

# Incident Management Using Total Stations

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Many strategies have been used to improve incident management. A novel approach to improving incident clearance when accidents require detailed investigation is described. This approach involves the use of computerized surveying equipment, called electronic total stations, for accident investigation. The use, advantages, and disadvantages of electronic total station survey equipment for expediting the investigation at serious traffic accidents are discussed. A comparison of three accident scenes where the coordinate method of accident investigation and total stations were used to measure the same incident showed that investigators can take over 70 percent more measurements per hour by using total stations. Furthermore, investigation with the total stations required only 46 percent of the time required with the coordinate method. A comparison of urban freeway accidents covering 1 year before total stations were used to 1 year during total station use showed an average time savings of slightly more than 51 min in the time to clear the scene of an incident. Accident drawings were also more accurate and could be prepared in less time.

A 1989 study of the nation's 37 largest urban areas by FHWA estimated that in 1987 more than 60 percent of all freeway congestion in urban areas was caused by incidents. Incident-related delay cost freeway users an estimated \$10 billion in excess fuel consumption and motorist delay. By 2005, the estimates indicate, more than 70 percent of all urban freeway congestion will be caused by incidents, costing users nearly \$64 billion (1).

Because of the tremendous effect that incidents have on our transportation system and the economic health of our nation, transportation professionals have focused more and more on incident management as an extremely effective tool to reduce congestion and increase safety on urban freeways across the country. Incident management is the "coordinated, preplanned use of human and mechanical resources to restore full capacity after an incident occurs, and to provide motorists information and direction until the incident is cleared" (2). Incident management can be divided into five basic tasks (3):

- Incident detection and verification,
- Incident response,
- Incident site management,
- Incident clearance, and
- Motorist information.

Many strategies have been used to improve incident management in each of these basic areas. However, few techniques have been devised to speed incident management when formal law enforcement investigation is required. This paper describes a novel approach to improving incident clearance

when accidents require detailed investigation. This approach involves the use of computerized surveying equipment—electronic total stations—for accident investigation.

In a recent study of incidents in the Seattle area, researchers found that almost 40 percent of the accidents in the most heavily traveled freeway sections involved injuries (4). Furthermore, as the number of injuries increased, so did the length of time required to clear the accident. In general, as accident severity increases, so does clearance time. One reason for this increase is the investigation time required for certain accidents. Measurements must be taken of the accident site, and detailed information on vehicle location must be collected. By reducing the amount of investigation time, the overall clearance time for these accidents can be reduced and with it, the subsequent congestion, excess fuel consumption, and pollution emissions.

In a recent demonstration project, electronic surveying systems were used by Washington State Patrol personnel; these systems are called infrared total stations. Several manufacturers offer this equipment. Total stations allow automatic distance measuring, and the measures are fed directly into a computer for analysis. Total stations were designed for general surveying work, and surveyors have used them for many years. This paper describes the use, advantages, and disadvantages of electronic total station survey equipment for expediting required investigation at scenes of serious incidents. Even though police or state patrol are most likely to use this technology, other incident management agencies—notably, state highway agencies—may be most interested in its use because it reduces the time to clear an incident, reducing delays to motorists and minimizing the time that incident respondents are exposed to danger during an incident.

## TRADITIONAL ACCIDENT INVESTIGATION

Accident investigation is a necessary part of incident response and management. On Washington State's highways and freeways this duty falls on the Washington State Patrol. They are required to investigate accidents involving fatalities, alcohol or other drugs, and suspected felonies. They also investigate any accident that they believe will be the subject of court action. The information is used to prosecute violators; produce statistics that influence safe vehicle, pavement, and highway design; and provide evidence during litigation.

A detailed investigation requires a large number of data. Troopers determine the cause of the accident by establishing the direction of travel, speed, and any unusual movements of all the vehicles involved. They must measure the locations at which skid marks start, end, or change direction; the locations at which curves begin or end; debris patterns; gouges and

scratches; intersections; warning signs; and any other potentially relevant details.

There are several steps to accident investigation. After the troopers have been called to the scene, they find the important objects to be measured. Next, they measure all the physical evidence at the scene. Then they remove their equipment from the site. Finally, back at the office, they file a report and recreate the scene in a scale drawing.

Although these steps have remained fairly constant over the years, accident investigation and reporting methods have evolved. Most often today, investigators use the coordinate method. They lay down a base tape straight through the accident scene. The locations of all other objects and sites are measured as a distance perpendicular to the base tape. This method takes a minimum of two people, and usually three: one to hold the tape, one to read the measurements, and one to write the numbers and descriptions of the measured points in a field book. Traffic control people are also required when measurements are made across traffic lanes.

Back at the office, staff painstakingly recreate the scene by hand. They start by drawing the baseline created in the field. They draw all the measured points to scale in relation to that line and rely on the field book notes to tell them what the points represent. They complete the drawing with hand-drawn vehicles, trees, signs, and any other objects measured.

This method of accident investigation is accurate, but it can cause problems for the troopers and the motoring public.

### Disadvantages to Motorists

The greatest negative effects of long clearance times associated with accidents that require formal investigation are probably borne by the traveling public. Depending on the size of the incident, current methods of accident investigation normally require that lanes, or even the entire roadway, be closed so that investigators can measure the site. Depending on the size of the accident, the road may be closed anywhere from 45 min to several hours.

Many studies have shown the serious effects of freeway incidents on congestion.

- A study in California showed that for each minute of blockage during off-peak periods on freeways, 5 min of congestion can be expected. During peak periods, the effects on congestion are much greater (5).

- A study in Houston showed that 80 percent of all incidents reduced capacity by at least one-third, regardless of whether a lane was blocked. On a three-lane freeway, the capacity was reduced by half when one lane was blocked (6).

- In Seattle motorists experienced an estimated 18.4 million hr of delay in 1984, 58 percent of which was the result of freeway incidents (7).

This congestion has important consequences to the public. For example, congestion causes safety problems. The longer the road is closed, the greater is the probability that secondary accidents will occur in the queue.

Also important, although difficult to quantify, are the costs of driver frustration. This frustration can, in turn, compromise safety, as delayed, angry drivers may take unreasonable risks.

### Disadvantages for Responding Personnel

The traditional method of accident investigation also has disadvantages for the personnel responding to the incident. A major consideration is safety. The coordinate method requires investigators to be in the traveled roadway to take most of their measurements. Even though lanes may be closed, these measurements are often taken next to open lanes of traffic, increasing the investigators' exposure to danger.

Another major disadvantage for those responding to incidents is time. Enforcement personnel report that they are able to take about 30 to 45 measurements an hour. Depending on the severity and size of the accident, investigation may take anywhere from 45 min to 6 hr or more. The extensive time required for full investigation not only affects the traveling public and increases all incident respondents' exposure to traffic dangers, but affects the efficiency of the organizations to which the respondents belong. The longer that respondents are at an incident scene, the longer they are unavailable for other duties and the more expensive the incident becomes. In addition, an investigator may need up to 8 hr to complete a scale drawing.

Data accuracy and completeness are also issues. Investigators must take measurements at a 90-degree angle from the baseline tape. If they measure objects 30 ft or more away from the baseline, they risk unintentionally moving the tape and creating errors. Furthermore, their longest tapes are fiberglass, which is temperature-sensitive and can stretch 2 to 3 in. over 300 ft.

A final factor is convenience. For example, the tape is lightweight and may blow in the wind. The investigators may also have trouble clearing a path for the baseline, which must be flat on the ground and run through the accident site. In addition, the longest tape is 300 ft. If the site is larger than that, the troopers must set out a second baseline.

### TOTAL STATION TECHNOLOGY

The electronic total station is a combination of an electronic distance meter, which uses an infrared light to measure distance, and a theodolite, or electronic transit. Several manufacturers offer this equipment. The cost for the field equipment is in the range of \$15,000, bought in any quantity (the list price is somewhat higher). Surveyors have used this equipment for about 15 years, but it has only recently been adopted for measuring accident scenes.

The electronic distance meter calculates distance by sending an infrared light to a prism on a rod, which is held on the object to be measured, and averaging the time the light takes to move to the prism and return. The infrared light replaces the measuring tape used in the coordinate method. The theodolite measures the horizontal angle from the 0 point at the baseline. Because the station has an internal level, it can also measure vertical angles.

To take measurements, an investigator places the total station at a site from which he or she can view all the objects to be measured. Because the prism is on a tall rod, the total station can measure over the tops of objects, including moving traffic. Most of the time one placement is all that is necessary. One person holds the rod with the prism on a point or object

to be measured. Another person sites the total station on the prism. This simple procedure allows the station to measure distance, horizontal angle, and vertical angle simultaneously. A small window shows the measurement information while it is being collected and calculated.

The total station also includes a computer that stores the data as they are electronically collected, replacing the traditional field book. The investigator keys in a code or label for each measured point. The code is a drafting or plotting command for use with an office plotter or computer system.

In the office, the total station connects directly to a plotter to download the information for a quick, crude plot. It can also be connected to a microcomputer so that the investigator can manipulate the data within a data base or drafting program. The drafting program interprets the assigned codes and plots a diagram. It can add details of cars, trees, and other objects that have been predrawn and stored in the computer. The investigator can even produce an animated recreation of the incident.

## EVALUATION

The research team evaluated the use of total stations for accident investigation as an incident management strategy. The purpose of the evaluation was to (a) determine the effectiveness of using total stations for accident investigation, (b) determine the value of using total stations for incident management, and (c) produce information that would encourage the use of total stations as an incident management strategy.

The research approach was broken into three parts.

1. Investigation times were compared on three accident scenes at which both the coordinate method and the total station method were used.
2. Incident clearance times were compared on urban freeway accidents in the Seattle area that required formal investigation. Accidents from 1989, before total stations were used, were compared with 1991, when total stations were used exclusively.
3. Researchers estimated the benefit-cost relationship of using total stations as incident management tools.

### Investigation Time

The first evaluation method involved the investigation itself. Three accident sites were measured with the traditional coordinate method and with electronic total stations. The first

accident (Site A) was a one-car fatality on a two-lane rural highway. The accident occurred at night. The driver ran off the road on a curve near an intersection and struck a roadside telephone pole. The driver died on the scene.

The second (Site B) was a two-car collision involving a police car. The accident occurred at night in a small town on a two-lane state highway. One car pulled out of a side street to turn left onto State Route 2. The driver apparently did not look to his left and was struck broadside by a police car traveling on the state highway. The accident resulted in serious injuries.

The final accident (Site C) also occurred on a two-lane rural highway at night. A county deputy was involved in the collision, and a very serious injury resulted. The driver of the civilian car crossed the centerline on a curve and struck the deputy's car head-on.

According to the Washington State Patrol detective that measured the scenes with the total station equipment, all three accidents were typical of accident scenes investigated. None of the geometrics was particularly complex. The investigation time evaluation compared two measures of effectiveness: measurements taken per hour and time to measure a scene fully. For each accident, Table 1 shows the number of measurements taken and the time required to investigate the scene fully with both the coordinate and total station methods.

From this information, the advantage of total station accident investigation is clear. A calculation based on the average of the three accidents reveals that electronic total stations require only about 46 percent of the time to investigate an accident scene that the coordinate method requires. In addition, investigators can take over 70 percent more measurements per hour with total stations than with the coordinate method.

One advantage of total stations that is not evident from these measures is the ability to provide more accurate and detailed collision and scene diagrams. In each of the three accidents listed, only the bare essentials of the accident scene were measured with the coordinate method, whereas the entire scene was measured and subsequently plotted with the total stations.

At Site A, investigators measured only part of the roadway curve, one edge stripe, four tire marks, and the final point of rest using the coordinate method. No intersection information was collected. With the total station method, they measured and plotted the entire intersection and roadway.

At Site B, similar results were obtained. Using the coordinate method, the investigators measured the site of impact, the tire marks, and the final point of rest. With the total station method, they were able to measure the entire intersection.

TABLE 1 Comparison of Investigation Techniques

Accident Site	Measurements per Hour		Time to Investigate	
	Coordinate Method	Total Station	Coordinate Method	Total Station
Site A	32.4	47.0	150 min	60 min
Site B	30.0	50.4	90 min	75 min
Site C	24.0	52.0	150 min	45 min
Average	28.8	49.8	130 min	60 min

At Site C, investigators used the coordinate method to measure the entire roadway over a 300-ft section of the curve where the accident took place. Using the total station method, the investigator measured the entire curve and tangent sections on either end of the curve. A ¼-mi section of roadway was fully detailed.

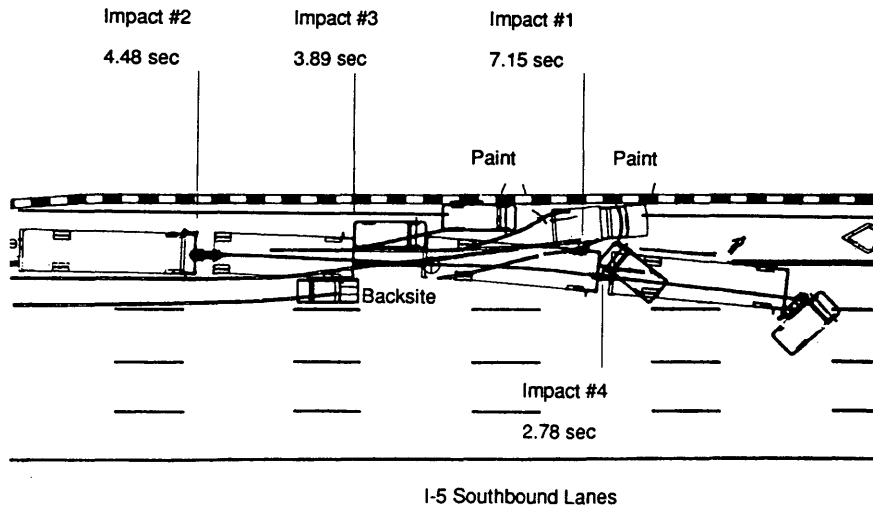
To give a better understanding of the improved quality of accident diagrams produced from total station data, typical diagrams produced from both types of investigation are presented here. Figure 1 is a reproduction of an accident scene investigated with the coordinate method. Figure 2 is a reproduction of an accident scene investigated with total stations. (Figure 2 is a black-and-white reproduction of color graphics, whereas the diagrams produced from the coordinate method were drawn in black and white.) Additionally, many more types of diagram can be produced quickly and efficiently. For accidents investigated with the coordinate method, only scene diagrams were produced. By using total stations for field in-

vestigation and an office computer, investigators can easily prepare momentum diagrams, time and distance diagrams, and vehicle damage profiles, as well as scene diagrams. The accident can even be presented with animation on a computer screen.

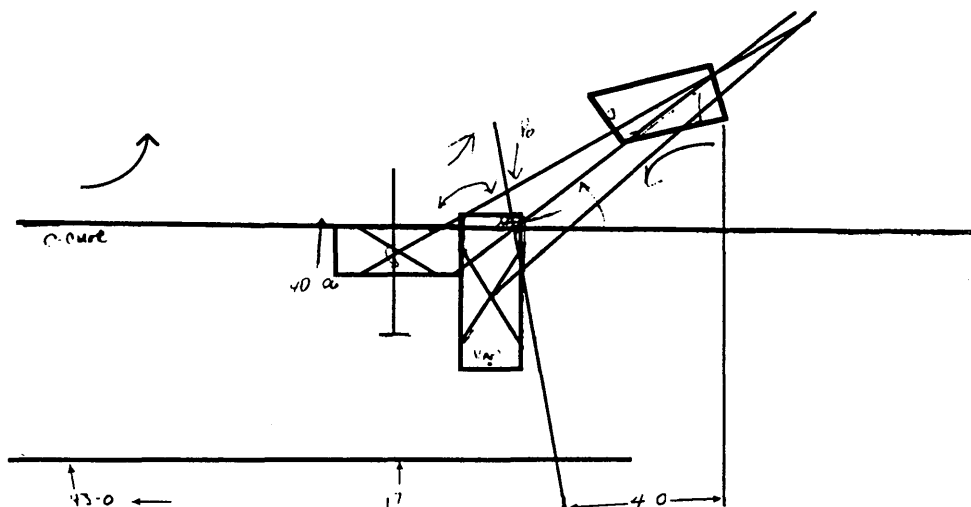
The Washington State Patrol estimates that its investigators need about 2 hr to complete a drawing that used to take 8 hr by hand. The system creates a computerized data base of site drawings that are reusable when an accident occurs at a previously measured site. Washington State Patrol has found this feature especially useful for complex intersections.

**Incident Clearance Times**

The evaluation of incident clearance times covered accidents on freeways within the Seattle urban area. These incidents have a great effect on motorist delay and overall freeway



**FIGURE 1** Typical scene diagram, total station method.



**FIGURE 2** Typical scene diagram, coordinate method.

operations. Incident management efforts are focused on incidents on these sections of roadway.

Urban freeway accidents that were investigated in 1989, before total stations were in use, were compared with urban freeway accidents that were investigated in the first 7 months of 1991, after total stations were in use on all investigations. The difference between the time at which the Washington State Patrol was notified of the accident to the time at which the incident was cleared was compared for the two groups of accidents. Researchers had to match two separate data sources to extract the needed information. One data source was the log of all traffic investigations. This data source did not include any indication of time of notification or time of clearance, but it did provide a list of all accidents that were investigated using the coordinate method in 1989 and total stations in 1991. The Washington State Patrol's computer-aided dispatch files were used to extract the time of notification and time of clearance. The only common fields in the two data sources were date, type of accident, and location. The two data sources did not use exactly the same descriptions for location and type of accident. Therefore, researchers had to be very conservative in determining matches between the two data sources. Although about 40 urban freeway accidents are investigated each year in the Seattle area, only 20 matches were found in the 1989 data and 16 in the 1991 data.

The next step was for the researchers to look at accident type to determine whether roughly similar types of accidents were investigated in the 2 years. In this process, the researchers discovered that a relatively rare type of accident was investigated in 1991 (a combination of automobile theft and vehicular assault) that did not appear in 1989. This was the only instance of this combination in any of the data searched. All other types were found on several occasions in both years. The automobile theft and vehicular assault incident was discarded in all further evaluation.

For all remaining accidents, 20 for 1989 and 15 for 1991, clearance times were determined by subtracting the time of clearance (the time that the roadway was cleared of the accident) from the time of notification (the time the state patrol first received information on the accident). The average and standard deviation were calculated for each set of clearance times. Accidents that were investigated with total stations were cleared an average of 51 min sooner than accidents investigated with the coordinate method (131 min for total stations and 182 min for the coordinate method). The standard deviations of clearance times for the two types of investigation were equivalent (68.5 min for total stations and 69.9 min for the coordinate method). The statistical significance of the difference in the means was tested at the 95 percent confidence level. The difference was statistically significant at that confidence level.

Clearance time alone does not fully describe the benefits of the system. Total stations can be set off of the roadway, and measurements can be taken across open lanes of traffic. Lanes can be opened more quickly, reducing motorist delay. About the same time that the state patrol began using total stations, the Washington State Department of Transportation (WSDOT) began keeping track of lane closure time for every incident to which it responded. These data were not available for the years in which the state patrol used the coordinate method, so a direct comparison was impossible. However, this advantage of total stations should not be overlooked.

### Benefit-Cost Relationship

The research team conducted a benefit-cost analysis of the use of total station equipment for accident investigation. The cost of the equipment was compared with the value to the traveling public of reduced fuel consumption and reduced delay. A simple computer model of freeway queueing analysis (FREWAY) was used to determine differences in delay for accidents investigated with total stations and with the coordinate method. Traffic volumes are the primary data needed for this model.

Because of the difficulty in finding hourly traffic volumes for each accident investigated, one peak-period accident that occurred in 1991 was selected as the basis for this evaluation. The accident occurred in the peak direction southbound on Interstate 5 (toward downtown Seattle) shortly after 7:00 a.m., the height of the morning peak period, on Wednesday, May 22, 1991. Because of a hardware problem in the computer that would have accumulated traffic information for the Seattle area freeway management system, exact data for that day were unavailable. The research team used the published 1990 peak-hour volume for the accident location (8). To use the results directly from the evaluation of clearance time, the research team assumed the average clearance times for the total station (131 min) and coordinate method (182 min) cases. A 4-hr simulation time was chosen.

No volume data were available other than for the peak hour; however, the model required volume information throughout the incident and through the time that congestion ceased. The researchers analyzed hourly data from the same section of freeway at other times of the year and found that about 87 percent of the peak-hour flow occurred between 8:00 and 9:00 a.m., about 67 percent between 9:00 and 10:00 a.m., and 58 percent between 10:00 and 11:00 a.m. Because the researchers believed that volumes in the mid-morning were more variable than during the peak period, a conservative estimate of 50 percent of the peak flows was used for the hours 9:00 to 10:00 and 10:00 to 11:00. Table 2 shows the volumes used for the simulation.

Because no information on lane blockages was available for this incident, the research team assumed that two lanes out of five were blocked for the duration of the incident. The model then calculated the unrestricted and incident capacities of the freeway segment. Table 3 presents the results of the simulation. As can be seen in the table, the use of total stations saved nearly 7,000 vehicle-hr of delay for this accident.

There are several weaknesses in this evaluation. The actual volumes were not used. The average clearance times, rather than the specific clearance time for the given accident, were used to normalize the accident. The exact number of lanes closed during the accident was not available. Finally, only

TABLE 2 Hourly Volumes Used for FREWAY Simulation

Time of Day	Traffic Volume
7:00 - 8:00 am	9090
8:00 - 9:00 am	7900
9:00 - 10:00 am	4500
10:00 - 11:00 am	4500

TABLE 3 Comparison of Simulation Results

Measure	Coordinate Method	Total Station
Total Delay	22,211 veh-hr	15,365 veh-hr
Average Delay	51 min/delayed vehicle	37 min/delayed vehicle
Delay Savings	-	6,846 veh-hr

local impacts were taken into consideration, even though an accident of this severity during the morning peak period would certainly affect conditions on many other links in the system. However, the research team took a conservative approach on each of these instances, so the benefits of using the total station equipment were underestimated. The simulation results should be viewed as typical savings for a representative peak-period accident.

The researchers checked the validity of these results with earlier incident research conducted by Mannering et al. at the University of Washington (9). The Mannering study analyzed the systemwide impacts of peak-period incidents at specific locations on the network. One such location was on Interstate 5 approximately 4 mi south of the location examined here. That research assumed a 75 percent reduction in capacity. The study concluded that for a 60-min incident at the southern location, the impact on the system amounted to slightly more than 16,000 vehicle-hr of delay, or roughly the same as the incident simulated here lasting approximately twice as long. The Mannering study also indicated that the longer the incident is in place, the greater is the relative impact of not clearing the incident. For example, the impact between clearing the incident in 60 min versus 50 min was estimated to be about 5,400 vehicle-hr of delay. The results of the Mannering study lend credence to the magnitude of impact presented in this paper.

The final step of determining the benefit-cost relationship of using total stations as an incident management tool was to assign costs to the benefits and compare these costs to the purchase price of the equipment. The field equipment cost WSDOT about \$15,000/system. The estimated benefit of 7,000 vehicle-hr of delay savings and an assumed value of time of \$7.00/vehicle-hr produce a benefit in reduced delay of \$49,000. For a single peak-period accident, the benefit is more than three times the cost of the equipment. Given that the value of time is a very controversial subject, the researchers determined the break-even point for the investment on the basis of reduced delay. The equipment would have paid for itself on the single accident simulated if the value of time was as low as \$2.14/hr.

The research team also estimated the benefit in reduced fuel consumption. Lindley's work suggests that each vehicle hour of delay wastes about 1.1 gal of fuel (1). Therefore, the estimated fuel savings for the simulated accident are 7,700 gal because of the use of total stations. Assuming a very conservative estimate of \$1.00/gal of fuel, the use of total station equipment to investigate the accident simulated saved \$7,700 by reducing fuel consumption. On savings in fuel consumption alone, the price of the equipment would have been offset with the second peak-period accident investigated.

Although this benefit-cost analysis was relatively simplistic, using many assumptions, the magnitude of the traffic benefits clearly outweigh the cost of the equipment.

## CONCLUSIONS

### Advantages of Total Station Investigation

The most dramatic advantage of using total stations for accident investigation is the reduced delay to the traveling public. The data from urban freeway accidents investigated with total stations and the coordinate method indicate an average clearance time savings of 51 min per investigated accident. Regardless of any assumptions concerning the cost of fuel and value of time, the equipment cost is offset on the first peak-period accident.

Because the equipment can measure over the tops of cars, respondents rarely have to close the roadway completely, if at all. If the road is closed, the closure is shorter because the total station measurement is much faster than previous methods. These differences affect the occurrence and severity of congestion and subsequent secondary accidents, user costs, excess fuel consumption, and driver frustration.

The use of total stations also has some advantage to respondents. First, it increases safety for the investigators. Because scene details can usually be measured from one site and the total stations can measure over the tops of vehicles, investigators have much less need to be in the roadway. Measuring is also faster. As seen in the preceding data, on-scene investigation with total stations takes less than half the time to investigate that the coordinate method requires. Therefore, investigators are in or near the roadway, exposed to traffic, for much less time.

The equipment is also small and portable. It easily fits into a car trunk already filled with police and investigative equipment.

Also beneficial are the computerized drawings, which can be produced faster and can convey more information than the hand drawings. Washington State Patrol has found the computerized data base of reusable site drawings especially useful for complex intersections.

In addition to operational benefits, the total station method is important in tort liability cases. The equipment produces a more detailed accident description and a more professional drawing of the scene. The system's ability to work with a microcomputer to animate the accident scene gives a jury a better understanding of the events, causes, and effects of an accident. Better records are also retained in the files. Overall, total station accident investigation removes much of the ambiguity of accident recreation that is common when a trial does not take place until several years after an accident has occurred.

In Washington State, this benefit is important enough that a major accident investigation team has been formed. The team comprises two commissioned Washington State Patrol officers (one responsible for collision investigation and one for interviewing witnesses); one Washington State Patrol commercial vehicle enforcement officer to assess vehicle condition; and one WSDOT engineer to record and document the location and condition of the roadway, traffic control devices, and roadway safety appurtenances. The total station is the central piece of equipment that the investigation team uses in its investigations.

Perhaps the best indication of the benefits of the total station method for accident investigation is that the Washington State Patrol has bought three additional systems and antici-

pates buying two more. With this additional equipment, every investigation team in the patrol will be equipped with a total station system.

#### Potential Disadvantages of Total Station Investigation

Like any technology does, the total stations have a few disadvantages. The first is their cost. Costs vary somewhat by manufacturer, but their prices range from \$15,000 to \$20,000, depending on the office equipment needed. However, as is shown in the benefit-cost analysis, the equipment cost can be recouped in the first peak-period accident investigation.

The system also has some minor physical limitations. It is hard to use in dense fog because it is difficult for the investigators to site the prism. Measurement can also be affected by heat waves on extremely hot days. The stations run on rechargeable batteries, so investigators must keep extra batteries ready. Finally, although the systems are fairly easy to use, training is necessary, and investigators should use the systems often to remain proficient.

#### RECOMMENDATIONS

The information presented shows that electronic total stations can be used to reduce incident clearance times in a part of the incident management process that is seldom viewed as subject to time reduction: accident investigation by enforcement personnel. The researchers highly recommend the use of this tool as part of an overall incident management system. The clear benefits to traffic management during incidents indicates that highway agencies and departments of transportation are the agencies receiving most of the benefit of these systems. The researchers recommend that these agencies consider the use of total stations as an element of their incident management systems to be funded in the same manner as other incident management strategies.

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