SEVERE DELAYS (blank)

On the traffic conditions page, a map of Omaha was included with icons that displayed the location of the WZSAS video detectors as well as the CMS sign locations. Users could roll the cursor over a detector location and the current traffic conditions would be displayed. Rolling the cursor over a CMS icon would display the same message in a text box that the sign displayed. Each of the two subsections (North and South) was also highlighted on the traffic conditions page in the color that corresponded with the current traffic condition. Figure 7 shows a screen capture of the traffic conditions page from the WZSAS web site.

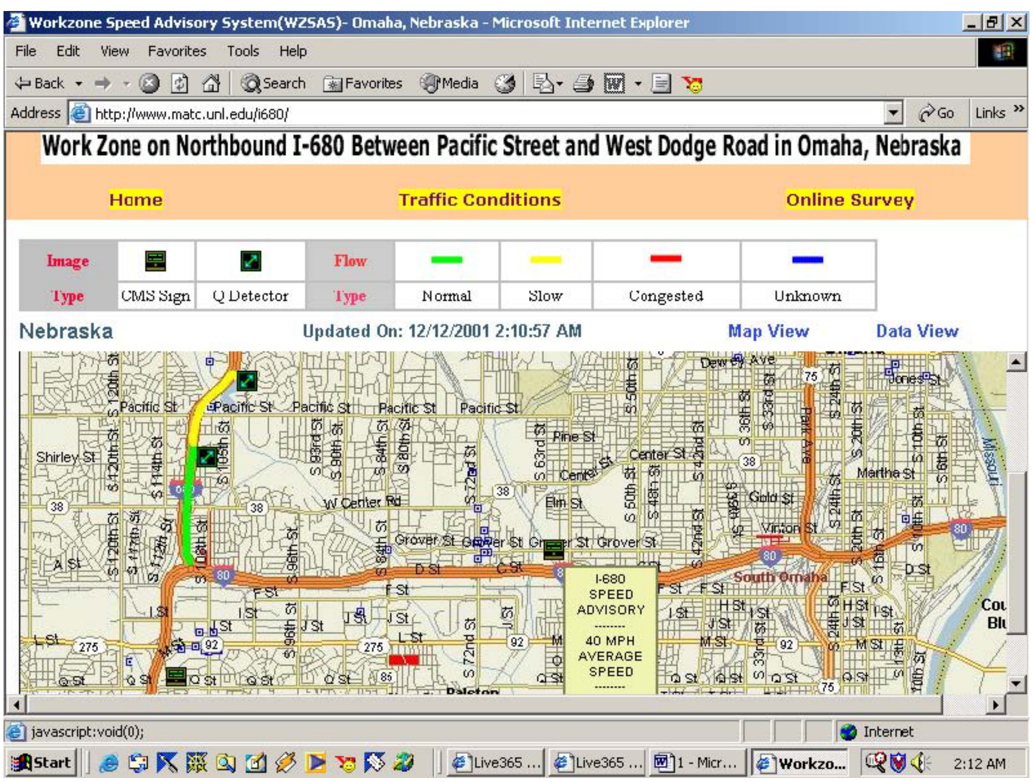

Figure 7. WZSAS Web Site Traffic Conditions Page

Public Information Campaign

As this study was the initial use of the WZSAS system, a public information campaign was launched. The NDOR issued a press release to local media outlets informing them of the implementation of the WZSAS system and web site. A local television station aired a story detailing the system on the evening news. The NDOR and UNL-MATC web sites contained links to the system web site. A link was also provided from the web site of an Omaha TV channel (TheOmahachannel.com).

TRAFFIC DIVERSION ANALYSIS

The effectiveness of the WZSAS system in encouraging traffic diversion during periods of work zone congestion was investigated. The primary measure of effectiveness was the change in traffic demand in response to the advisory speed messages. Driver comprehension of the traffic information provided was also assessed based on an Internet survey. The traffic diversion analysis process included three steps: data collection, data analysis, and interpretation of results.

Data Collection

Traffic speed and volume data were measured via video detection at two locations (labeled North and South) in advance of the work zone where the WZSAS system was installed. The data were downloaded on-site from the detection unit controller boxes during the field studies. Tube counters were also used to collect traffic volume data for the Pacific Street entrance and exit ramps. Figure 8 shows these data collection locations.

The data were collected for two four-week periods: a "before" period prior to message display (November 16th, 2001 to December 9th, 2001), and a "during" period when speed advisory messages were implemented (December 10th, to January 6th, 2002). The video-based data were collected at one-minute intervals and the tube-based data were collected at 15-minute intervals.

Data Analysis

Demand Calculation

Traffic demand is defined as the number of vehicles that currently wish to pass a point in a given period of time. If the traffic demand does not exceed the capacity of a freeway section, all vehicles are accommodated, and the flow rate measured in the field is the traffic demand for the section. However, during periods of congestion, traffic demand exceeds the capacity of the section and the measured flow rates in the congested section and downstream sections represent only the vehicles that can be handled, not the number that wish to travel through the system. For such cases, traffic demand was determined using a density-based demand estimation method (*11*).

The video detection unit collected speed, volume, and percent occupancy data. To estimate traffic demand, density data at one-minute intervals were also needed. Lane densities in vehicles per lane-mile were calculated from the percent occupancy as:

$$k = [52.80 / (L_V + L_D)](\% OCC)$$

where k = density in vehicles per lane-mile
$\% OCC$ = percent occupancy per lane
L_D = detection zone length in feet (both detection zones were 20 ft)
L_V = average vehicle length in feet (see Equation 2)

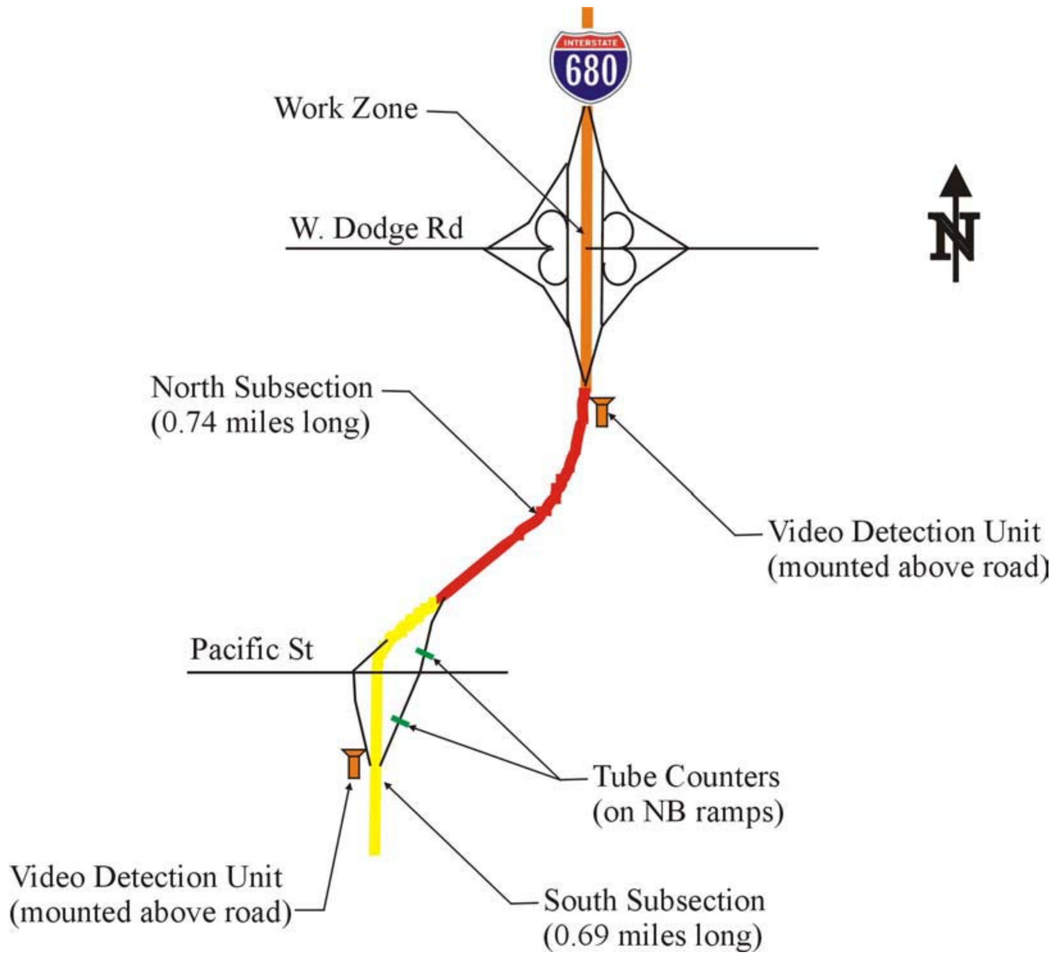

Figure 8. WZSAS Data Collection Locations

The densities were then used to determine speed-density and flow-density relationships. They are illustrated using data collected by the video detection unit located north of Pacific Street. Similar relationships were observed at the other data collection point south of Pacific Street. Based on the speed-density graphs, the free-flow speed for the study area was observed to be approximately u_f=70 miles/hour, and the jam density was k_j=110veh/lane/mile. Assuming a linear speed-density relationship, an optimum density of $k_o = k_j / 2$=55veh/lane/mile, and a lane capacity of $q_{MAX} = u_f k_j / 4$=1,925veh/hr/lane were determined for the section of I-680 studied.

Figure 9. Observed Speed-Density and Flow-Density Relationships

The video detectors were set to classify vehicle type by length. The detector program software required the designation of three user-modifiable classification types:

Small = 10 to 28 feet (passenger cars)
Medium = 28 to 29 feet (division category)
Large = 29 feet and above (heavy vehicles)

Observations on-site revealed the most accurate method of discerning vehicle type was to utilize the "Medium" category as a division between the "Small" and "Large" categories. Average vehicle lengths based on AASHTO design vehicle lengths (*12*) were determined using the following weighted average:

$$L_V = (N_L L_L + N_M L_M + N_S L_S) / (N_L + N_M + N_S) \quad \textbf{(2)}$$

where:
L_V = average vehicle length in feet
L_L = average large vehicle length in feet (60 ft)
L_M = average medium vehicle length in feet (28.5 ft)
L_S = average small vehicle length in feet (19 ft)
N_L = number of large vehicles counted per interval
N_M = number of medium vehicles counted per interval
N_S = number of small vehicles counted per interval

Results

Traffic demands were estimated from traffic flow and density data observed at the two camera locations during time periods before and after the deployment of the WZSAS system. The comparison between the "before" and "after" demands was made using data from every three-hour peak flow period during the study. Data were analyzed for each lane. A multifactor analysis of variance was performed to determine if a statistically significant (α=0.05) reduction in estimated traffic demand occurred due to WZSAS speed advisory messages. Results of the analysis are summarized in Table 2. The dependent variable "DEM" was the estimated traffic demand. The factor variable "Factor" was indicative of the study period (i.e., time period "before" or "after" deployment of the WZSAS system). The covariate "Min Msg ON" was the length of time (in minutes) when traffic conditions warranted the use of speed messages based on the message-selection logic shown in Figure 6.

The relatively high p-values for variable "Factor" indicate that the demand during peak-periods did not change significantly (α = 0.05) in response to deployment of the WZSAS system. The speed messages did not significantly affect vehicle diversion under the traffic conditions observed during the study. However, it should be noted that the system might be more effective under heavier traffic demands and more severe congestions.

Table 2. Peak Period ANOVA for Demand

Lane 1:

Analysis Summary
Dependent variable: DEM
Factors:
Factor
Covariates:
Min Msg ON
Number of complete cases: 60

Analysis of Variance for DEM - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
COVARIATES:					
Min Msg ON	2.49835E7	1	2.49835E7	26.64	0.0000
MAIN EFFECTS					
A:Factor	428947.0	1	428947.0	0.46	0.5016
RESIDUAL	5.34523E7	57	937760.0		
TOTAL (CORRECTED)	7.86964E7	59			

All F-ratios are based on the residual mean square error.

Lane 2:

Analysis Summary

Dependent variable: DEM

Factors:
Factor
Covariates:
Min Msg ON
Number of complete cases: 60

Analysis of Variance for DEM - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
COVARIATES:					
Min Msg ON	4.46757E6	1	4.46757E6	5.68	0.0205
MAIN EFFECTS					
A:Factor	1731.54	1	1731.54	0.00	0.9627
RESIDUAL	4.48334E7	57	786550.0		
TOTAL (CORRECTED)	4.93115E7	59			

All F-ratios are based on the residual mean square error.

Lane 3:

Analysis Summary Dependent variable: Cumul Peak Vol

Factors:
Factor

Covariates:
Min Msg ON

Number of complete cases: 60

Analysis of Variance for Cumul Peak Vol - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
COVARIATES:					
Min Msg ON	1.9446E7	1	1.9446E7	15.62	0.0002
MAIN EFFECTS					
A:Factor	1.41249E6	1	1.41249E6	1.13	0.2912
RESIDUAL	7.09449E7	57	1.24465E6		
TOTAL (CORRECTED)	9.15171E7	59			

All F-ratios are based on the residual mean square error.

SYSTEM RELIABILITY

In order for the NDOR and other agencies to apply the WZSAS system as a traffic management tool, its reliability was assessed. Two performance criteria, related to traffic speed measurement and advisory message selection, were identified. Table 3 summarizes the performance criteria and corresponding measures of effectiveness. Data collected by the research team were compared to the WZSAS control system log data to determine the performance of the system for each criterion in Table 3.

Table 3. System Applicability Performance Measures

Performance Criteria	Measures of Effectiveness
Accurate traffic speed measurements	Differences between traffic speeds measured by system and traffic speeds measured independently.
Display appropriate speed advisory messages	Differences between speed advisory messages selected and messages calculated independently.

Traffic Speed Measurement

The ability of the WZSAS system to accurately measure traffic speeds was evaluated by comparing speeds measured by the system to speeds measured by the research team during the study period.

Traffic at the two data collection locations was videotaped at selected times under congested and uncongested traffic flow conditions. The videotapes were analyzed using the Autoscope video image processing system to determine traffic speeds and volumes. These data were compared to the speeds and volumes measured by the video detection system during the same time period to check the accuracy of the video detection.

Advisory Message Selection

The ability of the WZSAS system to display appropriate speed advisory messages was determined in two ways. A system communications analysis was performed followed by an accuracy analysis of the system computer's message selection software.

The WZSAS system utilized a radio communications system to send data collected via video detection to the system computer at the NDOR District 2 office. The communications system was analyzed by comparing advisory messages calculated by the system and recorded in system logs to advisory messages that were determined by the research team using speed data downloaded from the system log.

The speed advisory messages, selected by the system computer and displayed on the CMSs, were determined based on measured speeds and the message selection logic shown in Figure 6. Advisory messages calculated independently by the research team were determined by applying the same message selection logic to data collected on-site via video detection and downloaded from the system log during field studies. These data were not sent through the WZSAS communications system. Data collected during the period of December 10th through January 6th were included in the analysis. The percent of messages correctly selected and displayed by the system were determined for the AM, PM and daytime peak hours, and the entire day during the four-week period. The results summarized in Table 4 indicate that the computer was over 90 percent accurate in selecting and displaying the appropriate speed advisory messages during the entire four-week period.

Table 4. Reliability of Advisory Message Selection

Time Period		Percent Of Correctly Selected Messages			
		Dec 10-16	Dec 17-23	Dec 24-30	Dec 31-Jan6
AM Peak	6:30 am – 9:30 am	93	92	98	97
PM Peak	3:30 pm – 6:30 pm	98	98	99	100
Daytime	6:00 am – 8:00 pm	98	97	99	99
Daily	12:00 am – 12:00 pm	94	97	99	99

WZSAS Web Site Traffic

The WZSAS web site received 1,203 visits in the four-month period (October to January) in which it was active. The most visits (269) occurred during the week of December 16-22, 2001and the busiest day overall (93 visits) was Thursday December 20, 2001. The majority of daily web site visits (over 60 percent) occurred in the hours between 1:00 PM and 10:00 PM. Approximately 60 percent of visits to the WZSAS web site originated from miscellaneous web sites, 26 percent originated from the NDOR web site link, and 12 percent were directed from TheOmahachannel.com web site link. A detailed breakdown of WZSAS web site traffic (*10*) can be found in Appendix A.

WZSAS Online Survey

An online survey was included on the WZSAS web site, which was active from October 2001 to January 2002. The survey was 12 questions long and was conducted to determine drivers' experience with the system, obtain their opinions regarding its usefulness, and their suggestions for improving it. The survey results are summarized in Table 5.

About 43 percent of the respondents indicated that they used I-680 everyday, and 37 percent used I-680 1-3 times a week. The remaining 20 percent used I-680 less than once a week. On a scale of 1-10, with 1 being poor and 10 being excellent, 74 percent of the respondents thought the usefulness of the speed advisory messages rated 5 or above, and 91 percent of respondents thought the accuracy of the speed advisory messages rated 5 or above. If they encountered major congestion on the freeway, 71 percent of the respondents indicated they would get off the freeway and take another route. Out of the respondents, 51 percent said they would like to know the speed of traffic, while 69 percent said they would like to know delay time. This indicates delay information may be more useful than speed information.

Table 5. WZSAS Online Survey Results

	Question	Response n = 35	#	%
1	Please enter your home zipcode. (location determined by zipcode)	Omaha	25	71
		Lincoln	5	14
		Ashland	1	3
		Blair	1	3
		Fremont	1	3
		Gretna	1	3
		Hastings	1	3
2	How often do you use I -680?	Everyday	15	43
		1-3 times per week	13	37
		2-3 times per month	7	20
		Never	0	0
3	How do you use I-680?	Only to drive to work	11	31
		Never to drive to work	16	46
		To drive to work and other locations	8	23
4	On a scale of 1-10, how useful do you find the WZSAS message signs to be in notifying you of traffic conditions?	10 - very useful	8	23
		9	0	0
		8	6	17
		7	5	14
		6	1	3
		5	6	17
		4	0	0
		3	2	6
		2	3	9
		1 - not very useful	4	11
5	On a scale of 1-10, how accurate do you feel the WZSAS speed information is?	10 - very accurate	7	20
		9	1	3
		8	5	14
		7	6	17
		6	6	17
		5	7	20
		4	0	0
		3	1	3
		2	0	0
		1 - totally inaccurate	2	6

Table 5. WZSAS Online Survey Results (continued)

	Question	Response n = 35	#	%
6	On a scale of 1-10, how useful do you find the information provided on the WZSAS website is on a daily basis?	10 - very useful	5	14
		9	0	0
		8	4	11
		7	4	11
		6	4	11
		5	4	11
		4	2	6
		3	3	9
		2	3	9
		1 - not very useful	6	17
7	If you find out about major traffic congestion on your normal route before leaving, what do you normally do?	Leave later	1	3
		Take another route	29	83
		Go on normal route as planned	4	11
8	What type of traffic information would you like? (check all that apply)	Speed of traffic	18	51
		Delay time	24	69
		Travel time from point A to B	15	43
		Alternate route	17	49
		Live video	8	23
9	How often do you listen to the radio or watch TV for traffic condition announcements?	Everyday	23	66
		1-3 times per week	9	26
		2-3 times per month	1	3
		Never	2	6
10	How slow does traffic on the freeway have to be moving before you will change your route?	50 mph	2	6
		40 mph	3	9
		30 mph	8	23
		20 mph	9	26
		10 mph	1	3
		Below 10 mph (stop and go)	12	34
11	If you encounter major traffic congestion on the freeway, what do you normally do?	Get off freeway & take another route	25	71
		Stay on freeway and wait it out	10	29

Table 5. WZSAS Online Survey Results (continued)

	Question	Response n = 35	#	%
12	Frequency of visiting web site?	Everyday	4	11
		1-3 times per week	6	17
		2-3 times per month	3	9
		Very Rarely	21	60
	User Comments	Good idea	3	
		Don't see signs; not on route	3	
		I-80 information would be nice	1	
		Put more construction info on internet	1	
		Signs more of a distraction than a help	1	
		Limited access to website	1	

The survey also revealed that 66 percent of the responding drivers watched television or listened to the radio for traffic announcements everyday. When asked what they would do if informed of major traffic congestion on their normal route before leaving, 83 percent of the respondents indicated they would take another route.

The responses to these questions indicate that a large portion of motorists rely on commercial broadcasts of traffic information. Also, the relatively large percentage of respondents willing to alter their trips with advance information on congested traffic conditions is a promising sign.

Note that the usefulness of the WZSAS survey is limited by the relatively small sample size (*35*).

PROBLEM AREAS AND RECOMENDATIONS

During our field studies, the WZSAS system experienced some operational difficulties. However, such difficulties are expected in an initial deployment, and it is important to document them for future applications. The following section includes a discussion of some of the problem areas identified, and recommendations to improve the effectiveness of the system.

Study Area

The study location was at a work zone in Omaha on I-680 at Dodge Street, where projected traffic volumes and roadway geometrics indicated that congestion was likely to occur during peak hours. Field investigations in November 2001 confirmed congestion occurred at the site; however congestion levels varied considerably from day to day. This variation in congestion is expected at a work zone because of the dynamic nature of the construction process; however, the levels of congestion were seldom high enough to activate the CMSs for more than one or two 15-minute intervals every day. In short, the location studied did not experience extended levels of congestion on a daily basis, which limited the study sample size. For future studies, it may be advisable to deploy the WZSAS at a work zone location where severe congestion levels are experienced for extended periods of time.

Sign Location

The WZSAS displayed speed advisory messages on two changeable message signs located upstream of the work zone. The sign serving eastbound drivers (CMS 1) was located 4.5 miles in advance of the work zone and 1.6 miles in advance of the I-680 exit gore. Three interchanges serving five streets to use as alternate routes are located between CMS 1 and the work zone along I-80 and I-680: (1) I-J-L Streets (2) Center Street, and (3) Pacific Street. CMS 2 (serving westbound traffic) was located 6.8 miles in advance of the work zone and 3.8 miles in advance of the I-680 exit gore. Four interchanges serving five streets to use as alternate routes are located between CMS 2 and the work zone along I-80 and I-680: (1) 72nd Street (2) 84th Street (3) L-Center Streets, and (4) Pacific Street.

The CMSs were placed in locations that provided drivers several options for diversion to alternate routes. However, this sign placement also increased the number of points inbound traffic could enter the system without seeing the signs or speed advisory messages. When this problem was considered during the study design phase, it was assumed that any variation of traffic volumes on these roads would be proportionate to variation of I-680 traffic volumes, negating the need to measure additional traffic volumes.

While the previous assumption may be sound, the percentage of drivers wishing to take I-680 who travel on I-80 past the CMS locations is not known and was not considered in the data analysis. It is possible that a majority of I-680 users entered the system at the interchanges between the CMS locations and the work zone, never seeing the signs. If a majority of I-680 traffic never saw the CMS signs, the results of the demand analysis do not accurately depict the effectiveness of the WZSAS. It is possible that every driver who viewed the speed advisory messages diverted but the majority of I680 users, never seeing the signs, continued along their normal route as planned.

For this reason a change in placement of CMSs is advised for future applications of the WZSAS. If multiple alternate routes are desired, a CMS should be placed on arterial streets prior to freeway entrances. This would ensure all drivers entering the system would be provided with the same advisory information. Note however that this option may be cost prohibitive due to limited availability of CMSs and the cost of their deployment.

Advisory Message Information

For this study, the advisory messages provided speed information in the work zone. Other types of information such as delay time, travel time, length of queue, and alternate route designation could have resulted in more significant traffic demand reduction. For example, 69 percent of the respondents to the WZSAS online survey indicated that they would like delay time information, 49 percent would like alternate route information, and 43 percent would like to see travel time information.

Another limitation of the WZSAS advisory messages was a lack of location information due to limited display space and message size constraints. The messages indicated the speed for I-680, but did not specify what section of I-680 the speeds were measured. A two-phase message, specifying both the speed and location, might improve drivers understanding of the messages.

CONCLUSION

The WZSAS is designed to provide real-time speed advisory information to drivers by means of portable CMSs strategically located in advance of diversion points upstream of a work zone. This study evaluated the effectiveness of the WZSAS in encouraging traffic diversion when there was congestion in the work zone. The system was evaluated using data collected from the control system's logs, field studies, user surveys, and system observations.

Traffic demands were estimated from traffic flow and density data observed at the two camera locations during time periods before and after the deployment of the WZSAS system. The comparison between the "before" and "after" demands was made using data from every three-hour peak flow period during the study. It was found that the total peak-period demands did not change significantly in response to the speed messages. The WZSAS system did not significantly increase vehicle diversion under the traffic conditions observed during the study period. However, it should be noted that the system might be more effective under heavier traffic demands and more severe congestions.

A web site was also in operation to simulcast the WZSAS traffic information sent to the CMS signs via the Internet. The web site included a home page, a traffic conditions page, and an online survey. To facilitate a graphical display of traffic conditions in the study area, the WZSAS web site assigned color codes based on the average speed of traffic and traffic flow conditions. The web site received 1,203 visits in the four-month period (October to January) in which it was active. The majority of daily web site visits (over 60 percent) occurred in the hours between 1:00 PM and 10:00 PM.

An on-line survey was also conducted through the WZSAS web site to determine drivers' experience with the system, obtain their opinions regarding its usefulness, and their suggestions for improving it. On a scale of 1-10, with 1 being poor and 10 being excellent, 74 percent of the respondents thought the usefulness of the speed advisory messages rated 5 or above, and 91 percent of respondents thought the accuracy of the speed advisory messages rated 5 or above. If they encountered major congestion on the freeway, 71 percent of the respondents indicated they would get off the freeway and take another route. Out of the respondents, 51 percent said they would like to know the speed of traffic, while 69 percent said they would like to know delay time. This indicates delay information may be more useful than speed information.

Some operational difficulties of the WZSAS system have been observed during our studies. Problem areas related to the initial deployment of the system have been identified, and recommendations for its improvement have been made. Further research is necessary to evaluate the effectiveness of this system under heavier traffic demands and more severe congestions.

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Appendix A

Figure A-1. Logs Detail Report.

Logs Detail Report

Report document date:	04/10/2002 1:39:39 AM
Internet sites analyzed	MATC
First date analyzed	10/05/2001
Last date analyzed	01/31/2002

Analysis content

1. Overall trends
2. Hourly visits
3. Daily visits
4. Weekly visits
5. Top requests
6. Summary
7. Daily hits
8. Browser products
9. Weekly bandwidth
10. Definitions

Overall trends

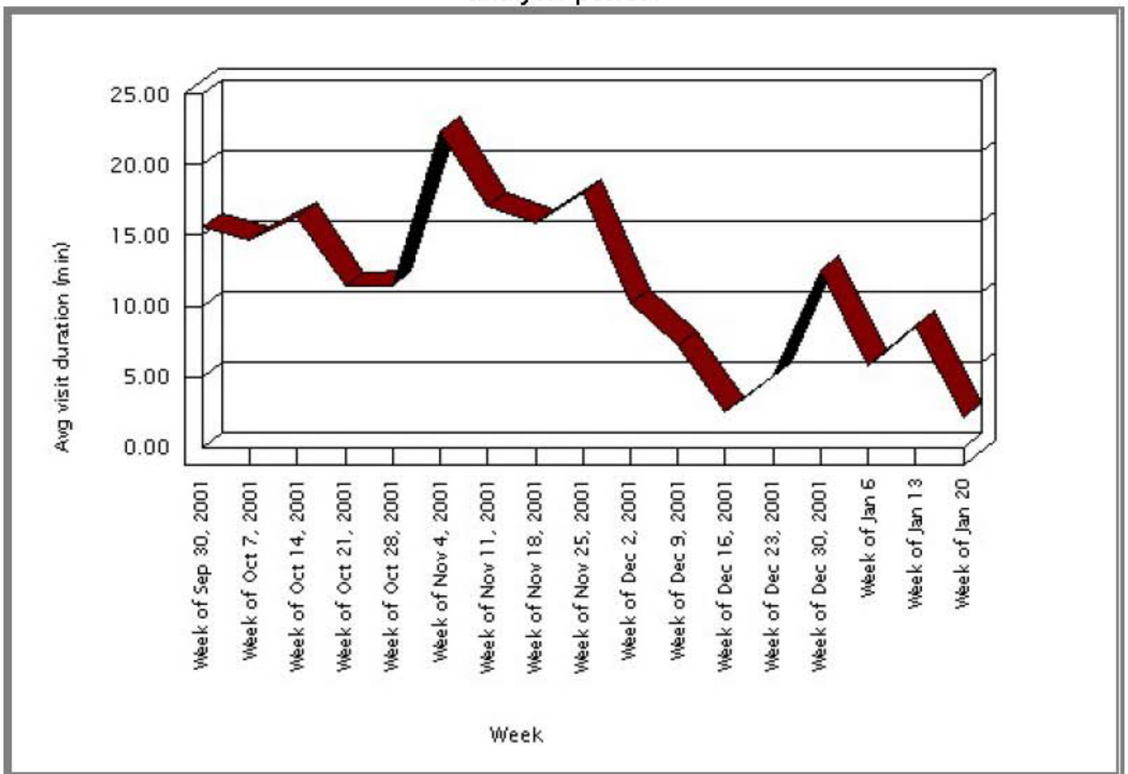
General activity statistics

Number of hits	35,077
Number of requests	10,661
Number of visits	1,203
Average requests per visit	8.86
Average visit duration	00:09:11

Figure A-2. Visit Duration Trends.

Visit duration trends

Shows the variation in the average length of time spent on your site per visit over the weeks in the analysis period.

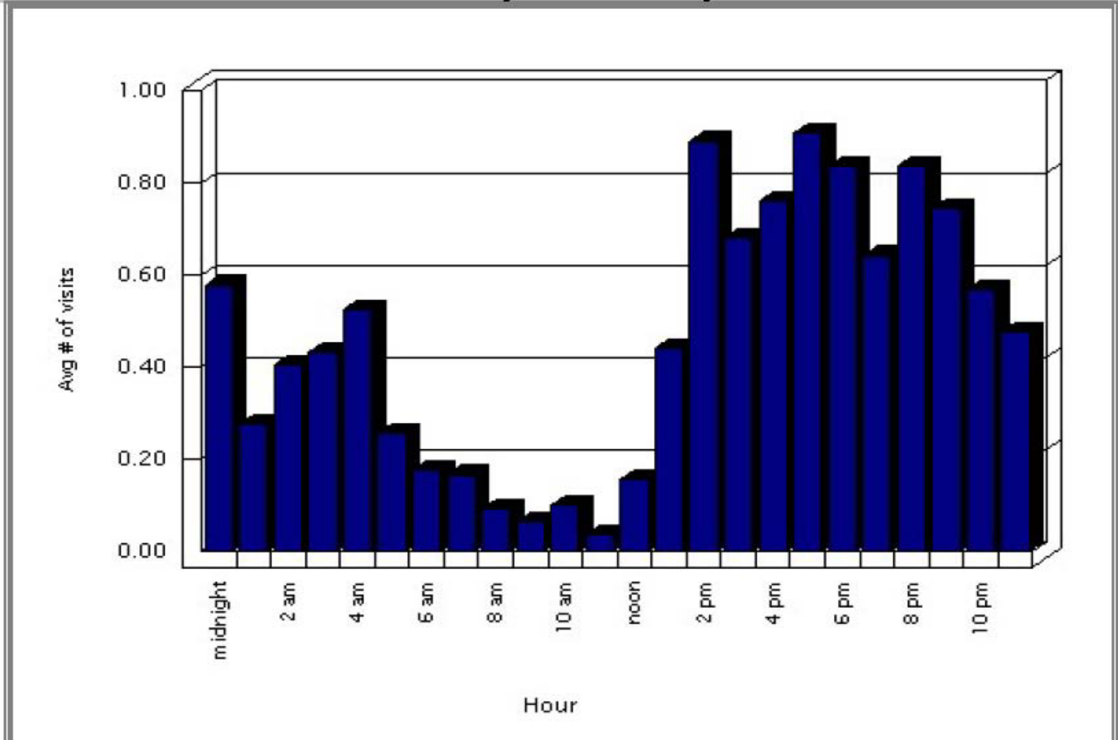


Week	Avg visit duration
Week of Sep 30, 2001	00:15:32
Week of Oct 7, 2001	00:14:37
Week of Oct 14, 2001	00:16:19
Week of Oct 21, 2001	00:11:22
Week of Oct 28, 2001	00:11:29
Week of Nov 4, 2001	00:22:23
Week of Nov 11, 2001	00:17:04
Week of Nov 18, 2001	00:15:52
Week of Nov 25, 2001	00:17:58
Week of Dec 2, 2001	00:10:11
Week of Dec 9, 2001	00:07:15
Week of Dec 16, 2001	00:02:28
Week of Dec 23, 2001	00:05:03
Week of Dec 30, 2001	00:12:34
Week of Jan 6	00:05:49
Week of Jan 13	00:08:37
Week of Jan 20	00:02:10
Avg	**00:11:34**

Figure A-3. Hourly Visits.

Hourly visits

Visits by hour of the day



Hourly visit statistics

Average number of visits (all hours)	0.46
% of visits (work hours)	36.58%
% of visits (nonwork hours)	63.42%

Figure A-4 Daily Visits

Daily Visits

Visits by day of week trends

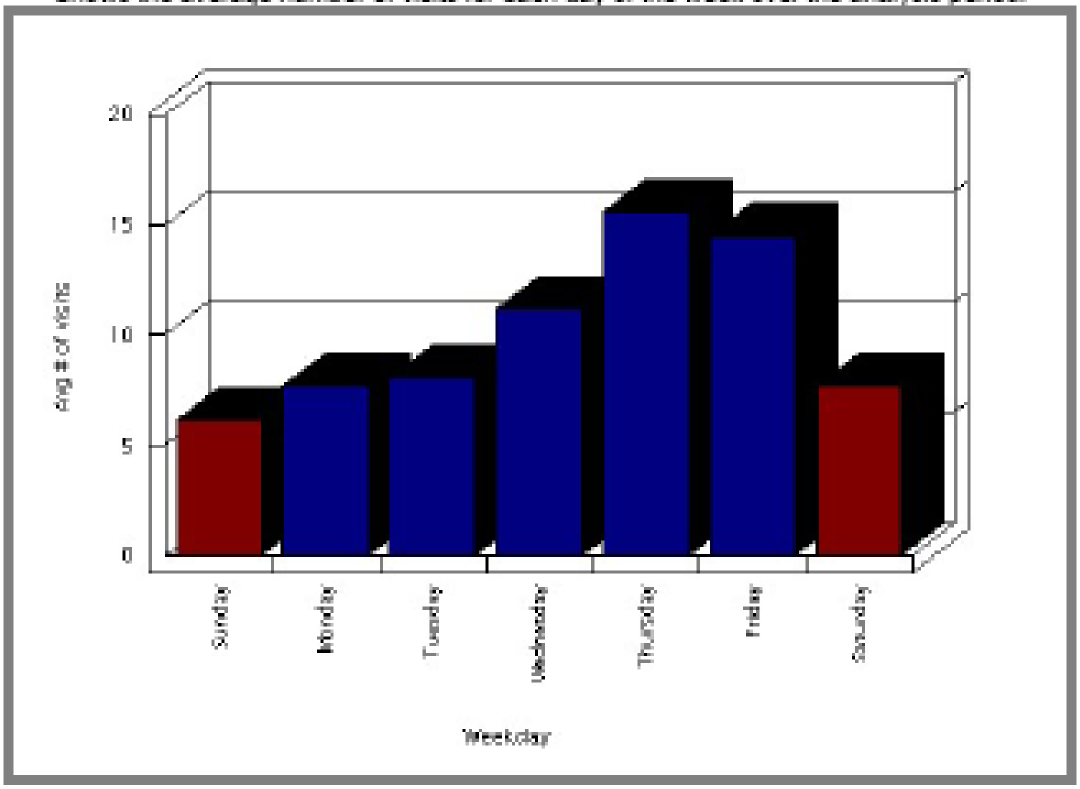
Shows how the visits per day of week vary over the weeks in the analysis period.

Week	**Weekday**							
	Sun	Mon	Tues	Wed	Thurs	Fri	Sat	**Total**
Week of Dec 16, 2001	13	8	13	9	93	78	55	**269**
Week of Jan 6	9	16	12	11	38	18	8	**112**
Week of Dec 23, 2001	12	12	7	18	8	32	10	**99**
Week of Nov 25, 2001	3	17	9	28	16	4	5	**82**
Week of Dec 9, 2001	4	7	9	26	20	13	7	**86**
Week of Oct 14, 2001	5	7	6	5	15	20	0	**58**
Week of Dec 30, 2001	7	3	6	19	12	17	8	**72**
Week of Dec 2, 2001	8	5	10	18	7	6	5	**59**
Week of Jan 13	5	616	13	18	16	10	17	**95**
Week of Nov 11, 2001	4	7	14	10	7	8	6	**56**
Week of Oct 28, 2001	7	4	3	13	6	5	0	**38**
Week of Jan 20	8	8	13	0	0	0	0	**29**
Week of Nov 4, 2001	2	5	12	3	4	6	3	**35**
Week of Oct 7, 2001	7	4	0	4	9	11	5	**40**
Week of Sep 30, 2001	0	0	0	0	0	10	0	**10**
Week of Nov 18, 2001	6	6	9	2	9	4	1	**37**
Week of Oct 21, 2001	4	6	0	6	5	4	1	**26**
Avg	**6**	**8**	**8**	**11**	**16**	**14**	**8**	

Figure A-4. Daily Visits (continued).

Visits by day of week

Shows the average number of visits for each day of the week over the analysis period.



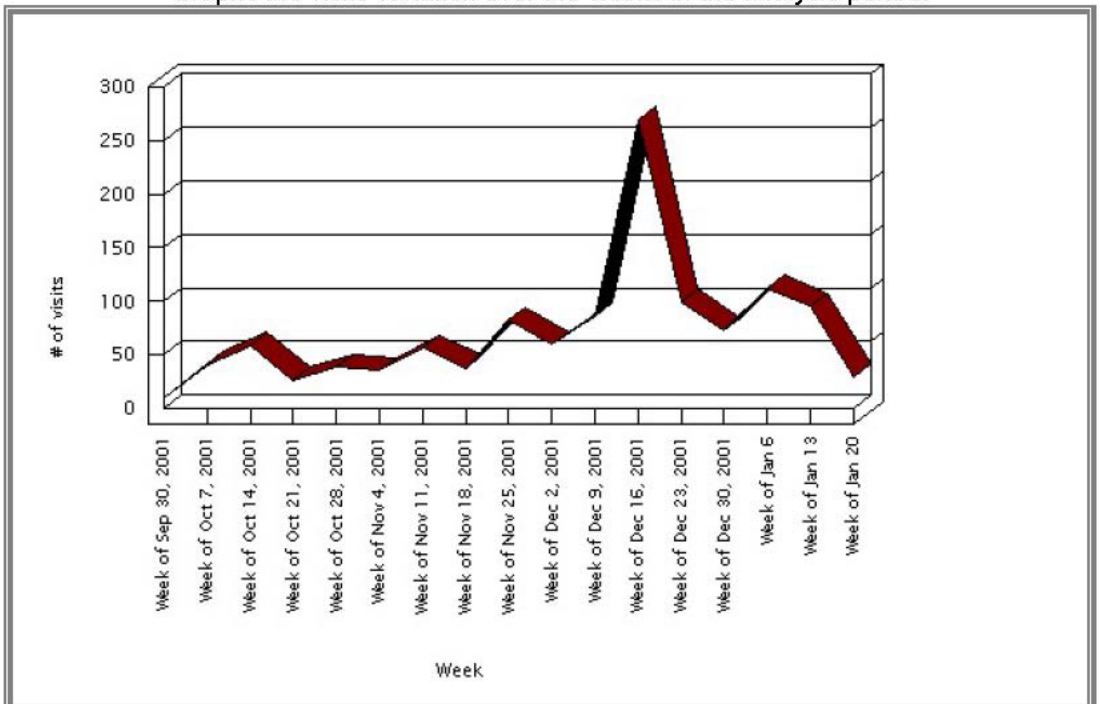
Weekly visit trends

Figure A-5. Weekly Visits.

Weekly visits

Weekly visit trends

Graphs the visits variation over the weeks in the analysis period.



Weekly visit and request trends

Shows for each week the average number of requests and visits plus the average number of requests per visit. Referring organizations have pages on their site that link users to your site. This graph shows the Shows the hits for each day in the analysis period. Weekdays are shown as blue bars and weekends as red bars.

Week	# of Requests	# of Visits	Avg Requests per Visit
Week of Sep 30, 2001	172	10	17.20
Week of Oct 7, 2001	511	40	12.78
Week of Oct 14, 2001	792	58	13.66
Week of Oct 21, 2001	202	26	7.77
Week of Oct 28, 2001	301	38	7.92
Week of Nov 4, 2001	558	35	15.94
Week of Nov 11, 2001	607	56	10.84
Week of Nov 18, 2001	366	37	9.89
Week of Nov 25, 2001	1629	82	19.87
Week of Dec 2, 2001	612	59	10.37
Week of Dec 9, 2001	765	86	8.90
Week of Dec 16, 2001	1294	269	4.81
Week of Dec 23, 2001	580	99	5.86
Week of Dec 30, 2001	794	72	11.03
Week of Jan 6	662	112	5.91
Week of Jan 13	705	95	7.42
Week of Jan 20	111	29	3.83
Average	**627**	**71**	**8.86**

Figure A-6. Top 10 Referring Organizations.

Summary

Top 10 referring organizations

top 10 organizations that users linked from to reach your site.

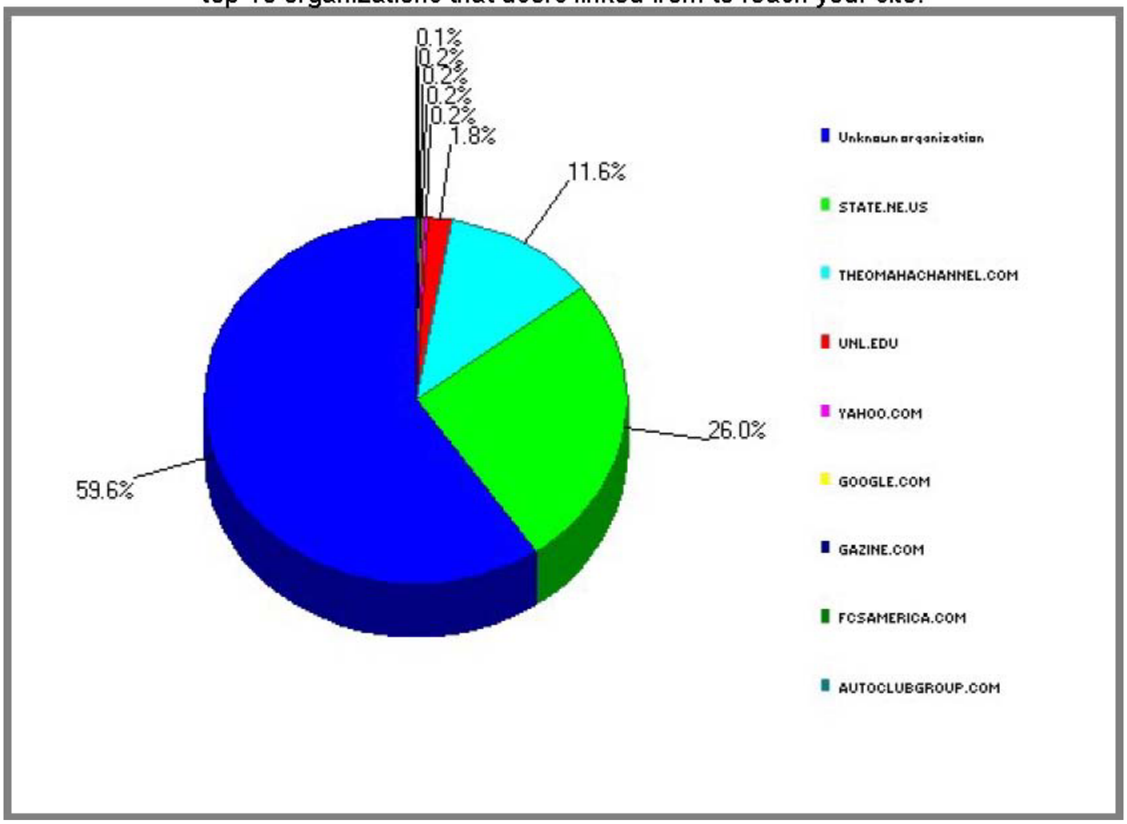


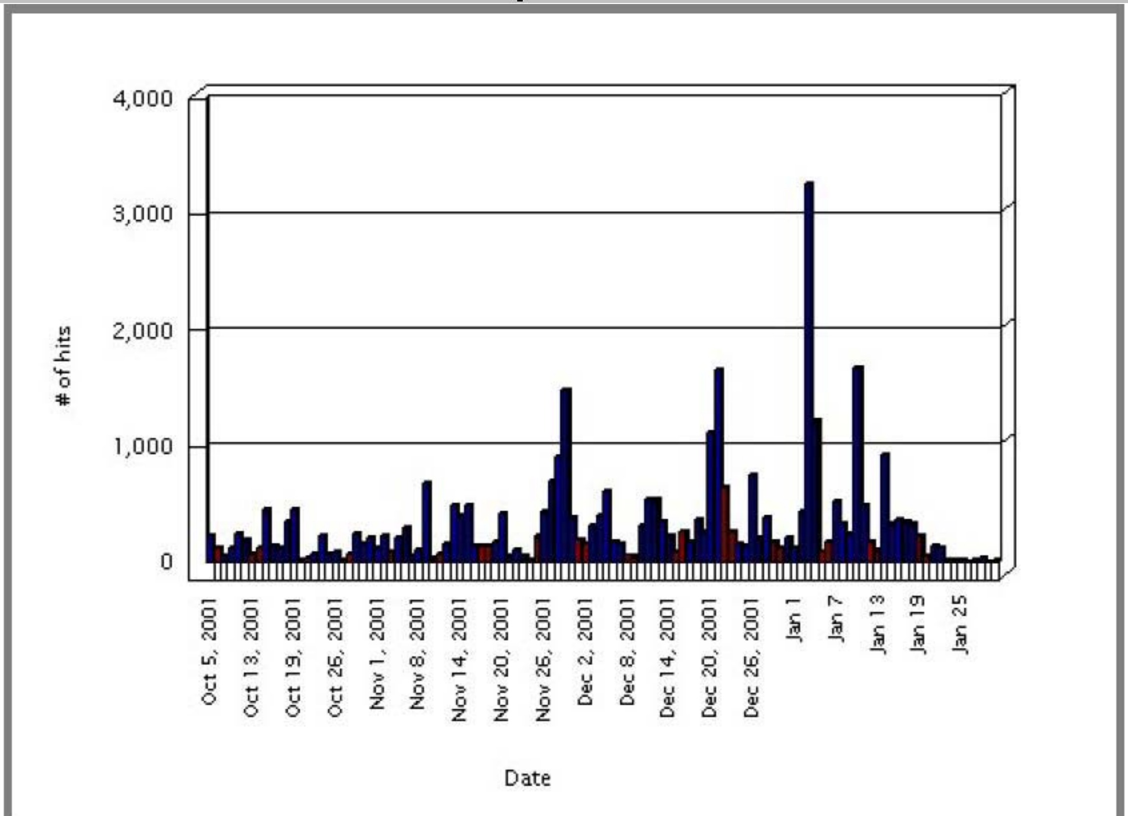
Figure A-6. Top 10 Referring Organizations. (continued).

Top 10 referring organizations				
	Referrer organization name	**# of visits**	**% of visits**	**Avg # of requests per visit**
1.	Unknown organization	717	59.60%	10.54
2.	STATE.NE.US	313	26.02%	7.59
3.	THEOMAHACHANNEL.COM	140	11.64%	3.63
4.	UNL.EDU	22	1.83%	5.68
5.	YAHOO.COM	3	0.25%	4.00
6.	GOOGLE.COM	3	0.25%	13.67
7.	GAZINE.COM	2	0.17%	6.50
8.	FCSAMERICA.COM	2	0.17%	7.50
9.	AUTOCLUBGROUP.COM	1	0.08%	10.00
	Total	**1,203**	**100.00%**	

Figure A-8. Daily Hits.

Daily hits

Daily hit trends



Daily hit statistics

Total hits	35,077
Average number of hits (all days)	321.07
% of hits (weekdays)	88.94%
% of hits (weekends)	11.06%

Most active date

Date	# of hits
Jan 3	3,263

Least active date

Date	# of hits
Jan 27	4

Figure A-9. Browser Products

Microsoft Version Trends
Top 10 Operating Systems

Shows the top 10 operating systems based on percentage of visits to your site.

	Operating system	% of visits
1.	Windows (16 bit)	77.97%
2.	Unknown operating system	14.96%
3.	Windows (32 bit)	6.07%
4.	Macintosh (PowerPC)	1.00%
	Total	**100.00%**

Browser Market Share

Shows the percentage of visits to your site using Netscape and Microsoft browsers over the analysis period.

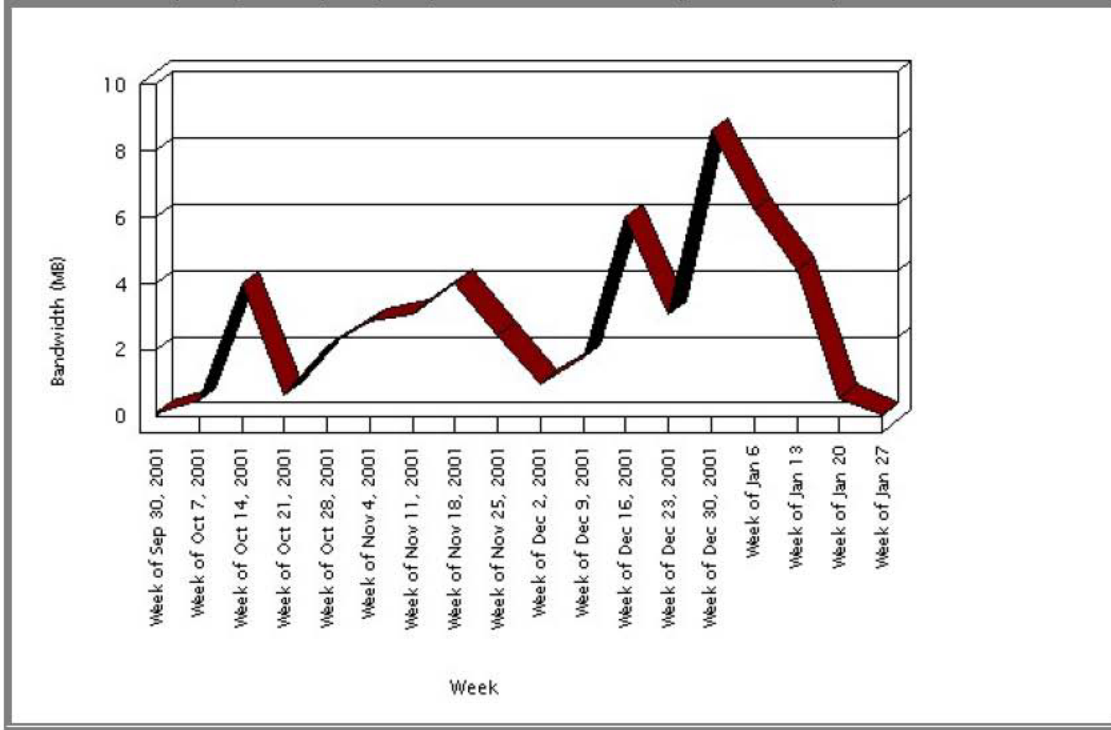
Week		**Browser Product**	
	Microsoft Internet Explorer	Netscape Navigator	Other Browser Product
Week of Dec 16, 2001	72.12%	24.54%	3.35%
Week of Nov 25, 2001	97.56%	2.44%	0.00%
Week of Dec 23, 2001	75.76%	20.20%	4.04%
Week of Dec 9, 2001	81.40%	3.49%	15.12%
Week of Jan 13	69.47%	26.32%	4.21%
Week of Jan 6	56.25%	28.57%	15.18%
Week of Oct 14, 2001	94.83%	5.17%	0.00%
Week of Nov 11, 2001	96.43%	3.57%	0.00%
Week of Dec 2, 2001	89.83%	10.17%	0.00%
Week of Dec 30, 2001	62.50%	30.56%	6.94%
Week of Oct 7, 2001	97.50%	0.00%	2.50%
Week of Sep 30, 2001	100.00%	0.00%	0.00%
Week of Nov 18, 2001	97.30%	2.70%	0.00%
Week of Nov 4, 2001	100.00%	0.00%	0.00%
Week of Oct 21, 2001	96.15%	3.85%	0.00%
Week of Jan 20	68.97%	20.69%	10.34%
Week of Oct 28, 2001	100.00%	0.00%	0.00%
Average	**85.65%**	**10.72%**	**3.63%**

Figure A-10. Weekly Bandwidth.

Weekly bandwidth

Weekly bandwidth trends

Shows the variation in bandwidth over the weeks in the analysis period. Use this information to plan your capacity requirements to assure good user experiences.



Week	Bandwidth (MB)	% of bandwidth
Week of Sep 30, 2001	0	0.15%
Week of Oct 7, 2001	0	0.93%
Week of Oct 14, 2001	4	7.82%
Week of Oct 21, 2001	1	1.22%
Week of Oct 28, 2001	2	4.09%
Week of Nov 4, 2001	3	5.54%
Week of Nov 11, 2001	3	6.03%
Week of Nov 18, 2001	4	7.84%
Week of Nov 25, 2001	2	4.77%
Week of Dec 2, 2001	1	1.92%
Week of Dec 9, 2001	2	3.42%
Week of Dec 16, 2001	6	11.72%
Week of Dec 23, 2001	3	5.96%
Week of Dec 30, 2001	9	16.76%
Week of Jan 6	6	12.10%
Week of Jan 13	4	8.59%
Week of Jan 20	1	1.07%
Week of Jan 27	0	0.07%
Avg	**3**	**5.56%**

Figure A-11. Definitions.

Definitions

Hit	Any connection to an Internet site, including inline image requests and errors.
Request	A *hit* that successfully retrieves content. Requests don't include inline image, ad view, or ad click requests or errors. Request counts are conservative because browsers and many Internet gateways intercept some requests before reaching the server, and these cached requests are never logged.
Visit	A series of consecutive requests from a user to an Internet site. If your log data includes *referrer* data, then new visits begin with referring links external to your Internet site. Regardless of whether or not you have referrer data, if a user doesn't make a request for a certain period of time, the previous series of requests is considered a completed visit.
User	Anyone who visits the site at least once. If your log data contains *persistent cookie* data, the software uses this data to recognize unique users. If no cookie data is available, the software uses a registered *username* to recognize users. If no registration information is available, the software uses as a last resort, users' Internet *hostnames*. Many organizations use Internet gateways, which mask the real Internet hostnames, so user counts may be conservative for those users determined through their Internet hostnames.
Organization	A commercial, academic, nonprofit, government, or military entity that connects users to the Internet, identified by an entity's Internet *domains*. Microsoft Site Server Express Analysis groups together all domains registered to the same organization as one organization. If a domain is unavailable in the database, one Internet domain is used to identify one organization.
Request duration	The time between two consecutive requests within the same visit. Microsoft Site Server Express Analysis assigns the last request of a visit a request duration of 0 seconds because its actual duration can't be determined.
Visit duration	The time between the first and last request of a visit. This time doesn't include how long users viewed the last request of a visit.
Ad view	A hit that successfully retrieves advertiser content. Ad view counts are conservative because browser software and many Internet gateways intercept some requests before reaching the server, and these cached requests are never logged.
Ad click	The number of requests caused by the user "clicking" on advertising content. Typically, users are directed to the advertiser's site after the ad click.
Ad yield	The percentage of ad views that resulted in an ad click.
Geography	The continent, country, region, state, city, and Zip code are based on an organization's Internet domain registration. Only Internet domains found within the Analysis database are included within region, state, city, and Zip code report documents. Each Internet domain is associated with only one Zip code, so all users from a domain used in multiple locations are considered to be at one location.