Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TX-99/4907-2		

4. Title and Subtitle	5. Report Date
USE OF PHOTOGRAMMETRY FOR INVESTIGATION OF TRAFFIC INCIDENT SCENES	October 2000
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Scott A. Cooner, P.E. and Kevin N. Balke, Ph.D., P.E.	Report 4907-2

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. Project No. 7-4907

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Construction Division Research and Technology Transfer Section P. O. Box 5080 Austin Texas 78763-5080	Letter Report September 1999-August 2000
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation.
Research Project Title: Functional Process Specifications for Improving Incident Response

16. Abstract

This task examined how the Texas Department of Transportation and police agencies might use photogrammetry to assist in the clearing of major incident scenes. Using the literature and surveys of police agencies currently using photogrammetry, the research team learned some basic information about the technology and theory behind photogrammetry and its application in the field. This letter report documents the findings of this literature, provides some basic information on photogrammetry, and documents its applications by several police agencies throughout the United States and the world. The researchers learned that, for the most part, the use of photogrammetry in incidents is still largely in the testing phase. Preliminary and anecdotal results from interviews with law enforcement agencies are that photogrammetry is cost-effective (compared to a Total Station) as long as the necessary training for basic proficiency is provided. Some drawbacks to photogrammetry include more processing time by officers in the office, difficulty photographing long scenes, and difficulty seeing skid marks and other evidence at the scene without enhancing the scene photos.

17. Key Words	18. Distribution Statement
Incident Management, Photogrammetry	No Restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	29	

REPORT 4907-2

USE OF PHOTOGRAMMETRY FOR INVESTIGATION OF TRAFFIC INCIDENT SCENES

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INTRODUCTION

The benefits of rapid clearance of traffic incidents have been widely reported. For every minute saved in clearing the incident, an estimated four to five minutes of associated motorist delay are also saved *(1)*. Currently, law enforcement officers spend a considerable amount of time during an investigation of a traffic incident documenting evidence and measuring important scene characteristics. This project will introduce a new technology application, photogrammetry, for its potential in reducing the clearance time associated with traffic incidents. Photogrammetry is the technology of obtaining information (whether it be three-dimensional data or qualitative data) through the process of analyzing and interpreting photos. Photogrammetry records objects with non-contact methods and calculates the real dimensions of objects within the photographic image. Photogrammetric investigation of traffic incidents involves taking pictures of the scene by the responding officer(s) in the field. The measurement of vital incident data (i.e., skid marks, vehicle deformation, object locations, etc.) can then be performed back in the office at a later time using a microcomputer equipped with specialized software designed to make measurements from imported photos. At this point in time this technology has not been widely validated for its effectiveness in an incident management type of application.

This memorandum is divided into five major sections. The first section provides some background regarding the impetus for this research. The second section documents the results of a literature review on the subject of using photogrammetry for crash investigation. Some basic information on the technologies and theory behind obtaining measurements from photos will also be included in this subsection. The third section contains summaries of interviews with law enforcement agencies regarding the use and testing of photogrammetry for traffic accident investigation. The fourth section includes information on some of the currently available software programs available for performing measurements on incident photos. The final section summarizes the significant issues and benefits associated with using photogrammetry to investigate crash scenes.

BACKGROUND

The idea for this research developed at the Incident Management conference held in Dallas, Texas, in September 1999. Mr. John O'Laughlin of PB Farradyne, Inc., gave a presentation on the use of photogrammetry by law enforcement and its potential application for incident management. Mr. O'Laughlin is a former Washington State Patrol officer, and he indicated that photogrammetry has more potential to reduce incident clearance time than Total Station technology. Total Stations have become popular with law enforcement agencies for measuring and producing scale diagrams of incident scenes. A Total Station is basically a modern instrument that combines a theodolite and an electronic distance meter. Most Total Stations are fully computerized and are capable of recording all the angle and distance measurements so the operator does not need to hand-record the data in a log book. The Total Station is taken back to the office and attached to a computer that reads the data and loads it into a computer aided drafting (CAD) package for measurement and diagraming. Mr. O'Laughlin mentioned that photogrammetry is not the perfect measuring tool and different tools and technologies have their place in accident reconstruction and incident management. Mr. O'Laughlin also suggested that organizations that have the availability, versatility, and understanding of both (close-range photogrammetry and Total Stations) will do better in the field as far as the way incidents are handled.

LITERATURE REVIEW

A literature review concentrating on the theory, technology, and applications of photogrammetry was performed in this study, with an emphasis on crash investigation. Several different methods were used including the *Transportation Research Information System* search tool and the Internet.

Photogrammetry Basics: Measurement Theory

Photogrammetry is a science that is based on the mathematical law that the spatial location of a point is clearly definable if it is represented in at least two images. All topographic maps and many city maps were produced through photogrammetry. In these cases, the photos were taken with large-format film cameras from low-flying aircraft and were then processed with an instrument called a stereoplotter to produce the map data.

Photogrammetry is not limited to traditional film cameras. Video cameras, still video cameras, digital cameras, and normal consumer 35 millimeter (mm) cameras can all be used to perform three-dimensional (3-D) measurement using photogrammetric techniques. The use of video or photography also allows one to document other traits of the object such as surface color, texture, and general condition. A high-speed camera can be used to capture an object in motion and hence photogrammetry can be used for vibrating and moving objects unlike most other 3-D measurement technologies.

Using photographs of the object being measured, one can make as many or as few measurements as necessary. At a later date, if more extensive measurements are needed, the photos can be reused to get measurements without revisiting the site or object. There are three central tenets for obtaining measurements from photographic images (*2*):

1. The assumption that a ray of light that comes from some point through the focal node of the lens of a camera and hits the film can be described by a perfectly straight line.

2. Knowing the camera position at the time of exposure so that where the ray of light hit the film can be used to calculate the equation of that ray of light in 3-D.

3. Each point that is to be measured needs to be visible in at least two photos, and preferably in three or more. These points are used to compute light ray positions and their intersections for determining positions in 3-D space.

There are a number of factors that can cause the above tenets to be false or partially incorrect:

1. Air effects: particles and turbulence in the air between the object and the camera bend the light ray.

2. Lens distortion: an imperfect camera lens distorts the path of the light ray. There are two major types of distortion–radial and tangential. Variations in angular magnification with angle of incidence are interpreted as radial lens distortion. Tangential lens distortion is the displacement of a point in the image cause by the misalignment of components of a lens.

3. Imperfect imaging: the film or imaging sensor [a charged couple device (CCD) in a video camera, perhaps] does not image the light ray perfectly (it blurs or shifts it).

4. Imperfect point location: the precise location of the imaging surface (film or CCD) relative to the camera at the time of the exposure is not known.

5. Equipment changes: the camera characteristics, such as focal length and lens distortion, change from photograph to photograph thereby interfering with the repeatability of the light ray measurement.

In most cases, the effects of these factors are negligible in the investigation of an incident scene because the photos are taken at close range, and the camera equipment used is calibrated, well-maintained, and has high-quality resolution.

Photogrammetry for Documentation of Vehicle Deformations

Real-life accidents are a major source of information about the crash behavior of cars and their safety systems. Because high quality data on crash behavior are hard to collect and a short window of time is necessary to evaluate the safety performance of different car models, researchers at Chalmers University of Technology and Folksam Insurance developed a methodology using photogrammetry for documentation of vehicle deformations (*3*). At the time of the study in the early 1990s, photogrammetry was a fairly new technique in the field of crash investigation; therefore, the practical implications and expected results were unknown.

Photogrammetry is a 3-D measuring technique based on image pairs showing the object of interest. This solution of measuring problems gives a clear division between the fieldwork, taking the photos,

and the photogrammetric calculations processing information in the photos to 3-D measurements. Since the information density in a photogrammetric image pair is extremely high and easily moveable in time and space, photogrammetry seemed like a good method for documentation of vehicle damage resulting from crash involvement.

Photogrammetric Methods in Crash Investigation

Exterior measurements are taken in some cases to document the crash profile of a car. Previous techniques for these measurements have primarily been limited to taking physical measurements of the crash profile at six equally spaced points across the damaged portion of the vehicle. A major disadvantage of this process is that after measurements have been taken and the vehicle is scrapped or repaired, there is no opportunity to review the measurements or to measure any forgotten items. A system developed in Sweden, jointly between Folksam Insurance and Chalmers University of Technology, allows photogrammetry to be used on vehicles to determine deformation. Research conducted by Lie et al. *(4)* evaluated the use of this system in New South Wales, Australia, by undertaking an in-depth vehicle factors study of 3000 crashes.

Figure 1 shows the layout of camera locations (depicted with the box with light symbol) used in the Folksam/Chalmers system to document vehicle damage. The 12 pairs of photos of the vehicle from the set locations are designed to ensure that all aspects of the vehicle are documented even if undamaged. Before taking the photos, the inspectors place a series of targets on the vehicle that become connecting points to link the photos together in the subsequent analysis. A scale ruler is also placed across the vehicle (depicted by four black boxes connected by a dashed line in Figure 1) to serve as a control measurement for the photogrammetry analysis. An Apple Macintosh computer with CDROM player and IBM compatible PC were used as the photogrammetry measurement system to analyze the 3000 crashes in Australia. The vehicle factors study produced favorable results including:

- No detailed experience of photogrammetry was required by the inspectors, although it did help.
- Photogrammetry allowed inspectors the ability to take accurate measurements (+/- 15 to 30 mm) at any time post crash.
- Times for setup and field photography are approximately 20 - 30 minutes, which compares very favorably to the time required to manually measure the deformation profile with measuring rods, particularly when it is considered that the whole vehicle interior and exterior profile is recorded in this time.
- Costs are increased by the additional analysis time and film processing expense; however, these extra costs have been offset by improved storage, retrieval, and most importantly by improved post analysis capability.
- The photogrammetry system had high acceptance by the field inspectors because of its ease of use and time-saving factors.

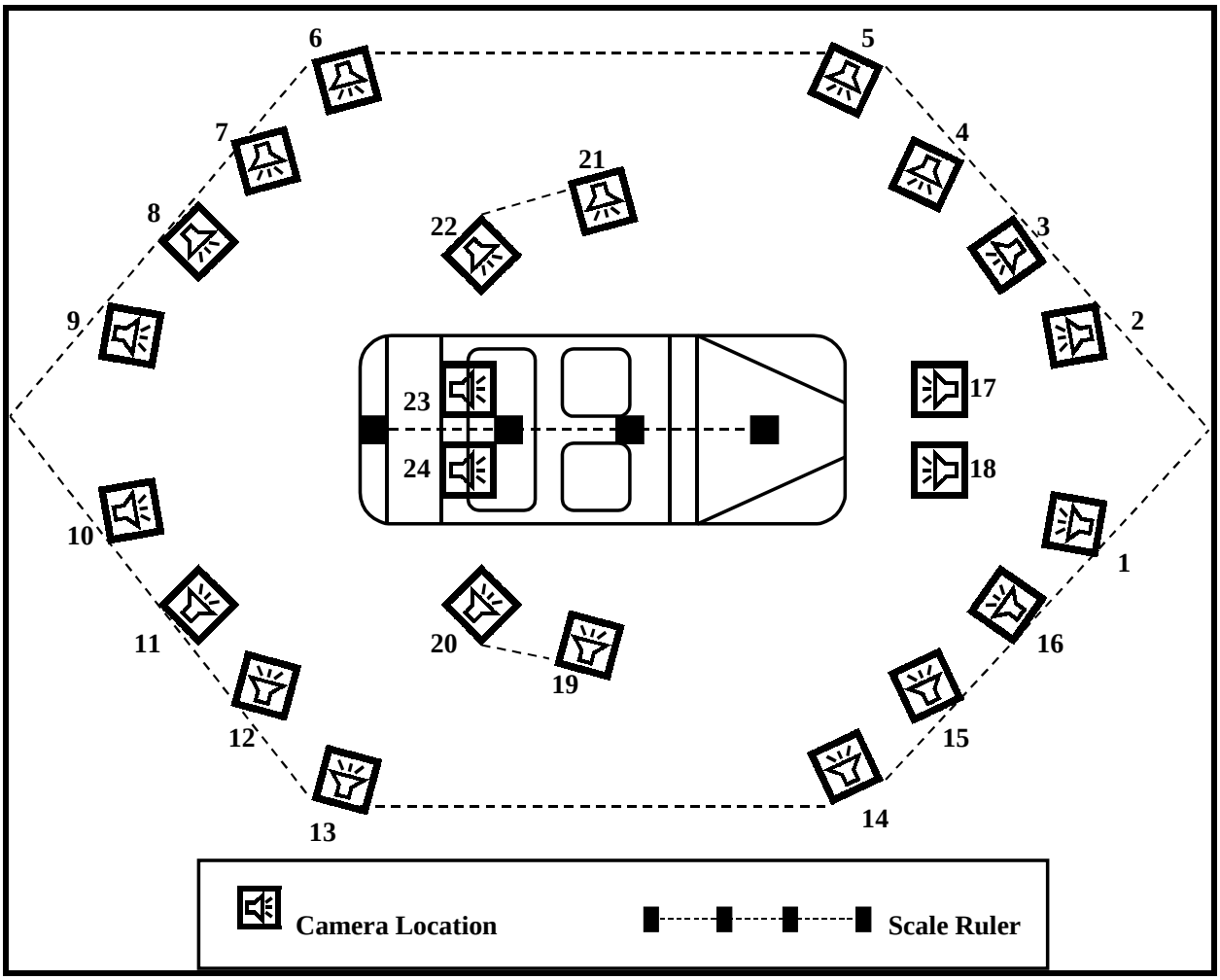

Figure 1. Folksam/Chalmers Photogrammetry System.

Application of Photogrammetry to Accident Reconstruction

MacInnis and Siegmund, noted accident reconstruction experts, authored a paper for a safety conference in Canada regarding the historical and current (as of 1989) use of photogrammetry for accident reconstruction (*5*). The paper introduced the mathematics of two-dimensional (2-D) single-exposure photogrammetry (many times a private reconstruction expert has only one scene photograph) and briefly assessed the accuracy expected. The accuracy presently expected when reconstructing an accident is less than that required in many "high-tech" applications. A previous study conducted by Sherz reported that the San Antonio Police expected an accuracy of about ±1 foot (0.3 meter). Experience in accident reconstruction has indicated that accuracies of this magnitude for the scene information are presently adequate to reconstruct most accidents.

MacInnis and Siegmund found that photogrammetry has yet to establish a firm foothold in North American accident investigation. The advantages of using photogrammetry are many, including:

1. The incident scene may not tolerate traffic closure for the time necessary to take detailed measurements.

2. Volatile scene data, such as tire marks in gravel, snow, or slush, may be disturbed, melted, or obliterated by diverted traffic, rescue vehicles, and salvage activity.

3. Additional details of vehicle damage may be revealed in the photos prior to salvage and towing.

4. Scene details may be so numerous or intricate that locating each mark by field measurement is impractical.

5. Photos can be taken by a lone officer.

6. The analyst can confirm scene measurements taken by others.

7. Any objects or items visible in the scene photos can be measured if needed for subsequent litigation.

There are a number of reasons why photogrammetry has not been applied by many accident investigation or general forensic professionals in North America:

1. Cost: performing 3-D photogrammetry in the manner of the Swiss requires expensive equipment, highly trained operators, specialized vehicles, and dedicated building space.

2. Training: the concepts and mathematics supporting photogrammetry are relatively complex and may not be enthusiastically adopted by police agencies.

3. Need: where simple measurements meet the needs of police or analysts, the utility of photogrammetry is less apparent.

4. Time: enhancement of marks or other evidence may be necessary at the scene before they show adequately in photos, particularly at night, which may offset some of the time-saving potential of photogrammetry.

5. Testimony: it is easier to convince a judge or jury of the reliability of a simple measurement taken by hand than to educate them in a more complex computer-based analytical technique.

INTERVIEWS OF PHOTOGRAMMETRY USERS

The second major element of this study was a survey of law enforcement agencies and other users throughout the United States and other countries regarding the use of photogrammetry for crash investigation. The survey of users was designed to gather information on the following major topic areas:

- Equipment: what equipment, hardware, and software are needed to process crash scenes using photogrammetry, and how much do they cost?

- Training: what training is necessary to be proficient using photogrammetry in the field and in the office, and how much does it cost?

- Measurement Accuracy: how accurate are the measurements obtained from scene photos compared to other traditional investigation techniques (e.g., tape measures, Total Stations, etc.)?

- Scene Processing Time: how long does it take to measure a typical traffic incident scene in the field and in the office?

- Benefits: what are some of the reported and anecdotal benefits of using photogrammetry for crash investigation?

- Downsides/Lessons Learned: what are some of the reported and anecdotal downsides and/or lessons learned regarding photogrammetric crash investigation?

The following subsections document highlights of the 14 interviews conducted during the study.

Washington State Patrol Interview Results

Sergeant (Sgt.) John Anderson of the Washington State Patrol (WSP) participated in an interview via electronic mail (e-mail) (*6*). Sgt. Anderson is the current supervisor of the WSP/Washington State Department of Transportation Major Accident Investigation Team (MAIT). Sgt. Anderson provided the following information regarding WSP's experience with using photogrammetry for collision investigation:

- WSP has been testing two copies of the PhotoModeler software program for approximately one year.

- There are currently five investigators throughout the state trained to use the software.

- WSP does not have any guidelines as to when and for what they will use photogrammetry.

- Under controlled conditions, WSP has used photogrammetry on mock collision scenes and crime scenes.

- WSP has not used photogrammetry on real-life collision scene work yet. This is primarily because WSP has a major commitment to the use of Total Stations, and one of the major limitations to date has been the use of photogrammetry over long distances [100 feet (ft) and above]. Many of the scenes MAIT investigates are over 300 ft in length, with some being as great as 600 ft.

- The primary use so far of the photogrammetry software has been rendering vehicle crash measurements, which take approximately two hours of processing time in the office using PhotoModeler.

- Taking photos of the mock collision scenes is a straightforward and easy process; however, photogrammetry does not export data directly to a CAD program with attributes like Total Stations can.

Arizona Highway Patrol Interview Results

Sgt. James Trapp and Sgt. Jeff King of the Arizona Highway Patrol (AHP) participated in an interview via telephone and e-mail (7). Sgt. Trapp is assigned to the Vehicular Crimes Unit and Sgt. King is currently working in the Collision Analysis and Reconstruction Unit. The following list documents the highlights of the information provided by the AHP officers regarding their experience with using photogrammetry for collision investigation:

- AHP has been using photogrammetry for approximately 10 years for processing of crime and collision scenes via aerial photography. The aerial images are normally supplied by a fixed-wing aircraft that is operated by the Arizona Department of Transportation (ADOT). This aircraft is normally in operation every other day or so, and the AHP can call and request a fly-by for a collision scene. If the aircraft is already up, the scene can sometimes be photographed that day and is normally accomplished by the next scheduled flight. Sgt. King mentioned that one potential drawback to this approach is that if you can't see it from above, you can't measure it. ADOT has analysis software that is used to obtain measurements that cost them approximately $500,000.

- Approximately one year ago, the AHP procured the PhotoModeler version 3.1 software for close-range photogrammetry applications. Officers were trained on the software and field techniques by John O'Laughlin of PB Farradyne, Inc., AHP officers use close-range photogrammetry for collision scenes approximately 5 to 10 percent of the time. For the close-range work, they normally shoot pictures in an oval pattern around the vehicle(s) at the scene. They have used this technique to determine bullet trajectories in shootings involving a vehicle.

- At this point in time, they have five different methods at their disposal for measurement of data at crash scenes:

  – Total Stations - they use the AIM Nikon units which cost approximately $15,000 to $16,000 each. A full-time unit has two Total Station units, and the part-time squad has eight. Three of the units were purchased for AHP by ADOT.

  – Tape Measure - conventional steel tape measures are still used in some situations, especially for measurement of an object to serve as a control distance.

  – Laser Units - LaserTech Impulse 200 units (http://www.lasertech.com) are also used in crash investigation. These units are cost effective (approximately $6000 per unit) and only require a single officer to make measurements.

  – Global Postitoning System (GPS) - they did not really provide any insight into exactly what this is but said that it costs approximately $35,000 per unit. It works well for any situation where line of sight between the unit and object to be measured is not blocked by any solid objects. Therefore, this unit is useful in fog, rain, nighttime, and other conditions that affect the usefulness of the Total Station and laser units.

  - Photogrammetry - aerial (i.e., photos of an incident scene taken from a police helicopter flying at a low level) and close-range methods have been used by the AHP for various applications.

- Sgt. King emphasized that none of the five methods listed above is applicable in all situations. All of them have their strengths and weaknesses.

- Sgt. King stated that if his superiors ordered him to use close-range photogrammetry for documenting the majority of collision scenes, he would be comfortable with that. The accuracy and relative ease of use were mentioned as positives of the photogrammetry equipment.

Utah Department of Transportation Interview Results

David Kinnecom and Richard Taylor of the Utah Department of Transportation (UDOT) participated in an interview via telephone and e-mail *(8)*. Mr. Kinnecom is the Traffic Management Engineer at UDOT, and Mr. Taylor is the engineer in charge of the incident management program. These engineers provided the following information regarding UDOT's experience with incident management that led them to pursue photogrammetry:

- Fatal and major accidents in the Salt Lake City metropolitan area were taking approximately three to four hours to be cleared from the roadway. Only 15 percent of that time (30 minutes) was spent on the response portion of the incident management process with the balance of the time on investigation of the incident scene. UDOT officials decided that an investment in equipment and training for the Utah Highway Patrol (UHP) in order to help reduce the time spent during the investigation portion of the incident management process was warranted based on the potential delay, fuel, and emissions savings.

- UDOT sponsored a pilot demonstration of using photogrammetry to investigate two mock scenes near Salt Lake City on Interstate 80.

- Congestion Mitigation and Air Quality (CMAQ) funds in the amount of approximately $40,000 were used to purchase the training (three one-day sessions) and equipment (digital cameras, SCSI cards, and PhotoModeler software) necessary for UHP to investigate scenes using photogrammetry.

- An evaluation of the CMAQ photogrammetry project will be performed after the first year of operation.

Utah Highway Patrol Interview Results

Sgt. Lynn McAfee of the Utah Highway Patrol (UHP) participated in an interview via e-mail *(9)*. Sgt. McAfee is classified as an Accident Reconstruction Specialist with UHP. Sgt. McAfee provided the following information regarding UHP's experience with using photogrammetry for collision investigation:

- UHP participated in the pilot demonstration session sponsored by UDOT, which compared photogrammetric and Total Station investigations on two mock incident scenes.

- UHP officers did all of the Total Station work (i.e., investigation and post processing) and performed the photogrammetric investigation of the mock scenes on their own.

- The mock scene investigation with photogrammetry took approximately 35 minutes, which included looking over the scene to identify evidence and taking the necessary photos.

- The Total Station investigation took approximately twice as long; it takes between 60 and 90 minutes for processing of a typical collision scene in the field.

- The editing time back in the office with photogrammetry is more than for a Total Station (to allow marking of points), but it is certainly worth the time savings at the scene and minimizes the closure time and delays to the public.

- Six officers are being trained to do all aspects of photogrammetry, including the processing in PhotoModeler. Other officers only need to understand the basics and know how to set up a scene to take the photos correctly. Therefore, the amount of training and knowledge that an officer needs to obtain evidence with photogrammetry is far less than what is required to train them on a Total Station.

- Prior to the mock scene training, officers had two days of initial training to learn about photogrammetry and the way it works. The training concentrated on calibrating of cameras (both digital and film type cameras) and using the PhotoModeler software for analysis.

- UHP is currently getting additional equipment and continuing to train on the use of photogrammetry in preparation for field implementation.

- Initial testing has shown that photogrammetry is very accurate (far more so than roll-a-tape measurements that were relied on for years).

- Photogrammetry can be the sole measurement technique used to process an incident scene. One known distance is needed to scale the project, but then anything in the photos can be measured with a high level of accuracy (exceeding the accuracy required for accident reconstruction).

- UHP is currently in the process of developing guidelines and standard operating procedures (SOP) for determining when to use photogrammetry for an accident investigation. The primary interest in photogrammetry is situations where traffic flow needs to be restored quickly due to traffic conditions. During the 2002 Winter Olympics in Salt Lake City, UHP plans on using photogrammetry on all serious accidents to minimize any traffic problems.

- UHP still has not used photogrammetry to investigate a real-world incident; however, it will be implemented on actual accident scenes very soon.
- UHP sees the following as potential benefits of photogrammetric investigation: (1) greater officer safety; (2) reduction of secondary collisions; (3) reduction in air pollution; (4) economic savings from fuel savings; (5) reduction in motorist delay; (6) ability to make measurements away from the scene; and (7) capabilities that enable preparation of information for court that will aid in prosecution.

- UHP sees the following as potential limitations/downsides of photogrammetric investigation: (1) additional editing time in the office as compared to a Total Station; (2) long scenes require photographing multiple blocks (where a Total Station could just shoot the entire scene).

Photogrammetry Training Instructor Interview Results

Dr. Harry Townes, a Professor Emeritus at Montana State University and instructor of the Photogrammetry in Accident Reconstruction course offered by the Society of Automotive Engineers (SAE), participated in an interview via e-mail *(10)*. As the instructor for the SAE course, Dr. Townes is recognized as an expert in the field of using photogrammetry for accident reconstruction. The following list highlights the information provided by Dr. Townes regarding his experience with using photogrammetry for collision investigation:

- Photogrammetry is not a difficult technique for investigating collisions; however, one must know what to do, or collected information may not be useable. The person doing the collecting must have training as a photogrammetrist, otherwise the person will not know how a photograph for photogrammetric analysis must be taken.

- A two- or three-day training session in the use of a photogrammetry program provides adequate preparation.

- The accuracy of photogrammetry can be as good as several inches at 200 ft. Total Stations should be used for control point measurement.

- Dr. Townes does not know of any legal challenges to photogrammetric measurements being used in court.

- Photogrammetry can be the sole technique used to process an incident scene, if done carefully, and can work effectively in most circumstances.

- The advantage of photogrammetry compared to using Total Station is a shorter “up front” time, which is paid for on the “back end” in a longer analysis time. Photos also have the advantage of recording all of the information at the scene, which might become important later when further evidence is necessary.

- At this point in time, photogrammetry is not used for accident investigation by very many law enforcement agencies; however, the Federal Bureau of Investigation (FBI) and the Central Intelligence Agency (CIA) both use it for different applications.

- Photogrammetry for collision investigation is beneficial because it records all data quickly, and everything is in the photos. The downsides are the necessary training, use of a Total Station for control measurement, and the “back end” analysis time required.

Nevada Highway Patrol Interview Results

Trooper (Trp.) Harold Hughes of the Nevada Highway Patrol (NHP) participated in an interview via e-mail (*11*). Trp. Hughes is responsible for investigating traffic incidents in his district, 180 miles south of the district headquarters in Elko. Trp. Hughes provided the following information regarding NHP's experience with using photogrammetry for collision investigation:

- The NHP does not currently use photogrammetry for investigation of traffic accident scenes. Total Stations, tape measure, and roll-a-tape are the techniques now used by NHP.

- Photogrammetry might be the technique of the future; however, it has many things lacking at this time. Pictures taken of a scene at night hardly ever come out good enough to see them, let alone for a computer to analyze and obtain measurements from them. Troopers are also accustomed to other techniques and do not generally have the necessary experience in working with computers, let alone complex photogrammetry software.

California Highway Patrol Interview Results

Sgt. John Garton of the California Highway Patrol (CHP) was interviewed via e-mail (*12*). Sgt. Garton is part of the Accident Investigation Unit created in March 1999. Sgt. Garton provided the following information regarding CHP's use of photogrammetry for accident investigation:

- There are not any guidelines to determine when to use photogrammetry because CHP is continuing to test the use of photogrammetry.

- Officers participated in a two-day training session to learn how to use the PhotoModeler software.

- Only three patrol divisions currently use photogrammetry for collision investigation. Most are very reluctant to use photogrammetry when they have something (Total Stations) with which they are already comfortable.

- PhotoModeler has been very accurate when tested against Total Station, especially for measuring vehicle crush/deformation resulting from collisions (used to estimate vehicle speeds).

- Photogrammetry has been cumbersome for on-scene investigation; when and if CHP goes to full-time use, it will be to do the roadway lines, curbs, etc. The physical evidence, tiremarks, etc., will continue to be documented with Total Stations.

- Weather and environmental issues in California (fog, smoke, and other issues) sometimes make scene photos tough to utilize and obtain measurements from.

- Photogrammetry does help expedite scene investigation time, but it is still limited in its operating use. CHP is also having difficulty with funding operations right now and needs additional equipment and training in order to expand the application.

Oregon State Police Interview Results

Senior Trooper Frank Morton of the Oregon State Patrol (OSP) was interviewed via e-mail *(13)*. Trp. Morton is stationed in the Bend District (Central Oregon) and supervises all of the accident reconstruction activities in this jurisdiction. Trp. Morton provided the following information regarding OSP's experience with using photogrammetry for collision investigation:

- The OSP currently uses Leica Total Stations for reconstruction purposes but is in the process of testing photogrammetry to open the highways faster after accidents.

- OSP purchased three copies of the PhotoModeler 3.1b software and three Kodak DC265 digital cameras.

- At this point, OSP is still learning the software and is having some problems calibrating the cameras that were purchased to support the program.

- The OSP does not believe at this time that photogrammetry will replace the Total Stations as its primary measurement technique for collision investigations.

- OSP will continue to use Total Stations on criminally prosecutable cases, adding the photos as back-up, should evidence at the scene be missed and need to be measured later.

- In less serious crashes, OSP anticipates relying heavily on photogrammetry for conducting the investigation and capturing all of the evidence. OSP also anticipates using the PhotoModeler program to support its 3-D animation program.

Ryerson University Interview Results

Mr. Dan Mills of the Department of Civil Engineering at Ryerson Polytechnic University in Toronto, Canada, participated in an interview via e-mail *(14)*. Mr. Mills is currently a researcher with the Vehicle Safety Research Centre (VSRC) program at the university. Mr. Mills provided information on the use of photogrammetry in Canada during his interview. The following list captures some of the significant portions of his responses:

- No Canadian police agencies are currently using photogrammetry to investigate traffic accidents; however, there is a lot of interest, and close-range photogrammetry demonstrations have been well attended at the VSRC.

- Scene analysis can be done in 3-D or if it is relatively flat in a 2-D, ortho-rectified image. 2-D analysis can be done with PC-Rect from Maginnis Engineering, and both 2-D and 3-D can be done by PhotoModeler from EOS Systems.

- SAE papers report the accuracy of the photogrammetry software packages relates back to the quality of imagery. If a lot is known about camera parameters, the images are high resolution, and there are control points. The accuracy of photogrammetry can equal that of a Total Station.

- In laboratory studies at the VSRC, photogrammetry has proven to take less investigation time (time in field out in traffic if the scene is not closed) than a Total Station; however, the post-processing analysis time is greater. The tests have shown that the time to photograph was anywhere from one-half to one-tenth of the time to map the same scene using a Total Station.

- A photogrammetric project has the advantage of reproducibility that a Total Station does not have. Scene evidence that gets missed (not that it ever happens) might be destroyed before someone notices and returns to an accident scene to collect the missed data. If the photos have full coverage of the scene, the data would be measurable from the photos.

New South Wales Police Interview Results

Sgt. Paul Feenan of the New South Wales (NSW) Police was interviewed via e-mail *(15)*. Sgt. Feenan is part of the Hunter Region Crash Investigation Unit in Newcastle, Australia. The NSW Police photogrammetry section is headquartered in Sydney, Australia. Sgt. Feenan provided the following information regarding the NSW Police Department's experience with using photogrammetry for collision investigation:

- NSW Police have been using terrestrial photogrammetry now for many years; however, it is different than the photogrammetry programs that use cameras and then plot with computer software like in America.

- A stereo camera unit (Pentax ST120V) that mounts on a large tripod, like a Total Station tripod, is used for photogrammetry. The cameras are mounted about one meter apart and photograph using glass plates. The glass plates are taken to the Sydney headquarters where they are plotted using a computer-based plotting machine (Wyld BC2 Analytical Stereo Plotter).

- The photogrammetry section works out of Sydney and provides a survey throughout the region. There are eight men, two vehicles, and three stereo camera units — one for smaller indoor scenes (i.e., murders, etc.) and two larger ones for collisions.

- Photogrammetry is typically used in the following three situations: (1) fatal collisions, (2) fatal or serious injury crashes where criminal charges are going to be filed, and (3) serious collisions that need interpretation to explain what happened. Therefore, approximately 80 to 90 percent of the collisions are investigated using photogrammetry.

- In Sydney and the immediate suburbs, the photogrammetry section will be dispatched to a collision scene to do the investigation immediately. In other regions, officers will mark the road using paint and clear the highway, then order the photogrammetry survey to be completed in the next few weeks. The road closure times in the outlying regions are much shorter by marking and clearing than in Sydney where they generally wait for the photogrammetry section to attend.

- Control cones are placed down the center of the area to be surveyed at a measured distance of 10 meters apart. If the cones are accurately spaced, the photogrammetry measurements are very accurate.

- The lateral range of the cameras is around 10 meters each side so they are normally placed in the middle of the road, which is very disruptive to traffic.

Hanamaki Police Interview Results

Lieutenant (Lt.) Masahito Sasaki of the Hanamaki Police was interviewed via e-mail (*16*). Lt. Sasaki is a Detective with the Hanamaki Police (HP) in Japan. The HP has a traffic section that is responsible for investigation of all accidents. Lt. Sasaki provided the following information regarding HP's experience with using photogrammetry for collision investigation:

- In a minor accident, drivers come to the nearest police station and show the vehicles to an officer. The officer writes a report, and a safety agency issues a certificate for insurance.

- In the case where either or both of the vehicles cannot be moved, the police attend the scene for the investigation.

- In the case of a serious or fatal accident, traffic officers go to the scene and investigate crash evidence. When the accident is hit-and-run, involves a number of vehicles, or has other difficult problems, officers normally use photogrammetry.

- The operation of making a drawing from the pictures of an accident scene is done at the Prefectural Police Headquarters. It normally takes a long time to finish an operation, so officers often comment that hand-drawing is faster and easier to understand than photogrammetry.

- Photogrammetry is commonly referred to as "ste-cam" (stereo camera). The software for photogrammetry is old and traffic officers do not enjoy using it.

Honolulu Police Department Interview Results

Sgt. Jay Addison of the Honolulu Police Department (HPD) was interviewed via e-mail (*17*). Sgt. Addison is the supervisor of the squad that is responsible for investigation of all traffic accidents. Sgt. Addison provided the following information regarding HPD's utilization of photogrammetry for investigation of traffic incidents:

- HPD started using photogrammetry four years ago after reading about it and thinking it would be an interesting new method that would enable investigators to speed up the processing of scenes.

- The HPD does not officially sanction the use of photogrammetry by its employees (i.e., it does not provide any funds to support it); however, HPD allows it to be used to strengthen other traditional investigation methods.

- Five officers have been trained to use photogrammetry but it is a complex program that probably is not suited to being used in and of itself (i.e., stand-alone without other investigation methods such as Total Stations).

- The equipment used for photogrammetric investigation is a 450 MHz, 21 GB, 128 MB RAM computer with video card along with the PhotoModeler software. Having a CD for storage of pictures is helpful since photogrammetry uses large quantities of memory (jpg and bmp files). The cost of this equipment package is probably less than $3500, and a good digital camera can be purchased for $1000 or less.

- Four different techniques (Total Station, tape measure, laser, and photogrammetry) are used to process scenes, and the measurements have been comparable.

- The combination of using Total Station and photogrammetry has reduced most scene investigation times nearly by half.

German Police Interviews

Interviews with several German police agencies were conducted to gather information on the use of photogrammetry in their country. Officer Klaus Neudold of the Manheim Highway Patrol (MHP), located in southwest Germany, participated in an interview via e-mail *(18)*. MHP has been using photogrammetry for investigation of traffic incidents since at least 1977. Officer Neudold gave the following information regarding MHP's use of photogrammetry:

- In the past, MHP used stereo-cameras for photogrammetry (about five to eight times per year). These cameras were mounted 1 meter apart and did not work with regular film. The photos were projected onto glass plates because they gave a more exact representation than regular film.

- The typical procedure at an accident scene was to take a photo, reload the glass plates, take the camera to another position, and so on until the scene was adequately documented. After finishing with the scene, the glass plates were taken to the police headquarters where a technician developed the pictures. This was a rigorous process and specialized training was necessary in order to produce the 3-D rendering of the accident scene.

- Now the MHP uses a new system called MR2; however, it has only been used three times in the last eight years because it is very difficult and requires a lot of extra work. The MR2 system uses a regular camera, but the scene must be cleared (involved cars and everything on the roadway) and items that are to be measured marked with chalk. A grid is then drawn on the road with chalk. Every point of the grid is measured with conventional methods, then the photos are taken. The photos are given to a civilian company that processes them into an exact drawing with specialized computer software.

Officer Udo Heeren of the Nordrhein-Westfalen Police (NWP) also participated in an interview via e-mail *(19)*. Officer Heeren is currently working with the Flying Squadron piloting a helicopter but was formerly involved in the investigation of traffic accidents on the ground. Officer Heeren provided the following information regarding the NWP's utilization of photogrammetry for crash investigation:

- There are two photogrammetry methods used by NWP for investigation of traffic collisions:

  – The first method, called "Monobild," is used by traditional patrol officers. In this method, the officer puts down markers on the road, measures the distance between the markers, and then makes the photos. The normal pattern is more or less a rectangular shape like the one shown in Figure 2. The measurement sheet and photos are then related. Due to the known distances all objects in the rectangles, and closely outside, are measured by the computer.

  – The second method, called "Rolleiflex," involves the use of a special metric camera. A glass plate is used in this camera, and the plate has marked crosses previously etched on it at known spacings. The pictures that are projected onto the glass plates can then be analyzed based on the known distances between the crosses. The primary advantage of this system is that officers do not have to take a lot of measurements of the scene. The primary disadvantage is the cost of the camera.

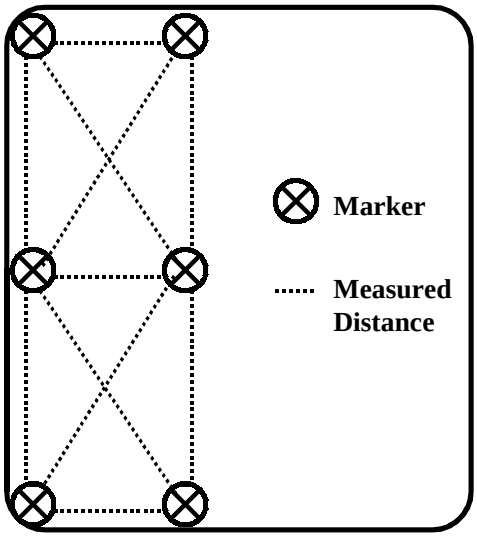

Figure 2. "Monobild" Layout.

DESCRIPTION OF PHOTOGRAMMETRIC SOFTWARE PROGRAMS

This section describes several of the photogrammetric software programs commonly used for obtaining measurements for accident investigation. The first subsection briefly documents PhotoModeler, which was cited by the majority of the interview respondents as the software utilized by their agencies. The second subsection briefly introduces the ShapeCapture software.

PhotoModeler Software

PhotoModeler is a Windows®-based program designed for extracting measurements and 3-D models from photos (*20*). By using a camera as an input device, PhotoModeler allows the user to capture large quantities of accurate detail in a very short time. To use PhotoModeler, several photos of a scene or an object are taken. The photos are displayed on-screen, and the operator marks each photo

with the mouse, tracing and tagging features of interest. PhotoModeler then combines the photos and locates the marked features in three dimensions. The marks become accurately measured points, lines, or polygons in a single, unified 3-D space. The end result is a 3-D model that can be transferred to any graphics or CAD program.

The minimum recommended personal computer hardware requirements for best performance of PhotoModeler are as follows:

- Windows 95, 98, or NT 4.0 (sp3+),
- Pentium-level processor,
- 16 MB RAM,
- 30 MB hard disk space,
- CD-ROM (2×),
- 800×600 screen with 32,000 colors, and
- sound hardware (for tutorials).

The accuracy of a final PhotoModeler measurement depends on a number of factors: the resolution and number of photos, the angles between the photos, the number of referenced points, and the quality of the camera description. A project using a single, low-resolution photograph taken with an unknown camera may achieve accuracy of 1 in 200 (e.g., for a 12-foot object, measurements will be within 3/4 of an inch). For projects using high-resolution photos with calibrated cameras, it is possible to achieve accuracy of 1 in 8000 (e.g., for the same 12-foot object, within 1/50 of an inch).

The PhotoModeler software includes a compact disc containing over 400 MB of excellent multimedia tutorials that can be used for training. This tutorial has two example projects relating to accident reconstruction (see Figure 3 for screen capture examples). In each tutorial, a movie accompanied by an audio script is used to guide the viewer through the steps involved in processing a series of photos of a scene into a scale diagram. The PhotoModeler web site (http://www.photomodeler.com) also contains extensive on-line documentation and examples of staged incident scenes where the software has been used to obtain scene measurements.

The PhotoModeler software costs $795 and can be purchased directly from EOS Systems or any PhotoModeler authorized service firm. One of the authorized service firms, DeChant Consulting Services (DCS), conducts courses to train individuals or agencies in the use of the PhotoModeler (*21*). At this time, DCS offers both basic and advanced training workshops that each last two days. There are four options available for each workshop:

Figure 3. PhotoModeler Screen Captures of Accident Reconstruction Tutorials.

- Option 1: On-site

  - at your facility;
  - $675 per student (minimum fee of five students per workshop);
  - client pays airfare, hotel accommodations, and expenses for the DCS instructor; and
  - client is required to furnish computing resources for the workshop exercises.

- Option 2: Full class

  - at Seattle, Washington, DCS area training facility; and
  - $750 per student (workshop designed for three to five students).

- Option 3: Partial class

  - at Seattle, Washington, DCS area training facility; and
  - $850 per student (workshop designed for two students).

- Option 4: One on one

  - at Seattle, Washington, DCS area training facility; and
  - $950 for DCS instructor to provide one-on-one student training.

The PhotoModeler software help file (*2*) contains useful information. The following subsections give guidelines to follow when taking photos for processing in the software.

Guideline 1: Get Good Camera Angles

The process of measurement is never perfect. Measurement is instead the process of reducing and minimizing errors so as to maximize accuracy. If PhotoModeler has incorrect camera positions or orientations, it will generate an incorrect position for the 3-D point. The closer the angle between the light rays is to a right angle (90 degrees), the smaller any possible error will be. It is for this reason that the angle between the camera stations (i.e., camera locations when photos were taken) should be as close to a right angle as possible.

> Guideline 1: Take photos with good angular separation (close to 90°). Avoid taking all your photos with similar points of view.

Guideline 2: Take at Least Three Photos

Another form of error is introduced during measurement by marking imprecision. No user can mark a point perfectly, and occasionally the point one wishes to identify is fuzzy or hard to position exactly in the photograph. If PhotoModeler has good camera station positions but imprecise point locations in the photos, the projected 3-D point will be inaccurate. To reduce this problem, the user should mark the desired point in three or more photos. That way, if the point was positioned incorrectly on one of the photos, the other two photos could compensate for it. If it is marked on only two photos, marking errors cannot be found and will cause an inaccurate 3-D point to be created.

> Guideline 2: Take at least three photos of the object or scene. Try to get all important points to show on at least three photos. For highest accuracy, try to image points on four or more photos.

Guideline 3: Get Good Horizontal and Vertical Separation

Another way of satisfying Guideline 1 (keeping the angles between the photos close to right angles) is to separate the camera stations not only horizontally but vertically. Two cameras can have right angles between their views in any 3-D orientation. The camera stations do not need to be all at one level. This guideline is particularly difficult for accident investigation because photos from above the scene are difficult to obtain.

Guideline 3: Try to take photos with good vertical and horizontal separation (i.e., try to get photos above and below the object or site of interest).

Guideline 4: Get Good Photograph Overlap

PhotoModeler needs points marked in two or more photos. Photos taken side by side should contain many of the same object features and points. PhotoModeler wants as many points referenced across photos as possible, but the user wishes to minimize the marking task since it takes time. To balance these two, it is best if the photos overlap as much as possible (60 percent overlap is desirable).

Guideline 4: Try to get good overlap of the photos (i.e., make sure a high percent of the points in any one photo show up in the adjacent photos).

Guideline 5: Take Many Pictures, Use Only Those Needed

In many situations, having to repeat picture taking is expensive. Sometimes the object or scene no longer exists or has changed. The photos themselves are inexpensive (especially true for digital cameras). For these reasons, it's a good idea to take many photos of the object being measured (within a reasonable amount of time, especially if the entire roadway or traffic lanes are closed).

Guideline 5: Take as many pictures of the site as possible, or as time constraints allow. Use three to six photos to start processing a project and add photos later if greater detail or accuracy is desired.

Guideline 6: Include a Scale Measurement

When you are taking the photos you should measure the distance between two points that you are photographing. This distance is necessary to add scale to the 3-D model being produced within PhotoModeler. In the case of an accident scene, there are several common methods for getting a control distance in a photograph: (1) pick a recognizable object – a lane stripe for example – and measure it with a tape measure; (2) place a large ruler or other object of known length in the scene.

Guideline 6: Obtain an accurate measurement between two points that you are photographing to add scale to the 3-D model.

Guideline Summary

To summarize, the guidelines to follow when taking photos for measurement are:

1. Try to get the angles between the shots as close to right angles (90 degrees) as possible.
2. Take at least three photos and try to get all important points on at least three photos.
3. Try to get as much overlap between adjacent photos as possible.
4. Try to get photos from both above and below the object, if possible.
5. Take many photos of the object but use only four at the start until you determine you need some others.
6. Measure the distance between two visible and clearly delineated points.

ShapeCapture Software

Another photogrammetry software, ShapeCapture [http://www.shapequest.com], is also used in accident and forensic applications. The screen capture shown in Figure 4 provides an example of how a point (in this case, a point on the base of an office building) can be located in two different photos. Mr. Gary Robertson *(22)*, owner of a ShapeCapture service company called GRAI Imaging, supplied a demonstration version of the software *(23)*. The main functions the ShapeCapture software performs are:

- the precise calibration of cameras;
- the extraction of target, and point features from images using advanced image processing;
- the registration of multiple images using photogrammetric bundle adjustment;
- the computation of the 3-D coordinates of the extracted features from two or more images;
- automatic stereo matching on targets;
- automatic point measurement on spheres, cylinders, quadrics, and plane surfaces;
- the fitting of data to standard geometric models (planes, spheres, cylinders, and circles); and
- the geometric modeling and texture mapping to visualize the data in VRML 1.0/2.0, CAD DXF, Rapid prototyping STL, and Wavefront OBJ (with MTL) formats.

The minimum hardware requirements for optimal performance of ShapeCapture are as follows:

- Pentium II 350, 64 MB RAM (96 MB or more is recommended);
- 8 MB graphics memory (16 MB or more is recommended); and
- a display resolution of 1280×1024 pixels and 16-bit color, or better, is recommended.

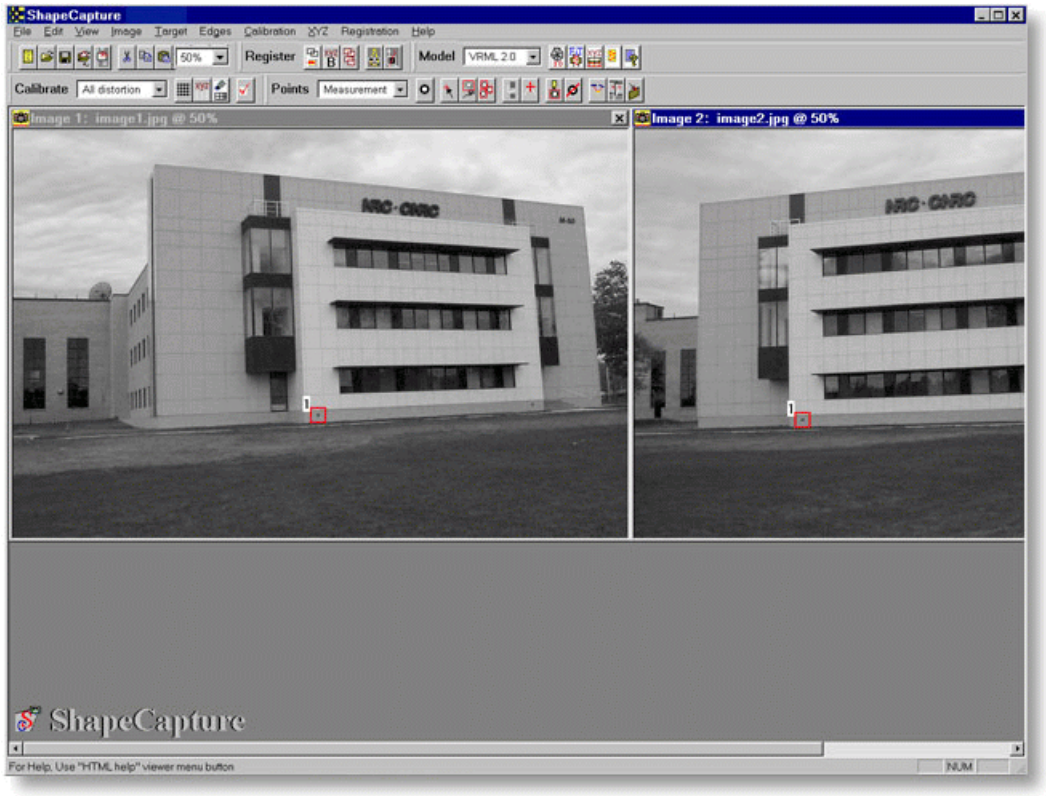

Figure 4. ShapeCapture Screen Capture.

Mr. Robertson and his associates at GRAI Imaging have been involved in accident investigation work for over 20 years. GRAI Imaging [http://www.grai-imaging.com] offers full training programs for the ShapeCapture software. GRAI employees have been extensively involved with air accident work, specifically in the Swiss Air crash investigation in the previous several years.

OVERVIEW OF THE ISSUES AND BENEFITS WITH PHOTOGRAMMETRY

The use of photogrammetry by law enforcement agencies for the investigation of traffic accidents is still a relatively new and untapped method. Photogrammetry has been utilized in areas outside of incident management (archaeology, architecture, aerial mapping, industrial machining, etc.) for many years. Photogrammetry has been used in countries outside of the United States (U.S.), namely Switzerland, Germany, Japan, and Australia, in some cases for as many as 50 years. The development of computer hardware and software and digital cameras over the previous five to 10 years has made photogrammetry a more intriguing method for law enforcement agencies in the U.S. looking for ways to save time and money. This study investigated the potential benefits and issues associated with using photogrammetry. The following items are the significant findings of this study:

1. Photogrammetry is still largely in the testing phase in the United States. A number of agencies (Arizona Highway Patrol, California Highway Patrol, Oregon State Patrol, Utah Highway Patrol, Washington State Patrol, etc.) are in the early stages of implementation; therefore, documentation of quantitative benefits is not yet readily available.

2. Preliminary and anecdotal results from the interviews of law enforcement representatives indicated that photogrammetry is a cost-effective (approximately $4500 for a typical setup including software, hardware, and digital camera vs. $15,000 to $20,000 for a typical Total Station setup) and time-saving tool for incident management application (reduction of investigation time compared to Total Station).

3. The training necessary for basic proficiency in using photogrammetry to process an incident scene is a two- to three-day workshop/seminar, which is less than the training for proficiency on a Total Station (five-day course is typical). Also, a number of officers can be trained to do the field portion of photogrammetry (i.e., taking of scene pictures with good technique) in a short period of time where only a few officers are trained to do the processing (i.e., obtaining measurements and production of scale diagrams) of the scene back in the office using a photogrammetric software package similar to the two documented in the previous section.

4. Photogrammetry has several drawbacks that must be considered in its evaluation as an effective incident management technique: (1) while the investigation time in the field can be reduced, the processing of measurements back in the office takes longer than with other methods; (2) long scenes are difficult to photograph and process with pictures; and (3) skid marks and other evidence at the scene might need to be enhanced, particularly at night, in order to be visible in the scene photos.

5. A majority of the law enforcement representatives who participated in the interviews indicated that they would recommend the use of photogrammetry to other police departments.

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