CRASH INVESTIGATION AND RECONSTRUCTION TECHNOLOGIES AND BEST PRACTICES

October 2015
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16. Abstract

Traffic crashes have an effect on the lives of those involved, the lives of those who respond to the incident and the lives of those who investigate the incident. The collection of evidence at a crash scene is very important but the exposure of responders to the dangers of traffic increases the chance of a secondary collision occurring. When technology is effectively applied to traffic incident management and crash investigation, safety is increased and traffic congestion is minimized. The use of traffic crash reconstruction technology has a significant impact on the safety of the investigators, the traveling public and the operation of the transportation system. This report examines available crash investigation and reconstruction technology. The evolution of traffic crash reconstruction technology has introduced many new types of equipment to this field, as well as constantly evolving innovations. The report provides information about each technology's capabilities and limitations to inform crash investigation units of the options available.

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METRIC CONVERSION CHART

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm^2
ft²	square feet	0.093	square meters	m^2
yd²	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km^2
		TEMPERATURE (exact degrees)		
ºF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	ºC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in^2
m²	square meters	10.764	square feet	ft^2
m²	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi^2
		TEMPERATURE (exact degrees)		
ºC	Celsius	1.8C+32	Fahrenheit	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m^2	0.2919	foot-Lamberts	fl

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

2-D – Two-dimensional
3-D – Three-dimensional
A&M – Agricultural and Mechanical
ACTAR - Accreditation Commission for Traffic Accident Reconstruction
AGL – Above Ground Level
AGPS – Assisted Global Positioning System
CAD – Computer Aided Diagramming
CAR – Collision Analysis Reconstruction
COA – Certificates of Authorization
DGPS – Differential Global Positioning System
DOD – Department of Defense
DOT – Department of Transportation
DUI – Driving Under the Influence
EDM – Electronic Distance Measurement Instrument
FAA – Federal Aviation Administration
FHWA – Federal Highway Administration
GCP – Ground Control Point
GLONASS - Global Navigation Satellite System
GNSS – Global Navigation Satellite System
GPS – Global Positioning System
HD – High-Definition
IACP – International Association of Chiefs of Police
IPTM - Institute of Police Technology and Management
ITS – Intelligent Transportation Systems
LiDAR – Light Detection and Ranging
N/A – Not Applicable
NAS – National Air Space
NTSB – National Transportation Safety Board
NUG – National Unified Goal
OEM – Original Equipment Manufacturer
RMT – Remote Measuring Target
RTK – Real Time Kinematic
SAE – Society of Automotive Engineers
SLR – Single-Lens Reflex
TCRU - Traffic Crash Reconstruction Unit
TIM – Traffic Incident Management
UAS – Unmanned Aerial System
WAAS – Wide Area Augmentation System

EXECUTIVE SUMMARY

Crash investigators have been reconstructing the circumstances surrounding traffic crashes since the first crash involving the automobile occurred. Investigations are carried out by law enforcement investigators and private crash professionals. While the majority of traffic crashes involve human error on the part of those involved in the crash, many crashes occur due to engineering issues. Without fully investigating and reconstructing a crash, the true cause or causes of the crash may not be determined.

While the collection of evidence at a crash scene is very important, the crash investigators and responders are at risk when they are exposed to vehicular traffic at the incident scene. As reported by the Federal Highway Administration's Traffic Incident Management Program, for every minute that the primary incident continues to be a hazard, the chance of being involved in a secondary collision increases by 2.8%. Traffic incident management is a vital part of the crash investigation process. By utilizing technology effectively for the management of traffic incidents and crash investigation, safety is improved and congestion is minimized.

While the safety of responders and motorists is the highest priority in Traffic Incident Management and crash investigation, the economic impact of congestion must also be considered. According to the 2015 Urban Mobility Scorecard[1] published by the Texas A&M Transportation Institute, travel delays due to traffic congestion caused drivers to waste more than three billion gallons of fuel and kept travelers stuck in their cars for nearly seven billion extra hours – 42 hours per rush-hour commuter. The result is a total nationwide price tag of $160 billion, or $960 per commuter. In addition, 18 percent or $28 billion of the delay cost was the effect of congestion on truck operations; the cost does not include any value for the goods being transported in the trucks.

The 2015 Urban Mobility Scorecard report predicts urban roadway congestion will continue to worsen without more assertive approaches on the project, program, and policy fronts. By 2020, with a continued good economy:

- Annual delay per commuter will grow from 42 hours to 47 hours,
- Total delay nationwide will grow from 6.9 billion hours to 8.3 billion hours,
- Total cost of congestion will jump from $160 billion to $192 billion.

The economic impact of congestion cannot be ignored. The utilization of traffic crash reconstruction technology has a significant impact on congestion and the cost to motorists.

The technology available for the investigation and reconstruction of traffic crashes has evolved over time. The basic investigative tools are a measuring tape, a rolling measuring device or a combination of these tools. The evolution of traffic crash reconstruction technology has introduced many new types of equipment to this field, as well as evolving practices and methods.

[1] *2015 Urban Mobility Scorecard*, Texas A&M Transportation Institute (August 2015)

Crash investigation equipment available today is capable of accurately capturing the evidence at a crash scene for the purpose of reconstructing crashes.

The evaluation of technology can be very subjective. To minimize the subjectivity, a panel of experts in the field of traffic crash reconstruction was established. The panel, consisting of representatives of law enforcement, private traffic crash reconstruction professionals, state departments of transportation, and the National Transportation Safety Board (NTSB), was consulted to guide the research of the technology. Each technology was rated on Responder Safety, Quick Clearance and Court Acceptance using the criteria presented in Table 1. Table 2 summarizes the results of this research.

Table 1. Technology Rating Criteria

Rating Criteria			
Responder Safety	Very Unsafe	Unsafe	Safe
Safe, Quick Clearance	Extended Clearance	Moderate Clearance Time	Quick Clearance
Court Acceptance	Not Accepted	Some Acceptance	Accepted

Table 2. Research Summary

Reconstruction Equipment	Roadway Clearance	Responder Safety	Court Acceptance	National Unified Goal Ranking	Court Acceptance Ranking	Cost Ranking
Mechanical Measurement Tools	■	■	●	12	1	1
Photogrammetry	●	●	▼	7	7	2
Light Detection and Ranging (LiDAR)	▼	●	▼	10	8	3
Electronic Total Station	■	▼	●	11	2	4
Reflectorless Total Station	●	●	●	2	3	5
Global Positioning System (GPS)	●	▼	●	9	9	6
Semi-Robotic Total Station	●	●	●	3	4	7
Robotic Total Station	●	●	●	4	5	8
Imaging Station	●	●	●	6	11	10
Three-dimensional (3-D) Laser Scanning	▼	●	●	8	10	11
Unmanned Aerial Devices	●	●	▼	1	12	12
Hybrid Total Station	●	●	●	5	6	9

CHAPTER 1 INTRODUCTION

The Federal Highway Administration's (FHWA) investigation of practices and technologies that affect crash reconstruction supports improved safety of incident responders and the traveling public. The successful investigation of these methods guides successful Traffic Incident Management (TIM), as identified in the National Unified Goal for TIM (NUG) which can be found at http://timnetwork.org/national-unified-goal-nug/.

Most roadway-related Intelligent Transportation Systems (ITS) mainly address improved detection and notification activities as illustrated in Figure 1 which is courtesy of FHWA's Strategic Highway Research Program (SHRP2) National TIM Responder Training Program. Roadside detectors and cameras support the identification of traffic disruptions. Cameras add a deeper level of validation and understanding, while message signs alert, inform, or guide decisions for drivers and those contemplating travel on a roadway. The technology used in crash reconstruction, in concert with ITS equipment, supports the timely removal of traffic crash obstructions in the response and clearance phases, and maintains the integrity of the crash investigation data collected at the scene.

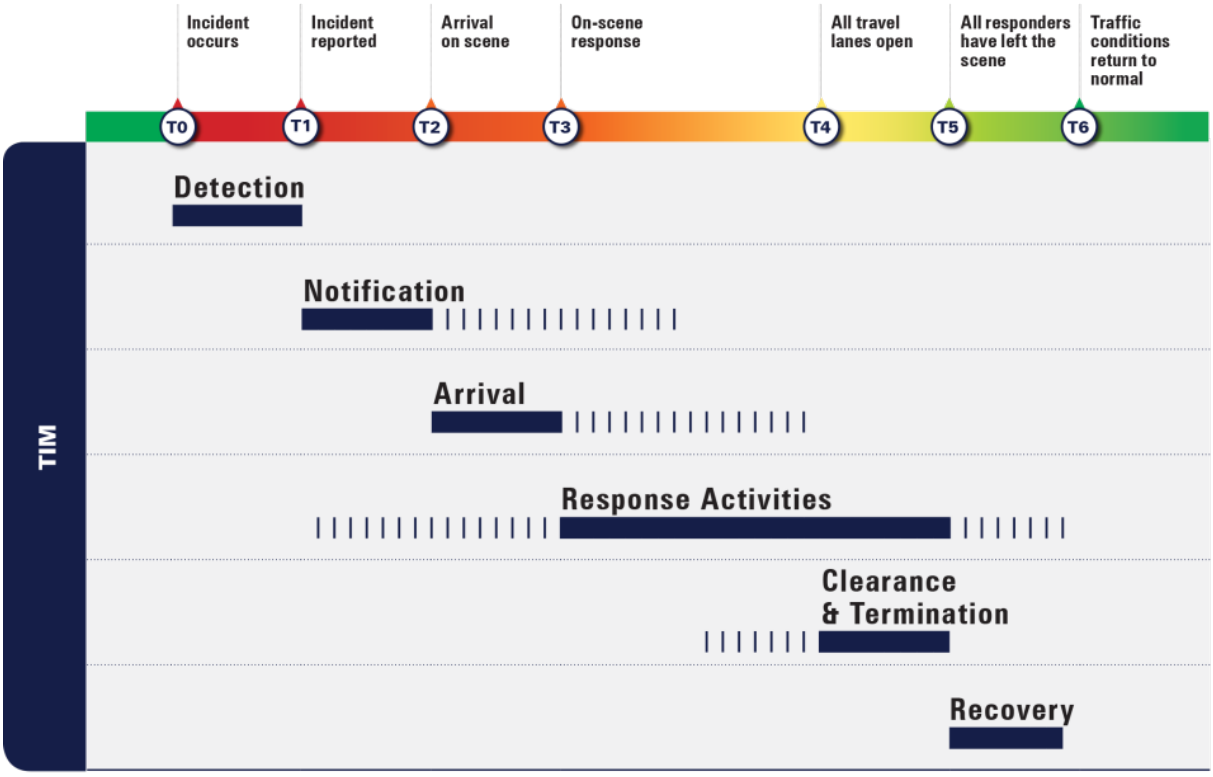

Figure 1. Graph. Traffic Incident Management Event Sequence

Technologies from other disciplines have been or are being studied and evaluated to support crash investigation and TIM activities. Among these are:

- Fire apparatus that are equipped with advanced lighting and incident scene clearance tools,
- Ambulances that are equipped with the most recent patient care innovations,
- Towing and recovery vehicles that have computerized systems,
- Law enforcement professionals that have highly specialized onboard and mobile equipment for completing their tasks and contributing to other aspects of TIM.

As agencies move toward reliable reporting of TIM-related performance measures, these technologies and the practices that employ them will be vital parts of the maturation of TIM programs.

PROGRESSION OF LAW ENFORCEMENT INVESTIGATION TECHNOLOGY

There are currently many types of technology used for traffic crash investigation and reconstruction. The basic method involves the use of measuring tapes, rolling measuring devices, levels and formula calculations to determine the course of events and the cause of a crash. This method is currently in use in the majority of law enforcement agencies throughout the United States.

Technological improvements have generally addressed accuracy, speed, or a combination of both. However, in some jurisdictions the laws and policies that govern crash investigation have not kept pace. When transportation professionals engage law enforcement and other public safety professionals, they must recognize that quick clearance starts with responder safety. Attention to responder safety priorities can be a sensitive issue in many locations where law enforcement professionals feel as though they are being pushed to open roads more quickly and without regard for the important task of collecting crash investigation evidence.

There have been considerable changes in the technology that is available for traffic crash reconstruction. Many methods use a platform commonly used in surveying to create a forensic map of a crash scene. Other methods use lasers or Global Positioning System (GPS) devices. In addition to the forensic maps of the crash scene, many technologies allow for the creation of crash simulations and three-dimensional (3-D) models. These technologies also capture data used to determine the course of events and the cause of a crash.

Much of the technology in use today is widely available and becoming more affordable, while emerging technology is expensive and not widely available. There is currently no reference guide for law enforcement administrators or other traffic crash reconstruction professionals to use when planning equipment purchases. The available information is based on the experience of individual agencies or manufacturers.

The technologies and best practices identified in this report will assist agencies in determining which technologies will best meet their crash investigation and TIM needs. There is no “one size

fits all" approach for traffic crash reconstruction. The basic, mechanical measuring process and equipment may fit the needs of some, but others may need more advanced, specialized capabilities to achieve their goals. The research conducted for this report examined the technology in use today, how it can be used to achieve the goals of the NUG, the cost of the technology, and its availability for use in traffic crash reconstruction.

The underlying needs for this research are to provide a safer environment for responders, a safer environment for motorists, and to minimize the effect that traffic crashes have on traffic flow. The manner in which the technology is applied is just as important as the technology itself. The most advanced technology available is no more valuable if it is not used in an efficient manner to minimize the exposure of personnel to the dangers of traffic in the roadway.

Law enforcement professionals must weigh the need to obtain and record information related to crashes versus the danger to investigators, responders and other highway users. Most crashes that occur are minor, they are cleared quickly, and do not require in-depth investigation and reconstruction. However, in-depth investigation of moderate and major crashes is necessary due to the circumstances, severity, or other factors. These crashes take longer to investigate and often result in roadway closures. Closing lanes on a highway increases the risk of a second crash occurring. In many cases, secondary crashes are more severe than an initial crash. Reducing the number of secondary crashes on the nation's highways is a primary goal of the Federal Highway Administration and is an important part of the Towards Zero Initiative.

A crash reconstructionist has a job that is unique, and any reconstructionist could be faced with a scenario such as the following:

1. An incident occurs that requires and gets emergency response.
2. The need for crash reconstruction and investigation is identified and a call is made for a trained specialist, who now asks:
    - Do I have the technology tools I need and are they in working order?
    - Are there special circumstances I need to worry about?
    - How has traffic been affected?
    - How is traffic affecting the scene?
    - Will I encounter delays in ingress to the scene?
    - Will the scene be intact or altered by the time I get there?
    - Has evidence been preserved?
    - What do I need to tell those on-scene to do until I get there?
    - Will I need to go anywhere else other than the crash scene?
    - Will I need to talk with specific persons not available now?
    - How will I communicate with responders on-scene until I arrive?
    - When I arrive, what can I do to minimize the effects on traffic while still protecting responders and motorists?

- Is the technology that I have the best for this investigation or do I need to call for assistance?
- Can the evidence at the crash scene be marked and the mapping completed at a safer, more convenient time?

TRAFFIC CRASH RECONSTRUCTION 101

There is no one type of technology that addresses all the needs for traffic crash reconstruction. Each crash or incident involves unique circumstances. In many jurisdictions the cost of training and equipment prohibits every officer from being a certified crash reconstructionist. Neither the crash reconstructionist nor the needed equipment is involved in the initial incident response.

In many instances the crash reconstructionist (an individual or team) is called to the crash scene after the initial response. The investigator must rely on first responders to preserve all evidence and protect the scene. Anything at the scene of a crash could be evidence, therefore the roadway remains closed until the investigators can complete the scene investigation activities. Depending upon the response time for the investigator and the necessary equipment, a closure can extend from minutes to hours. The availability of the equipment and the proximity to the crash scene are vital.

The investigator must record information from the crash scene to complete the reconstruction. This data includes, but is not limited to:

- Tire marks,
- Vehicle positions,
- Body positions,
- Marks in the pavement,
- Debris,
- Roadway grade,
- Other environmental evidence.

This information is essential to determining the true cause of a crash and accurate recording is essential so that investigation results are uncompromised. The recording of the information is a determining factor in the length of time needed for the crash scene investigation. Technology can decrease data collection time and improve the accuracy of the data collected.

Evidence collected at the beginning of the investigation may not be as easily recognized and determined due to the nature of modern automobiles. Tire marks and other evidence exist, but the life of evidence diminishes if not recorded immediately. Evidence can be marked and recorded, roadway markings that are in the travel lanes can be recorded, and the roadway can be opened to traffic. Other information for the crash reconstruction, such as the roadway geometry can be recorded after the roadway has been reopened to traffic. This approach reduces the exposure of investigators to the dangers of traffic and reduces the risk a secondary incident.

After the investigation at the scene is completed, the recorded information must be processed to complete the reconstruction. Modern technology utilizes computer software to complete scale diagrams and mathematical calculations to determine speed and other factors, as well as determine the cause of the crash. Depending upon the software and the proficiency of the investigator in its use, this process can be time consuming. The verification of the results is essential even with the use of the computer software. The investigator must be able to defend the results of the reconstruction when testifying in court. The technology used in the traffic crash reconstruction process assists the investigator with the recording and processing of critical information.

RELATIONSHIP BETWEEN CRASH RECONSTRUCTION AND TRAFFIC INCIDENT MANAGEMENT

Effective quick clearance of roadways is a special issue when reconstruction activities are required on-scene. Planned and coordinated procedures among all responders creates success which is exemplified when the reconstruction teams are familiar with their surroundings, trust the responders on-scene to assist, and work with a dual focus on completing the investigation and opening the roadway.

Responders and investigators working cooperatively and selecting their work patterns to focus on clearance of a lane or lanes progressively help prevent secondary crashes. The coordinated efforts include pre-established procedures for evidence preservation protocols that responders understand and can easily follow. There are benefits to procedures for responder collection of information prior to the arrival of the investigators which are reflected in trimming time from the crash investigation and clearance timeline.

While physical evidence is a major part of an investigation, responders can provide context and contribute to the efficiency of the investigation associated with appropriate and thorough investigative work. Responders can describe changes in weather, effects of passing traffic, and give context to the traffic control signage and other directional advice that motorists had if the incident is in a work zone or other modified traffic pattern.

Pre-planning and established procedures create a more effective use of TIM. The relationships that result from a cooperative TIM environment, from preparedness to response through recovery, are the keys to success.

When responders know what investigators need and help provide it, and when investigators depend upon that knowledge and experience, the incident scene is safer and the roadway is opened more quickly. Lessons learned from those cooperative experiences result in better preparedness for the next investigation.

CHAPTER 2 INPUT FROM EXPERIENCED CRASH RECONSTRUCTION PROFESSIONALS

Selection of crash investigation technology at the local levels typically depends on the experience of those involved and the cost of what is chosen. An expert panel, diverse in experience and geographic location, was convened to assist with the research and report development. The collaboration of the Federal Highway Administration (FHWA) and the International Association of Chiefs of Police contributed to the panel member selection. The panel represents the spectrum of crash reconstruction personnel throughout the United States from various law enforcement communities, the private sector and the National Transportation Safety Board (NTSB). Panel members are from Arizona, Arkansas, Florida, Illinois, Massachusetts, Michigan, Minnesota, Missouri, Nebraska, Oregon, Pennsylvania, Utah, Virginia, and Washington State as shown in Figure 2. Names of panel members are listed in Table 3 and biographies of each member are included in Appendix A.

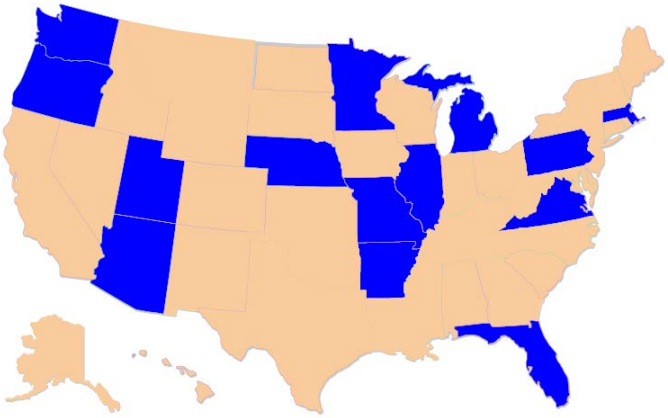

Figure 2. Graph. Expert Panel Members' Geographic Distribution

Predicting and determining the future of traffic crash reconstruction requires extensive research of the evolution of practices and equipment. Understanding the technology and methods evolution that has happened and is happening provides a clearer vision of the future.

Most traffic crash investigation in the United States uses traditional measurement tools. The tools utilized most commonly are a rolling measurement device or a tape measure. Measurements obtained using these mechanical tools are used to create crash scene diagrams and to complete mathematical formulas.

Table 3. Crash Reconstruction Technology and Best Practice Panelists

Name	Organization
Tom Simon	Arizona Department of Public Safety
Scott Skinner	Oregon State Police
Tracy Flynn	Pennsylvania State Police
Dave Keltner	Illinois State Police
Andy Klane	Massachusetts State Police
John Graves	Hillsborough County Sheriff's Office
Mike Anderson	Salt Lake County Sheriff's Office
Victoria Boldt	Sarpy County Sheriff's Office
Keith Jackson	Collinsville Illinois Police Department
Bill Johnson	Kansas City Missouri Police Department
Brian Reeves	Springfield Missouri Police Department
Greg Gravesen	St. Paul Minnesota Police Department
Ron Heusser	Engineering Accident Analysis
Nate Shigemura	Traffic Safety Group, LLC
Matthew S. Jackson	Jackson Reconstruction, Inc.
James D. (Dave) Bean	National Transportation Safety Board
Angie Kremer, P.E.	Michigan Department of Transportation

As traffic crash reconstruction has evolved, other types of technology have become available to law enforcement officers. Several law enforcement agencies use equipment traditionally used by surveyors. Crash investigation equipment that is now readily available includes:

- GPS coordinate technology,
- 3-D scanning and imaging equipment,
- Photographing a crash site,
- Equipment initially developed for speed measurement utilizing lasers.

The evolution of equipment has led to incredible advances, including unmanned aerial systems (UAS). Although not currently readily available for public use, research conducted around the world is leveraging these advances. The research conducted under this project sought to validate significant areas of crash reconstruction including manpower, methodology, and technology. These areas of emphasis effectively, quickly and accurately support the use of the results of the

investigation in court. Advocates for new approaches who want to convince law enforcement agencies to change policies must generally illustrate three things:

- Reliability of the technology,
- Likelihood that court acceptance will be maintained/increased,
- Increased unobligated time for officers will result.

RESEARCH OF PRACTICES AND TECHNOLOGIES

The project research focused on current traffic crash reconstruction technologies and the existing practices employed by traffic crash reconstruction professionals, professional organizations, and equipment vendors. A survey gathered information to identify the current traffic crash reconstruction technology.

There are a number of factors to consider when discussing the technology used for traffic crash reconstruction. Some of the practices and methods have been used for many years and are still very accurate. There are also be practices or technology that are inefficient for crashes on the highway since they prolong roadway closures.

Considerations of the research include:

- **Availability of equipment and software** - There are many software packages available and used for reconstruction tasks that lead to the production of a report. The compatibility of software is a critical element in selecting technology. The software must be capable of interpreting the data and displaying the results.
- **Current usage and acceptance by practitioners and the courts** - The technology must reliably function as designed and it is essential that it operate consistently in differing environments. The reliability depends on the support of the manufacturer and the vendor of the equipment. Issues certainly arise in the use of the equipment and the support of the manufacturer and vendor is essential for success. Reliability is a key factor for court acceptance.
- **Ease of use, including training and education requirements** - Training requirements for proper set-up, use and production of a final result, as well as licensing and/or certification of operators are also among the concerns of law enforcement agencies and those who are responsible for using the equipment. Specialized training and regular use of the equipment is required to sustain proficiency.

FUNDING DECISIONS

The decision by law enforcement agencies and private reconstruction firms concerning which technology to use is primarily driven by the cost of the equipment and operation. Although traffic crash reconstruction is important to all users, the funding that is available decides what choices are made.

The purchase of equipment is only the beginning. Software, personnel training, equipment, and the maintenance of competencies in the use of the investigation method for court acceptance are also vital to the process of traffic crash reconstruction. The expected service life of the equipment is an important consideration since a limited service life often results in costs for new equipment, procedure changes, and retraining.

The research criteria for this project are equally important to the purchaser and the user of the technology. The research examined information concerning the allocation of funding for traffic crash reconstruction as many decisions in law enforcement are budget-driven.

Participation in a Traffic Incident Management (TIM) Program as a best practice was an important part of the discussion with the Expert Panel and others contacted during the project.

The manner in which a law enforcement agency approaches the investigation and reconstruction of a crash is also a factor in determining the best choice of technology. Most of the crashes that involve reconstruction are fatal crashes or involve some aspect that may result in litigation. The proper recording and recovery of evidence is essential to traffic crash reconstruction. A crash of this nature is essentially a crime scene or the basis for some type of civil litigation. The application of the technology will determine the effect that the investigation has on responder safety, traffic management options, and overall incident management.

One of the aspects of traffic crash reconstruction that is often overlooked is the availability of peer support for the technology and the practices that are in place when reconstructing a crash. Agencies can share information about their experience and practices with similar equipment and methods, further enhancing the capabilities of each organization. A successful program in the Midwest involved the purchase of equipment, software and training for law enforcement agencies in a large metropolitan area. The program implemented a single software package across the agencies to improve the compatibility and consistency of crash investigation throughout the area. As a result, there is now a large “team” of reconstruction professionals throughout that metropolitan area who can assist one another with investigations.

BEST PRACTICES

The project research identified the current best practices and technologies for crash investigation and reconstruction. Multiple practices were identified as having great value in various situations. The Expert Panel was engaged at various points in the project research providing expert insight, input, and review of the results produced.

CHAPTER 3 RESEARCH METHODOLOGY

The Expert Panel involved in this project represents the spectrum of crash reconstruction professionals throughout the United States. The diversity of the panel is important since, in most cases, the policies that govern traffic crash reconstruction are localized and localized policies can dictate the technology that is employed. The research team used surveys and interviews of these experts to gather information about the equipment and practices employed for crash investigation and reconstruction.

SURVEY OVERVIEW

A survey gathered inputs from reconstruction professionals regarding their use of technology and how it is utilized to accomplish the National Unified Goal for Traffic Incident Management (NUG). The findings revealed various types of technology and practices currently in place nationwide. The different practices and technologies currently in use for traffic crash reconstruction, as well as those that are emerging were identified and documented.

The criteria for the analysis included the following:

- Type of technology,
- Availability of technology,
- Acceptance in field of crash investigation and traffic crash reconstruction,
- Current use in field of crash investigation and traffic crash reconstruction,
- Acceptance in court,
- Ease of use,
- Training requirements,
- Training availability,
- License or certification requirements,
- Software compatibility,
- Reliability,
- Vendor/manufacturer support,
- Cost of equipment,
- Cost of upkeep,
- Service life.

The current practices and technologies were analyzed based on established criteria and were assessed to identify those that represent the best practices in traffic crash reconstruction. Due to the diversity of situations and environments faced by agencies and organizations employing crash reconstruction practices and technologies, multiple best practices were identified.

Surveys, distributed to the members of the Expert Panel and to other professionals in the field of traffic crash reconstruction, inquired about the technology they use or they have experience

using. Research summary tables for each technology identified were developed supporting comparison and providing information about capabilities and benefits. The inputs gathered from the survey responses are documented in the tables in Chapter 5 along with information compiled through other research sources.

The Expert Panel assisted with the development of the topics in the survey as well as the questions. Since the use of the technology to accomplish the goals of the NUG is an essential part of this project, the following questions were asked:

Responder Safety	How does this technology affect exposure to risk for on-scene responders?
Safe, Quick Clearance	How does this technology affect clearance times for crashes and how does that balance with the collection of prosecutorial information?
Prompt, Reliable Communications	How can aspects of collected information be used and shared to improve incident management activities over time?

CHAPTER 4 RESEARCH RESULTS

The project research activities focused on current traffic crash reconstruction technologies and the existing practices utilizing those methods. The research reviewed information available on the internet and inputs from traffic crash reconstructionists, professional organizations, and equipment vendors who were contacted. The survey discussed in Chapter 3 gathered inputs from reconstruction professionals regarding their use of technology and how it is utilized to accomplish the National Unified Goal for Traffic Incident Management (NUG). These practices range from very simple to technically complex.

The tables in Chapter 5 summarize each technology that is currently in use and those that are viewed as useful for the future of traffic crash reconstruction. Provided in Chapter 5 for each technology or method is a detailed description followed by a summary sheet which contains the research results in the manner described below.

The use of the technology to achieve the goals of the NUG is color-coded in the tables. This research data visually depicts the role that the technology and its use play in achieving these goals. Each technology was rated on Responder Safety, Quick Clearance and Court Acceptance using the criteria in Table 4.

Table 4. Technology Rating Criteria

Rating Criteria			
Responder Safety	Very Unsafe	Unsafe	Safe
Safe, Quick Clearance	Extended Clearance	Moderate Clearance Time	Quick Clearance
Court Acceptance	Not Accepted	Some Acceptance	Accepted

For the purpose of this project, it was assumed that the technology is being utilized to achieve maximum compliance with the NUG. Each technology was rated in the following areas:

- **Cost of Ownership** – The cost of the technology versus the benefit of its use to the collection of prosecutorial information. (1=high cost to low benefit; 5=low cost to high benefit),
- **Availability** – Will the technology be available for all of the crash investigation teams in a jurisdiction? (1=no availability; 5=always available),
- **Amount of Training Required for Usage** – How much training is required to use the technology and methods, and attain an original certification on the product? (1=burdensome amount of training; 5=little amount of training),
- **Retraining to Continue Certification** – How often is retraining required to maintain certification on the technology? (1=monthly; 5=annual or longer),

- **Setup and Takedown** – How much time is required to setup the equipment and take the equipment down to store it for future use? (1=long setup/take down; 5=short setup/take down),
- **Opportunities for Enhancement** – Does the technology accommodate future enhancement? (1=no future enhancements; 5=high number of enhancements),
- **Court Acceptability** – Are the technology results accepted in court? (1=not acceptable; 5=always acceptable).

The scoring matrix provides a range of 1 being the lowest possible score for the category to 5 being the highest score for the category. For areas of technology that the expert had little to no experience, a score of not applicable (N/A) was used.

The totals in the tables were determined by multiplying the number of responses in each category by the 1 through 5 rating scale at the top of the table. The values in the tables are intended to provide the reader with a comparison of the Expert Panel responses in each rated category. By reviewing the information in the tables, the reader will be able to understand the criteria that they may need to rate a technology or method considering the acquisition or updating of crash reconstruction technology. It is important to note that a high raw score in the tables may not be the best choice of technology based upon its compliance with the NUG, its cost, and its availability. Those criteria will be detailed further in the report. Not all of the respondents rated each category for the different technologies.

Representative survey responses and comments regarding the technology or method in terms of Responder Safety, Quick Clearance and Court Acceptance are included to provide additional insight and perspective for the reader.

The data, as well as the survey responses and other sources, provide recommendations to readers who are contemplating the acquisition or update of crash reconstruction methods. Information is provided to guide readers based upon the conditions and situations in which the technology will be used.

The safety of responders is at the forefront of recommendations. The application method is a critical part of the decision-making process to provide a safer environment for responders and other highway users, and to minimize any negative impact on traffic conditions.

CHAPTER 5 TECHNOLOGY OVERVIEW

MECHANICAL MEASUREMENT TOOLS

Mechanical measurement tools typically consist of a measuring tape, a rolling measuring device, or a combination of the two. A carpenter's level is often used to determine the grade(s) of the roadways and, when used properly by well-trained investigators, provides incredibly accurate results. Additional equipment is needed to create a diagram of the crash scene, including a protractor, compass and different types of curves. A summary of the costs of the equipment is provided in Table 5.

Table 5. Mechanical Measurement Tools Equipment and Costs

Equipment	Cost
Measuring tape	$30 to $50
Measuring wheel	$70 to $120
Assorted additional equipment	$100

The mechanical measuring tools are used to record baseline measurements at a crash scene. The technology works well on straight, level roadways, however, accuracy is more difficult to attain on curved roadways. Manual recording is required for each measurement and is subject to human error.

Mechanical measurement tools are straightforward and the training needed is minimal. Investigators can normally create a basic diagram after approximately 4-6 hours of instruction. Additional training is required to handle complex crash investigations. Recognized, entry-level crash investigation courses vary from a few hours to over 40 hours, whereas recognized, advanced courses vary from 40 hours to 80 hours.

Well recognized in courts across the country, mechanical measuring tools apply accepted mathematical formulas and principles. Mechanical measuring tools have been applied since traffic crashes were first investigated. The mathematical formulas for this method of traffic crash reconstruction are derived from physics equations. Information collected by more advanced types of technology must be capable of verification by use of mechanical measuring tools.

While mechanical measuring tools can be very accurate and the results are recognized in court, the use of these types of tools increases the exposure of officers and investigators to the dangers of traffic and extends the roadway clearance time. In addition, it is difficult to obtain accurate measurements at crash scenes involving curved roadways and roadways with significant changes in elevation.

Description: Mechanical Measurement Tools

Mechanical measurement tools have long been applied to crash investigation. The use of cloth tape often required two investigators for Trilateration or Cartesian (base line) measurement. The roller wheel was introduced in 1950.

Average Cost: less than $500

Figure 3. Photo. Mechanical Measurement Tool
Source: Michigan State Police

Technology Rating Index – as judged by the experts

Safe, Quick Clearance **Responder Safety** **Court Acceptance**

Table 6. How the Experts Rated Mechanical Measurement Tools

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	2	2	15	4	45	**68**
Availability	1	0	0	0	90	**91**
Amount of Training Required	0	0	12	4	70	**86**
Retraining to Continue Certification	0	2	0	4	60	**66**
Setup and Takedown	2	2	3	16	50	**73**
Opportunities for Enhancements	15	4	3	0	0	**22**
Court Acceptability	0	0	21	8	50	**79**
TOTALS	**20**	**10**	**54**	**36**	**365**	**485**

The following are comments provided by the reviewers about Mechanical Measurement Tools:

- Responder Safety
  - Requires personnel close to road and roadway evidence to take measurements.
- Safe Quick Clearance
  - Takes a longer period of time to make each measurement, cannot gather as many measurements as other methods.
  - Takes longer and is less accurate. The value of prosecutorial information depends on accuracy needed but is generally lower than other options available.
- Prompt, Reliable Communications
  - Information cannot be shared easily unless it is populated into a computer program for later use.
  - Reliable, but slow and prone to error.

ELECTRONIC TOTAL STATION

Crash reconstructionists in the United States have utilized the Electronic Total Station since the early 1990s. It is comprised of four components: the Theodolite, the Electronic Distance Measurement Instrument (EDM), an optical prism, and a data collector. The Electronic Total Station utilizes surveying principles to create a map of a crash scene.

The theodolite is a very precise instrument used to measure horizontal and vertical angles between points. The EDM measures the slope distance between points. The Electronic Total Station uses reflected light from an optical prism to capture distance and angles from the theodolite for each point measured. The geometric data, combined with graphic attributes recognized by the software, generates an accurate scale map of the scene. The map is a visual depiction of the crash scene and the gathered data can be used in mathematical formulas to reconstruct the crash. A summary of the costs of the equipment is provided in Table 8.

Table 7. Electronic Total Station Equipment and Costs

EQUIPMENT	COST
Theodolite, Electronic Distance Measurement Instrument (EDM), Optical Prism, Data Collector, Essential accessories (tripod, prism pole(s), tape measure).	$8,000 to $10,000 (varies widely)

There are a number of manufacturers of Electronic Total Stations. Although they may vary in the accessories that are available, they function much the same, measuring angles and slope distances. There are a number of data collectors available for use with the Electronic Total Station, some of which are weather resistant for use in inclement conditions. Some Electronic Total Stations are not well suited for use in inclement weather which could skew the data collection results as well as damage the equipment.

The use of an Electronic Total Station is more complex than the mechanical measuring process; therefore the training is much more extensive. The recommendation for the basic training necessary is a minimum of 40 hours and does not include field projects that should be completed following the basic course. In addition to the basic training and field projects, operators must use the equipment frequently to maintain proficiency.

Crash investigation techniques involving the use of an Electronic Total Station are accepted in courts across the United States. The principles for creating a map of a crash scene are the same as those used in surveying applications. The data consists of angle and distance measurements that are calculated and used by software to document the crash scene.

Although the data collected using an Electronic Total Station is very precise, its use increases the exposure of officers and investigators to the dangers of traffic. The use of the Electronic Total Station requires that the measurements be obtained with the use of an optical prism located directly over the evidence to document or map. This process can be slow depending upon the complexity of the crash scene and the proficiency of those operating the equipment. In addition to the increased exposure to traffic, the roadway clearance time is lengthened. The roadway or traffic lanes must remain closed while the measurements are collected.

Description: Electronic Total Station
Electronic Total Stations produced from 1990 to about 2000 are controlled by an internal microprocessor, allowing performance of a number of different measuring tasks. These tasks include staking out points, polar coordinate measurements, making calculations, and communicating data to a field data collector. This unit is infrared only and not capable of reflectorless measuring.

Average Cost: $9,400

Figure 4. Photo. Electronic Total Station
Source: Kansas City Police Department and KC Scout

Technology Rating Index – as judged by the experts

Safe, Quick Clearance **Responder Safety** **Court Acceptance**

Table 8. How the Experts Rated Electronic Total Station

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	0	0	21	12	10	**43**
Availability	0	0	0	20	35	**55**
Amount of Training Required	0	2	24	12	0	**38**
Retraining to Continue Certification	0	4	15	0	20	**39**
Setup and Takedown	1	4	15	12	5	**37**
Opportunities for Enhancements	1	12	6	4	10	**33**
Court Acceptability	0	0	0	4	55	**59**
TOTALS	**2**	**22**	**81**	**64**	**135**	**304**

The following are comments provided by the reviewers about Electronic Total Station:

- Responder Safety
  - Reduces exposure to traffic when compared to manual measurement means. Still requires some exposure to traffic by prism pole operator.
  - Reduces risk to investigators, reduces on-scene crash investigation time.
- Safe Quick Clearance
  - Set up is heavily dependent on the individual operator's expertise in using it. For those properly trained, set up is not time-consuming and subsequent measurements can be taken much quicker (and with more precision and accuracy) than the roller wheel or tape methods.
- Prompt, Reliable Communications
  - Very easy to share data.
  - Data format easily shared between parties, somewhat dependent on the knowledge of the individual storing the data. An individual not properly trained could produce a nearly indecipherable data file.

REFLECTORLESS ELECTRONIC TOTAL STATION

The Reflectorless Electronic Total Station followed as a variation of the Electronic Total Station, and has been in use for reconstruction in the United States since approximately 2001. The Electronic Total Station is comprised four components which include the Theodolite, the Electronic Distance Measurement Instrument (EDM), an optical prism, and a data collector. Similar to the Electronic Total Station, the Reflectorless version utilizes the principles of surveying to create a map of a crash scene. The Reflectorless version adds the functionality of reflectorless measurements to about 350 meters, or 1150 feet. These distances are to an industry standard grey card. When measuring to a roadway from ground level, a user should expect maximum measurements to about 400 feet.

The theodolite is a very precise instrument used to measure horizontal and vertical angles between points. The EDM measures the slope distance between points. The Electronic Total Station uses reflected light from an optical prism to capture distance and angles from the theodolite for each point measured. The geometric data, combined with graphic attributes recognized by the software, generates an accurate scale map of the scene. The map is a visual depiction of the crash scene and the gathered data can be used in mathematical formulas to reconstruct the crash. A summary of the costs of the equipment is provided in Table 11.

Table 9. Reflectorless Electronic Total Station Equipment and Costs

EQUIPMENT	COST
Theodolite, Electronic Distance Measurement Instrument (EDM), Optical Prism, Data Collector, and essential accessories (tripod, prism pole(s), tape measure).	$7,000 to $8,000
Collector and Evidence Recorder.	$2,400
Forensic Computer Aided Diagramming (CAD) Software.	$1,000

The Reflectorless Total Station added the ability to record measurements with the EDM without the use of an optical prism. The station aims at the point of interest directly, eliminating the need to hold the prism pole over the point. The EDM utilizes a laser rather than the infrared signal to measure the slope distance. These measurements are limited in range. As with the Electronic Total Station, at each point the precision aiming must be performed before the measurement is taken.

Since the use of a Reflectorless Electronic Total Station is more complex than the mechanical measuring process, the training is much more detailed. The recommendation for the basic training necessary is a minimum of 40 hours and does not include field projects that should be completed following the basic course. In addition to the basic training and field projects, operators must use the equipment frequently to maintain their proficiency and maintain court acceptance.

Using a Reflectorless Electronic Total Station, the technician can minimize personal exposure to traffic by carefully selecting the instrument location and recording measurements in the reflectorless mode. When the reflectorless mode is selected, the mapping time lengthens as

measurements are timed to be recorded between vehicles while the roadway is open to traffic. However, since these measurements are being collected while the roadway is open to traffic, the effect on traffic flow is minimal.

Description: Reflectorless Total Station

In addition to the features from previous total stations, the Reflectorless Total Station allows for measurements to objects or points without placing an optical prism at those points. The process includes: pointing the instrument towards the relevant evidence point, aiming the crosshair at the object and pressing the data collector button to collect the shot. The reflectorless function of the EDM portion of the instrument permits distances to be measured well beyond normal crash scene distances. These instruments when first introduced allowed reflectorless measurements up to 350 meters or 1150 feet.

Average Cost: $18,200

Figure 5. Photo. Reflectorless Total Station
Source: KC Scout

Technology Rating Index – as judged by the experts

● **Safe, Quick Clearance** ● **Responder Safety** ● **Court Acceptance**

Table 10. How the Experts Rated Reflectorless Total Station

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	0	2	18	20	20	**60**
Availability	0	2	3	24	35	**64**
Amount of Training Required	0	0	36	8	10	**54**
Retraining to Continue Certification	0	4	18	4	25	**51**
Setup and Takedown	0	4	24	20	5	**53**
Opportunities for Enhancements	0	12	9	16	10	**47**
Court Acceptability	0	0	0	4	75	**79**
TOTALS		**24**	**108**	**96**	**180**	**408**

The following are comments provided by the reviewers about Reflectorless Total Station:

- Responder Safety
  - Optimal, fairly available measurement device. In many cases, enables measurements to be taken some distance from the roadway and out of traffic.
  - Greatly lowers exposure risk since no officer need be in the roadway.
  - Reduces on-scene crash investigation time.
- Safe Quick Clearance
  - Allows relatively quick scene clearances, compared to tape measures, etc. Captures scene detail required for diagrams and reconstruction analysis.
  - Reduces time necessary to set up and take down, as well as reduced time to measure, all reducing time to return to a normal traffic pattern.
- Prompt, Reliable Communications
  - Data is easy to share.
  - Information can be shared with anyone who has a compatible program that will communicate with the total station.

SEMI-ROBOTIC TOTAL STATION

The Semi-Robotic Total Station followed as a variation of the Electronic Total Station and has been in use for traffic crash reconstruction in the United States since the early 2000's. The semi-robotic total station is comprised of four components. These components are the Theodolite, the Electronic Distance Measurement Instrument (EDM), an optical prism, and a data collector. A summary of the costs of the equipment is provided in Table 14.

Table 11. Semi-Robotic Equipment and Costs

EQUIPMENT	COST
Theodolite, Electronic Distance Measurement Instrument (EDM), Optical Prism, Data Collector, and essential accessories (tripod, prism pole(s), tape measure).	$14,200
Collector and Evidence Recorder.	$2,400
Forensic Computer Aided Diagramming (CAD) Software.	$1,000

The Electronic Total Station and the Reflectorless variant utilize the principles of surveying to create a map of a crash scene. The Semi-Robotic variant eliminates the need to mechanically aim the EDM at the prism. A tracking laser maintains aim automatically and updates distance measurements. The Semi-Robotic Total Station increases the ability to measure in the reflectorless mode to 500 meters or approximately 1640 feet. When measuring to a roadway from ground level, a user should expect maximum measurements to about 700 feet. The measurement time is reduced since the instrument is constantly measuring.

The theodolite is a very precise instrument used to measure horizontal and vertical angles between points. The EDM measures the slope distance between points. The Semi-Robotic Total Station uses a laser reflected from an optical prism to capture these angles and distances. The collected data provides attributes which are recognized by the software. The data is input to diagramming software designed to create a scale map of the scene. The map is a visual depiction of the crash scene and the gathered data can be used in mathematical formulas to reconstruct the crash.

The Semi-Robotic Total Station includes the ability to record measurements with the EDM without the use of an optical prism by an added function of auto-tracking the prism. The station is motorized horizontally and vertically. As the laser tracks the prism's movement about the scene, the need to precisely focus and aim the station is eliminated. There are occasions when obstacles block the laser and a loss of auto-tracking occurs. The station operator may re-establish tracking or a remote aiming process may be performed to point the station toward the prism to reinitialize auto-tracking. The communication range between the collector and station is about 350 meters or 1150 feet.

As the use of a Semi-Robotic Total Station is more complex than the mechanical measuring process, the training is much more involved. The recommendation for the basic training necessary is a minimum of 40 hours and does not include field projects that should be completed

following the basic course. In addition to the basic training and field projects, operators must use the equipment frequently to maintain their proficiency and maintain court acceptance.

With the use of a Semi-Robotic Total Station, the technician can minimize personal exposure to traffic by carefully selecting the instrument location and recording measurements in the reflectorless mode. When this option is selected, the mapping time may be lengthened as measurements are timed to be recorded between vehicles while the roadway is open to traffic. However, since these measurements are collected while the roadway is open to traffic, the effect on traffic flow is minimized.

Description: Semi-Robotic Total Station
Unassisted operation for measuring and recording of data. The Semi-Robotic Total Station seeks out an Active Remote Measuring Target (RMT), locks onto it, and follows movement between points. No fine adjustments or focusing are needed and there are no issues working in the dark. In most cases, it is possible to stake out and gather survey data as fast as the system can move.

Average Cost: $20,900

Figure 6. Photo. Semi-Robotic Total Station
Source: Kansas Highway Patrol and CSI Mapping

Technology Rating Index – as judged by the experts

● **Safe, Quick Clearance** ● **Responder Safety** ● **Court Acceptance**

Table 12. How the Experts Rated Semi-Robotic Total Station

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	0	6	9	8	0	**23**
Availability	4	0	9	4	0	**17**
Amount of Training Required	0	2	18	0	0	**20**
Retraining to Continue Certification	0	2	9	0	10	**21**
Setup and Takedown	0	6	3	8	0	**17**
Opportunities for Enhancements	0	4	9	0	5	**18**
Court Acceptability	0	0	0	4	30	**34**
TOTALS	**4**	**20**	**57**	**24**	**45**	**150**

The following are comments provided by the reviewers about Semi-Robotic Total Station:

- Responder Safety
  - Lower risk and exposure to traffic than mechanical and electronic total station. User can set up in a safe area to avoid traffic.
  - Reduces risk to investigators, reduces on-scene crash investigation time.
- Safe Quick Clearance
  - Reduces the quick clearance time of other total station instruments by removing the need to find and focus on areas of interest through scope.
  - Set up heavily dependent on the individual operator's expertise in using it. For those properly trained, set up is not time-consuming and subsequent measurements can be taken much quicker (and with more precision and accuracy) than the roller wheel or tape methods.
- Prompt, Reliable Communications
  - Data is easy to share.
  - Information can be shared with anyone who has a compatible program that will communicate with the total station.

ROBOTIC TOTAL STATION

The Robotic Total Station followed as a variant of the Electronic Total Station and has been in use for traffic crash reconstruction in the United States since the mid 2000's. The Robotic Total Station is comprised of five components: Motorized Theodolite, Electronic Distance Measurement Instrument, Optical Prism, Data Collector, and a Repeater. Like the other variations of the Electronic Total Station, the Robotic variant uses the principles of surveying to create a map of a crash scene. It eliminates the need to mechanically aim the EDM at the prism. The fully Robotic Total Station provides an added function of auto-tracking the prism via a remote controller. The controller functions to re-establish tracking of the prism more efficiently. A search command can be sent from the remote controller to the command station to turn to the prism, eliminating the need to manually aim the station at the prism and return to the prism lock status.

A tracking laser is used to maintain aim automatically and updates distance measurements. The Robotic Total Station increases the ability to measure in the reflectorless mode to 100 meters or approximately 3280 feet. When measuring to a roadway from ground level, a user should expect maximum measurements to about 1200 feet, which is sufficient to cover a ¼ mile crash site. The measurement time is reduced since the instrument is constantly measuring and updating the collector.

The station is motorized horizontally and vertically. As the laser tracks the prism's movement about the scene, the need to precisely focus and aim the station is eliminated. The addition of the repeater provides the option of one person operation at incident scenes. The data collector connects to the repeater which then connects to the unit via a long range Bluetooth. Should connection be lost, the repeater provides a method to reconnect the devices.

The theodolite is a very precise instrument used to measure horizontal and vertical angles between points. The EDM measures the slope distance between points. The Robotic Total Station utilizes an infrared light laser that is reflected from an optical prism to capture distances. The collected data is given attributes which are recognized by the software. The data is transferred into diagramming software designed to create a scale map of the scene. The map is a visual depiction of the crash scene and the gathered data can be used in mathematical formulas to reconstruct the crash. A summary of the costs of the equipment is provided in Table 17.

Table 13. Robotic Total Station Equipment and Costs

EQUIPMENT	COST
Theodolite, Electronic Distance Measurement Instrument (EDM), Optical Prism, Data Collector, and essential accessories (tripod, prism pole(s), tape measure).	$18,300
Collector and Evidence Recorder.	$2,400
Forensic Computer Aided Diagramming (CAD) Software.	$1,000

As with the other variations of the Electronic Total Station, the Robotic variant is more complex, and the training is much more involved. The basic training necessary is recommended to be a

minimum of 40 hours and does not include field projects that should be completed following the basic course. In addition to the basic training and field projects, operators must use the equipment frequently to maintain their proficiency.

The technician can minimize exposure of personnel to the dangers of traffic by carefully selecting the instrument location. When the Robotic Total Station arrives at the incident scene in a timely manner, the mapping of the scene can usually be completed by the time vehicle removal is complete. In cases where points of evidence remain to be measured, the reflectorless configuration is available to complete the work. When the reflectorless option is selected, the mapping time may be lengthened as measurements are timed to be recorded between passing vehicles while the roadway is open to traffic. However, since these measurements at being taken while the roadway is open to traffic, the effect on traffic flow is minimized.

Description: Robotic Total Station

Introduced in the 2000's, Robotic Total stations operate unassisted and allow the operator to control the instrument from a data collector via remote control. The Auto-tracking feature (an upgrade from auto pointing) allows measurement of distance by a modulated infrared carrier signal, generated by a small, solid-state emitter aligned with the instrument's optical path and reflected by a 360 degree prism. The maximum reflectorless range of these instruments is about 500 meters or 1,640 feet.

Average Cost: $26,200

Figure 7. Photo. Robotic Total Station
Source: Missouri State Highway Patrol

Technology Rating Index – as judged by the experts

● **Safe, Quick Clearance** ● **Responder Safety** ● **Court Acceptance**

Table 14. How the Experts Rated Robotic Total Station

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	1	4	6	12	5	**28**
Availability	3	2	6	12	0	**23**
Amount of Training Required	0	0	21	4	0	**25**
Retraining to Continue Certification	0	2	9	0	15	**26**
Setup and Takedown	0	4	15	4	0	**23**
Opportunities for Enhancements	0	4	9	8	0	**21**
Court Acceptability	0	0	0	0	40	**40**
TOTALS	**4**	**16**	**66**	**40**	**60**	**126**

The following are comments provided by the reviewers about Robotic Total Station:

- Responder Safety
  - Cuts exposure time greatly. Less manpower required on-scene.
  - Reduces investigators risk and on-scene crash investigation time.
- Safe Quick Clearance
  - Allows very quick measurements of all scene data. Scenes are cleared much quicker than traditional methods. Captures much more scene detail because of ease and speed of use.
  - Reduced time on-scene and processing from older models.
- Prompt, Reliable Communications
  - Mostly flawless data collection and sharing. The data formats are usually compatible with most of the diagramming programs used in the industry.
  - Information reviewed and analyzed for building safer roads and traffic patterns as well as adjusting law enforcement activities in those areas.

TOTAL STATION HYBRID

The Total Station Hybrid is a recent variant of the Electronic Total Station. The use of this variant is increasing in the field and is currently used by a number of agencies and organizations in the United States, including the National Transportation Safety Board (NTSB).

The Total Station Hybrid is comprised of seven components consisting of the Motorized Theodolite, Electronic Distance Measurement Instrument, Optical Prism, Data Collector, a Repeater, a Global Positioning System (GPS) Antenna, and a Data Pack. The Total Station Hybrid has all of the functionality of the Robotic Total Station and adds Real Time Kinematic (RTK) GPS. A summary of the costs of the equipment is provided in Table 20.

Table 15. Total Station Hybrid Equipment and Costs

EQUIPMENT	COST
Theodolite, Electronic Distance Measurement Instrument (EDM), Optical Prism, Data Collector, and essential accessories (tripod, prism pole(s), tape measure).	$34,000
Collector and Evidence Recorder.	$2,400
Forensic Computer Aided Diagramming (CAD) Software.	$1,000

The Total Station Hybrid method supports one-person operation and beyond line of sight measurements. Up to this point, the Electronic Total Stations discussed have been capable of line of sight measurements only. For beyond line of sight measurement, the Total Station Hybrid is transitioned to GPS measurement. The repeater and the GPS functions may not be used simultaneously.

The true Hybrid mode is a blend between the Robotic Total Station and GPS. The Total Station Hybrid uses polar coordinate measuring on all three axes assisted by RTK GPS.

The GPS technology in this application operates more accurately than GPS, Assisted GPS (AGPS), Differential GPS (DGPS) and Wide Area Augmentation System (WAAS). Survey-grade measurement requires some repeatability in measurement. A minimum of three measurements are averaged to meet the general recommendation for reliability. Elevation data should always be recorded optically when the measurement is critical to an analysis. The robotic functionality eliminates the need to mechanically aim the EDM at the prism. The Total Station Hybrid provides the function of auto-tracking the prism via a remote controller. The controller functions to reestablish tracking of the prism more efficiently. A search command from the remote controller to the station turns the station to the prism which eliminates the need to manually aim the station at the prism and return to a prism lock status.

Similar to the Robotic Total Station, a tracking laser maintains aim automatically and updates distance measurements. The Total Station Hybrid has the ability to measure in the reflectorless mode to 1000 meters or approximately 3280 feet. These distances are to an industry standard grey card. When measuring to a roadway from ground level, a user should expect maximum

measurements to about 1200 feet. The measurement time is reduced since the instrument is constantly measuring.

The Total Station Hybrid is motorized to rotate horizontally and vertically. As the laser tracks the prism movement about the scene, the need to precisely focus and aim the station is eliminated. The added functionality of the RTK GPS provides the ability to measure evidence points beyond line of sight of the station. This method requires a wireless connection to a base station. In remote locations, where a public base station is not available, a private connection may be available for purchase or remote base stations may be erected by the mapping technician.

The theodolite is a very precise instrument used to measure horizontal and vertical angles between points. The EDM measures the slope distance between points. The Total Station Hybrid uses an infrared light reflected from an optical prism, or point of evidence when used in the reflectorless mode, to capture distances. For line of sight measurements, the data provides attributes which are recognized by the software. When the GPS function is used, the Total Station Hybrid records the polar coordinates of the evidence points. The data is input to software designed for creating a scale map. The map is a visual depiction of the crash scene and the gathered data can be used in mathematical formulas used to reconstruct the crash.

As with other variants of the Electronic Total Station, the Total Station Hybrid is more complex and the training is much more involved. The basic training that is necessary is a minimum of 40 hours and does not include field projects that should be completed following the basic course. In addition to the basic training and field projects, operators must use the equipment frequently to maintain their proficiency and court acceptance.

Crash investigation techniques involving the use of an Electronic Total Station are accepted in courts across the United States. The use of GPS technology is also recognized as accurate. The combination of the Electronic Total Station and GPS technology has been utilized in the survey industry for many years. The principles for creating a map of a crash scene are the same as applied in surveying. The data consists of angle and distance measurements and the calculated polar coordinates used by software to document the crash scene. It is essential that the operator of the equipment be properly trained and proficient in the use of the equipment for courts to recognize its results.

The technician can minimize personal exposure to traffic by carefully selecting the instrument location and recording measurements in the reflectorless mode. When the Total Station Hybrid arrives at the incident scene in a timely manner, mapping can be accomplished by the time vehicle removal is complete. In cases where points remain to be measured, the reflectorless configuration is available to complete the work. The added functionality of the RTK GPS provides the ability to measure evidence points beyond line of sight of the station. This method requires a wireless connection to a base station. In remote locations where a public base station is not available, a private connection may be available for purchase or remote base stations may be erected by the mapping technician.

Description: Total Station Hybrid
In addition to the features provided by robotic sets, the Total Station Hybrid switches from either auto-tracking the prism or control by the remote control prism unit to RTK GPS measurements when the prism is out of view of the instrument. Position data is determined by receiving signals from GPS satellites. GPS systems in application could have errors on the order of millimeters to centimeters. Reflectorless range increases to 1000 meters.

Average Cost: $35,800

Figure 8. Photo. Total Station Hybrid
Source: Sokkia Corporation

Technology Rating Index – as judged by the experts

● **Safe, Quick Clearance** ● **Responder Safety** ● **Court Acceptance**

Table 16. How the Experts Rated Total Station Hybrid

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	2	2	0	4	10	**18**
Availability	3	0	3	0	10	**16**
Amount of Training Required	0	2	6	8	0	**16**
Retraining to Continue Certification	0	2	6	4	5	**17**
Setup and Takedown	0	4	3	8	0	**15**
Opportunities for Enhancements	0	0	3	12	0	**15**
Court Acceptability	0	0	0	0	25	**25**
TOTALS	**5**	**10**	**21**	**36**	**50**	**122**

The following are comments provided by the reviewers about Total Station Hybrid:

- Responder Safety
  - Requires target to be over evidence, meaning in scenes that are not closed to traffic, individual must be in the road.
  - Reduces risk to investigators, reduces on-scene crash investigation time.
- Safe Quick Clearance
  - Reduces quick clearance time as opposed to other total station instruments by cutting out the need to find and focus on areas of interest through scope.
  - Enhances TIM quick clearance.
- Prompt, Reliable Communications
  - Mostly flawless data collection and sharing. The data formats are usually compatible with most of the diagramming programs used in the industry.
  - Information reviewed and analyzed for building safer roads and traffic patterns as well as adjusting law enforcement activities in those areas.

CLOSE-RANGE PHOTOGRAMMETRY

Modern Close-Range Photogrammetry systems, (herein referred to as "photogrammetry") consists of a consumer grade digital single-lens reflex (SLR) camera with a wide angle lens. Photogrammetry, utilizing software, has been used for traffic crash reconstruction in the United States since approximately 1992. The camera is calibrated and used with photogrammetric markers for scene measurements. Photogrammetry is the use of photographs or digital images, to obtain measurements for the purpose of constructing two-dimensional (2-D) and three-dimensional (3-D) diagrams of crash or crime scenes. A summary of the costs of the equipment is provided in Table 23.

Table 17. Photogrammetry Equipment and Costs

EQUIPMENT	COST
Digital SLR Camera and lens.	$1,000
Photogrammetric markers (40).	$500
Software Basic version.	$1,000
Software Professional version.	$2,595

Photographing a crash scene uses a camera calibrated for photogrammetry with specific camera and lens settings to "measure" feature points of interest. In Photogrammetry, 2-D measurements can be made in a plane with one photograph through a process called orthorectification.

In 3-D, multiple photographs are used in a process called convergent triangulation. Strong perspective overlap of featured points of interest is required to successfully obtain 3-D measurements from the digital images.

On-scene, the investigator acquires sufficient photographs of the objects of interest. Each feature point of interest needs observation in at least 3 images from different perspective viewpoints in order to support accurate measurements.

Ideally, points of evidence are captured in at least three overlapping photographs. The photographs are imported into a Photogrammetry software program where the operator references 2-D images and the 2-D references are triangulated into 3-D object points through a process called bundle triangulation. The photogrammetry 3-D dataset of points, lines and polylines can then be exported as a Drawing Interchange Format (DXF) file and input to most Computer Aided Diagramming (CAD) programs to draw a diagram of the scene to scale.

The training that is necessary to become proficient in the use of Photogrammetry is not as extensive as the training necessary to become proficient with any of the variations of the Electronic Total Station. A recommended basic amount of training is three days. As with other types of technology, the investigator must use the photogrammetry system to maintain proficiency and court acceptance.

While the photographs may be taken by someone who is not familiar with photogrammetry or evidence identification, the use of the photogrammetry software to process the data requires the

investigator be familiar with the process and be proficient. Crash investigation techniques involving photogrammetry have been accepted in courts in the United States.

The use of Photogrammetry can aid in the quick clearance of traffic crashes. The scene of more serious crashes requires the use of photographs to record the crash scene. Photogrammetry combines the processes of photography and measurement. It can be completed by one person which reduces the manpower needs at the scene of crashes. Since digital cameras are more readily available and accessible than other types of technology, there is less time involved in waiting for the arrival of reconstruction equipment.

The use of photogrammetry is limited by weather conditions, much like other types methods in use today. The investigator must be able to see the evidence measured. While the at-scene time may be reduced by the use of Photogrammetry, the processing of the data for the purposes of reconstruction may involve more time on the part of the investigator in the post-processing of the photographs on a computer. The time savings using photogrammetry is realized at-scene for quick clearance objectives. The post-processing of the photographs is generally about the same time as the overall combined at-scene and post-processing work required using a total station.

Description: Photogrammetry
Photogrammetry is the science of making measurements from photographs, especially for recovering the exact positions of surface points. Photogrammetry systems use a calibrated lens mounted on SLR cameras. Employed to reduce at-scene investigation time, post-processing is required to produce a crash diagram.

Average Cost: $1,000 to 4,000 with templates and software

Figure 9. Photo. Photogrammetry
Source: Timothy Robbins of M-CRASH Group, LLC.

Technology Rating Index – as judged by the experts

● **Safe, Quick Clearance** ● **Responder Safety** ▽ **Court Acceptance**

Table 18. How the Experts Rated Photogrammetry

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	0	0	12	8	20	**40**
Availability	3	4	6	8	10	**31**
Amount of Training Required	1	4	12	12	5	**34**
Retraining to Continue Certification	0	2	3	16	10	**31**
Setup and Takedown	0	2	3	12	30	**47**
Opportunities for Enhancements	0	2	0	12	35	**49**
Court Acceptability	0	0	9	8	25	**42**
TOTALS	**4**	**14**	**45**	**76**	**135**	**274**

The following are comments provided by the reviewers about Photogrammetry:

- Responder Safety
  - Increases safety since a scene can be quickly mapped.
  - Reduces risk to investigators, reduces on-scene crash investigation time.
  - Requires placement of targets in the road and extra time to photograph the scene properly.
- Safe Quick Clearance
  - One of the fastest methods to create an accurate diagram thus can greatly accelerate clearance times.
  - Very good, two steps done (measurements & photographs) in one step (photographs).
- Prompt, Reliable Communications
  - Output easily imported into diagramming software packages.
  - Properly taken photographs allow other information to be extracted at a later date.

THREE-DIMENSIONAL LASER SCANNING

Three-dimensional (3-D) Laser Scanning has been adopted in many areas of the country as a tool for traffic crash reconstruction, and has increased significantly in the past 10 years. The 3-D Laser Scanner consists of a phase shift, a time-of-flight laser measuring device, or both. A summary of the costs of the equipment is provided in Table 26. The laser scanner is placed on a tripod and, while rotating horizontally, spins a mirror vertically to make measurements by indiscriminately distributing a laser beam. As many as a million measurements per second can be recorded by certain models. However, similar to the total station reflectorless mode, the laser has a limited range. When the angle of incident is low between the laser head and roadway, the effective measurement range is reduced.

Table 19. Three-dimensional Laser Scanning Equipment and Costs

EQUIPMENT	COST
Three-dimensional (3-D) Laser Scanning.	$60,000 to $200,000
Annual calibration.	$5,000

The 3-D Laser Scanners capture what is in the line of sight of the scanner. The 3-D scanners allow for operation by one person which reduces the number of personnel exposed to the dangers of traffic. The time necessary to complete a scan is dependent upon the density of the scan. Higher density scans require longer scan times.

The end product is not a typical line drawing. A point cloud is generated on which analysis must be performed. As an example, an analysis is necessary to determine where a curb transitions into the roadway surface. There is a large amount of data that is recorded, and the data may be used for many purposes.

The 3-D Laser Scanners in use today for traffic crash reconstruction are also equipped with a high-definition (HD) digital camera to accurately document the crash scene. The 3-D Laser Scanners do not require a target and are much more automated than previous versions. The processing time for the data is significantly less than in the past and the data can easily be managed by a computer. The 3-D Laser Scanner produces a photo-like product that can be imported into computer aided diagramming (CAD) software. In addition, the data allows the investigator to view the scene from different points of view in the scan.

Due to the complexity of the 3-D scanner, specialized training is necessary to become proficient in its use. Training is available from the equipment manufacturers and from training providers. The recommendation is a minimum of 24 hours of training in the use of the software to process the data. This training may not provide specific information in the use of the 3-D Laser Scanner to reconstruct traffic crashes.

Law enforcement investigators recommend that a minimum of 40 hours of training be completed in the use of the software and the equipment including the basic training and application in traffic crash reconstruction. The use of the software to process the data requires that the investigator be familiar with the process and be proficient.

Crash investigation reports involving the use of 3-D Laser Scanning have been accepted in courts in the United States. While the science involving 3-D Laser Scanning has been accepted, it is essential that the operator be properly trained and proficient in the use of the equipment for courts to recognize the results it produces.

The use of 3-D Laser Scanning can be beneficial in quickly clearing traffic crashes. If the scanner is readily available, the scan can be completed in a matter of minutes. As indicated above, the higher the density of the scan, the longer it will take to complete the scan. The scanner can be set up out of the roadway and the roadway may be open to traffic while the scan is completed. However, items of evidence that are blocked by passing traffic may not be recorded.

Additionally, laser energy has a tendency to bounce off of shiny surfaces such as a vehicle body or absorbed by a black tire. When a return signal is missed because of poor reflectivity, no measurement is recorded and a hole is left in the point cloud. Typically, at a distance of 10 meters, a point spread of ½ inch will take less than 4 minutes. This density spread is not acceptable for collision investigation because, at a distance of 100 meters, the point spread is nearly 4 feet. This issue may be eliminated by increasing the scan density which increases the scan time substantially. Similar to the total station, the 3-D Laser Scanner is a line of sight instrument and must be moved around the crash site repeatedly to complete data gathering. A single dome (360 degree) scan may contain several million measurements. Scenes documented using multiple scans must be registered or combined to facilitate measurement from one scan into another.

The use of 3-D Laser Scanning may be limited by weather conditions, such as rain that may reduce the quality of the scan. Like other types of technology, the investigator must be able to see what is being measured. While the at-scene time may be reduced by the use of 3-D Laser Scanning, the processing of the data for the purposes of reconstruction may be time consuming on the part of the investigator.

Description: 3-D Laser Scanning
Using point cloud data collected from the laser scanner, investigators are able to develop highly detailed 3-D models for analysis. For example, lines of sight can be analyzed from various vantage points or the scan data may be compared with Original Equipment Manufacturer (OEM) CAD files for vehicle deformation analysis. Additionally, the scan data can also be used to create crash animations to simulate the actual event for use in the courtroom.

Average Cost: $48,000 – 58,000

Figure 10. Photo. Three-dimensional Laser Scanning
Source: FARO Technologies and the Modesto Police Department

Technology Rating Index – as judged by the experts

▽ **Safe, Quick Clearance** ● **Responder Safety** ● **Court Acceptance**

Table 20. How the Experts Rated Three-dimensional Laser Scanning

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	4	8	3	0	5	**20**
Availability	5	2	3	0	5	**15**
Amount of Training Required	0	8	6	4	0	**18**
Retraining to Continue Certification	1	2	3	8	5	**19**
Setup and Takedown	1	0	9	4	10	**24**
Opportunities for Enhancements	0	0	0	0	30	**30**
Court Acceptability	0	0	0	8	30	**38**
TOTALS	**11**	**20**	**24**	**24**	**85**	**164**

The following are comments provided by the reviewers about 3-D Laser Scanning:

- Responder Safety
  - Reduces risk to investigators, reduces on-scene crash investigation time
  - Allows the user to scan at a distance, out of harm's way.
  - Requires roadway to be closed if moderate to heavy traffic.
- Safe Quick Clearance
  - Takes longer to scan scenes if detail (no gaps) desired. Enormous scene detail and topography information is captured. Sometimes low contrast evidence is not clear.
  - Allows significant amount of data to be collected in a short period of time. Movements of the instrument for viewpoints sometimes increases time needed.
- Prompt, Reliable Communications
  - Collects vast amounts of data which could be used for study purposes in the future.
  - Proprietary software and doesn't work well with other programs. The technology is constantly improving.

UNMANNED AERIAL SYSTEMS

Unmanned Aerial Systems (UAS) involve a remotely piloted aircraft carrying a precision high-definition (HD) camera. The lightweight, multi-rotor aircraft takes off and lands vertically and is designed to fly under 400 feet Above Ground Level (AGL) to provide separation from manned aircraft.

The UAS are gaining acceptance in the field of traffic crash reconstruction. A flight conducted specifically for aerial mapping uses multiple technologies. The aircraft is designed to be reliable and maintainable by the user in compliance with accepted practices. Electrically-powered and highly maneuverable, a UAS uses a programmed Ground Control Point (GCP) or Real Time Kinematic (RTK) Global Positioning System (GPS) flight path. The area of interest is identified on an on-line, live map. The altitude assignment, flight path, and photography settings identification begins the initial mapping process. The flight path is calculated for current wind conditions for the most efficient flight path. Safety measures such as maintaining line of sight by a trained observer and the pilot utilizing a ground control station are included. Computer-monitored battery power returns the aircraft to the take-off / safe landing position in the event that the batteries need to be charged or changed. Flight duration in most crash scene documentation cases will be well within battery capacity.

The flight computer controls stability during the flight. The camera's gimbal mount provides assurance for stable geo-referenced photographs. As each photograph is recorded, the image is geo-tagged with precision measurements obtained by the on-board RTK GPS. For a multi-lane highway environment of 1000 feet in length, flight time estimates may last less than 10 minutes. The images may be examined at the scene following the flight to determine their suitability for post-crash photogrammetric analysis.

The time required to process the aerial images is dependent on computer processor speed. The final product is an orthomosaic map, digital terrain model and ultimately a point cloud similar to that created by the 3-D Laser Scanner.

The use of Unmanned Aerial Systems is regulated by the Federal Aviation Administration (FAA). Under the current conditions of most FAA-issued Certificates of Authorization (COA), or 333 exemptions, the operator must be a private pilot to operate the system and be accompanied by an observer. The FAA continues to evaluate the integration of UAS into the national air space system. Efforts are under way to revise the requirements for operation and change is constantly monitored.

The final operating rules will require more training than is now required to become proficient with other types of technology given the aerial aspect of utilizing the NAS (National Air Space) to achieve the NUG and TIM goals. For example, the pilot / operator may be required to complete the ground school portion of flight training to receive a certificate to operate the system. Training to remain proficient in the use of the UAS and the software that is necessary to process the aerial images may be necessary. Proficiency may be gained and tracked by logged flight time by applied use or recurrent training.

The Unmanned Aerial Systems that are currently available range in price from approximately $2,000 to $65,000 or more with inclusion of the software. While the price is substantial, the

prices continue to decrease as the technology is more widely used. A summary of the costs of the equipment is provided in Table 29.

Table 21. Unmanned Aerial Systems Equipment and Costs

EQUIPMENT	COST
Ground Control Point (GCP) Reference.	$4,000 to $15,000
Consumer-grade systems.	$2,000 to $6,000
Commercial grade Real Time Kinematic (RTK) Global Positioning System (GPS).	Less than $40,000

The use of UAS will reduce the time needed for crash scene investigation. When a UAS arrives at the incident scene in a timely manner, mapping can usually be completed in a matter of minutes. These systems allow the crash scene to be mapped without personnel in the roadway exposed to the dangers of traffic. Mapping can completed while the roadway is open to traffic in some cases.

The use of Unmanned Aerial Systems may be limited by weather conditions. While some of the systems are resistant to weather, conditions such as fog, rain, snow, and high winds may make Unmanned Aerial Systems unsuitable for use. FAA regulations require that the Unmanned Aerial System be within line of sight of the operator. Special allowances may need to be addressed by the FAA to ensure safety and compliance with current rules. A well-selected control station should not limit the scene documentation process. Unmanned Aerial Systems reduce on-scene time and, properly prepared for, the post-crash data processing time is comparable to a scene documented with a total station considering a comparable end product.

Description: Unmanned Aerial Systems
Unmanned Aerial Systems (UAS), remotely piloted Aircraft, are rapidly growing in popularity in commercial applications. These devices are regulated by the FAA. The application to crash investigation comes by way of aerial mapping. The accuracy of this technology is dependent on altitude, camera resolution, flight planning software and weather. Geo-referenced photographs are used to create detailed 3-D point clouds, Digital Surface modeling and orthomosaic generation.

Average Cost: GCP $4000 – $15,000
RTK GPS Up to $65,000

Figure 11. Photo. Unmanned Aerial Systems
Source: Michigan DOT

Technology Rating Index – as judged by the experts

● **Safe, Quick Clearance** ● **Responder Safety** ▽ **Court Acceptance**

Table 22. How the Experts Rated Unmanned Aerial Systems

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	0	2	15	4	0	**21**
Availability	3	4	3	0	5	**15**
Amount of Training Required	0	8	6	4	0	**18**
Retraining to Continue Certification	1	2	3	8	5	**19**
Setup and Takedown	0	0	6	8	15	**29**
Opportunities for Enhancements	0	0	0	0	30	**30**
Court Acceptability	0	2	0	8	10	**20**
TOTALS	**4**	**18**	**33**	**32**	**65**	**152**

The following are comments provided by the reviewers about Unmanned Aerial Systems:

- Responder Safety
  - Decreases risk as UAS can be flown from off roadway.
  - Improves responder safety since it can be used after the collision has been cleared.
  - Reduces risk to investigators and on-scene investigation time.
- Safe Quick Clearance
  - Rapidly documents collision and crime scenes and re-opens roadways in less time. FAA restrictions being interpreted.
  - Quick method for documenting a scene.
  - Allows the responder to take the scene back to the office for measurements.
- Prompt, Reliable Communications
  - Data transformed via photogrammetry software. Once that is complete, data sets are easily transferred.
  - Photos document how scene was actually cleared. Possible use for case studies.

GLOBAL POSITIONING SYSTEMS

The Global Navigation Satellite Systems (GNSS) Systems make use of a satellite navigation system including the Navistar Global Positioning System (GPS) operated by the DOD or GLONASS operated by the Russian Aerospace Defense Force. The use of GPS Systems is commonly referred to as GPS mapping.

GPS Systems typically consist of two units. One is a rover and one is a base. The systems must have cellular access through a Data Collector to a GPS remote base station, or, if no cellular service is available, a second unit can be utilized as a base station. These units communicate with each other using a Class II Bluetooth connection that allows communication over a radius of approximately 1000 feet. This distance is usually great enough for use in completing investigations at most traffic crash scenes. A summary of the costs of the equipment is provided in Table 32.

Table 23. Global Positioning System Equipment and Costs

EQUIPMENT	COST
Dependent upon type and model.	$6,000 to $20,000
Data collector and Evidence Recorder.	$2,400
Forensic Computer Aided Diagramming (CAD) Software.	$1,000

Initially, the GPS Systems available for traffic crash reconstruction were expensive. However, there are units currently available that are much more affordable. The units that are available for traffic crash reconstruction are capable of centimeter accuracy when used in the carrier phase GPS mode. This level of accuracy supports the use of GPS Systems for crash reconstruction.

As with other complex technologies, training to become proficient in the use of GPS Systems is much more involved. The recommended basic training needed is a minimum of 40 hours and does not include field projects that should be completed following the basic course. In addition to the basic training and field projects, operators must use the equipment frequently to maintain their proficiency and maintain court acceptance.

The introduction of a new Real Time Kinematic (RTK) GPS system has emerged. It offers a pair of GPS antenna, (base and rover) that utilize class 1 Bluetooth range. A complete RTK GPS system is now available for about ½ the cost of a radio controlled GPS system. This system requires nearly clear sky above the base and rover antenna. The system allows for one antenna to serve as the base unit. Up to three rovers may operate from the single base supporting a multi-disciplinary approach to scene documentation. Crash scene investigation may be reduced by two-thirds with this application.

Description: GPS Systems
GPS devices are everywhere and in many devices, including mobile phones. Recently, GPS receivers are also being used to provide essential data for crash reconstruction. Speed and vehicle position may be recorded if a GPS device is in use at the time a crash occurs. This data can then be used by analysts to determine a vehicle's path and speed before, and even after a collision.

Average Cost: $7,000 – 30,000

Figure 12. Photo. Global Positioning Systems
Source: Missouri State Highway Patrol

Technology Rating Index – as judged by the experts

● **Safe, Quick Clearance** ▽ **Responder Safety** ● **Court Acceptance**

Table 24. How the Experts Rated GPS Systems

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	0	4	6	4	15	**29**
Availability	1	0	3	12	15	**31**
Amount of Training Required	0	6	6	8	5	**25**
Retraining to Continue Certification	0	2	6	8	5	**21**
Setup and Takedown	0	2	6	4	20	**32**
Opportunities for Enhancements	0	4	3	0	25	**32**
Court Acceptability	0	2	3	4	25	**34**
TOTALS	**1**	**20**	**33**	**40**	**110**	**204**

The following are comments provided by the reviewers about Global Positioning Systems:

- Responder Safety
  - Positive and negative attributes when it comes to Responder Safety. It is very easily used as a one person unit, however that person can become unaware of the hazards around them when their full attention is given to the operation of the unit. With that said, it greatly reduces the time spent on-scene over the Reflectorless and Robotic Total Stations.
- Safe Quick Clearance
  - Set up time is low; scenes are cleared more quickly.
  - Increases data collection speed; scene cleared much faster.
- Prompt, Reliable Communications
  - Communications are not possible with satellites in some situations such as buildings, terrain, and foliage blocking sight line to satellites. There are places it cannot be used due to the line of sight obstructions.
  - Information gathered is the same as the Total Stations and has the same ease and restriction on the sharing of the data.

LIGHT DETECTION AND RANGING SYSTEMS

Light Detection And Ranging (LiDAR) has been used for traffic crash investigation and reconstruction for some time. LiDAR Systems consist of a LiDAR Unit and a Data Collector. A summary of the costs of the equipment is provided in Table 35. LiDAR is a remote sensing technology that measures distances by illuminating the target with a laser then analyzing the reflected signal to determine the distance. As a standalone device, the LiDAR will only measure slope distances. The addition of an angle encoder will allow recording of polar coordinates. The measurements recorded utilize an angle encoder much like those recorded by an Electronic Total Station.

Table 25. Light Detection and Ranging Systems Equipment and Costs

EQUIPMENT	COST
Light Detection and Ranging (LiDAR), Angle Encoder, and Software.	$7,000

LiDAR is routinely used by law enforcement as a speed measuring tool. Distance measurement is a function of the LIDAR in calculating speed. The measurements necessary for traffic crash reconstruction use the laser to measure distance rather than speed. Measurements can be captured using a prism, reflectors, or they may be captured reflectorless. This data is used to create a map of the crash scene.

The use of LiDAR systems in traffic crash reconstruction is complex, much like the Electronic Total Station. The recommendation for the necessary basic training is a minimum of 40 hours and does not include any field projects that should be completed following the basic course. In addition to the basic training and field projects, operators must use the equipment frequently to maintain their proficiency and maintain court acceptance.

The LiDAR can be handheld or tripod mounted. The tripod-mounted LiDAR Systems are recommended since errors may be introduced with handheld configurations due to the instability introduced by the human in the loop. Without mechanical stability and optical magnification, aiming to precision points may be difficult. Using the unit without a graphic controller may result in measurement errors.

A technician using LiDAR may minimize personal exposure to traffic by carefully selecting the instrument location and recording measurements in the reflectorless mode. In the reflectorless mode, the mapping time may be lengthened as measurements are timed to be recorded between vehicles while the roadway is open to traffic. However, since these measurements are collected while the roadway is open to traffic, the effect on traffic flow is minimized.

The use of LiDAR Systems may be limited by weather conditions, with rain reducing the effective range. As with other technologies, the investigator must be able to see what is available for measurement. While the at-scene time decreases with the use of LiDAR Systems, the processing of the data for the purposes of reconstruction may be time-consuming on the part of the investigator.

Description: LiDAR Systems
LiDAR is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. LiDAR is popularly used to make high-resolution maps.

Average Cost: Approximately $7000 with the LiDAR, Angle Encoder and Software

Figure 13. Photo. Light Detection and Ranging Systems
Source: Laser Technology, Inc.

Technology Rating Index – as judged by the experts

▼ **Safe, Quick Clearance** ● **Responder Safety** ▼ **Court Acceptance**

Table 26. How the Experts Rated Light Detection and Ranging Systems

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	0	6	6	8	0	**20**
Availability	1	0	9	8	5	**23**
Amount of Training Required	0	2	15	4	0	**21**
Retraining to Continue Certification	0	2	3	4	10	**19**
Setup and Takedown	2	0	6	12	0	**20**
Opportunities for Enhancements	2	2	3	4	0	**11**
Court Acceptability	0	0	3	12	15	**30**
TOTALS	**5**	**12**	**45**	**52**	**30**	**144**

The following are comments provided by the reviewers about LiDAR Systems:

- Responder Safety
  - Allows for roadway mapping without being in the traffic.
  - Allows for measurements across/away from moving traffic, reducing possible exposure.
- Safe Quick Clearance
  - Clearance rates decrease for simple scenes. Clearance rates increase for complex scenes.
  - Improves clearance times since some of the evidence can be measured after the roadway is open to traffic.
- Prompt, Reliable Communications
  - Allows for very accurate measurements supporting detailed reports.
  - Supports information sharing with anyone who has compatible software.

IMAGING STATIONS

The Imaging Station is essentially a Robotic Total Station with a built-in camera which adds the ability to intelligently scan an area visible through the camera lens. An area of interest is identified by aiming the internal camera. Once selected, the software predicts points that will need to be measured to model the observation. After the establishment of a prediction, the operator may remove points from or add points to the prediction selection and begin the scanning process.

The Robotic Total Station followed as a variant of the Electronic Total Station, and has been in use for traffic crash reconstruction in the United States for some time. The Robotic Total Station is comprised of five components. These components are the Motorized Theodolite, Electronic Distance Measurement (EDM) Instrument, Optical Prism, Data Collector, and a Remote Controller. In addition to these components, the Imaging Station incorporates a through-the-lens digital camera. The Imaging Station utilizes the principles of surveying to create a map of a crash scene. A summary of the costs of the equipment is provided in Table 38.

Table 27. Imaging Stations Equipment and Costs

EQUIPMENT	COST
Imaging Station with Motorized Theodolite, Electronic Distance Measurement Instrument, internal camera, optical Prism, remote controller, and essential accessories (tripod, prism pole(s), tape measure, and Software).	$36,000
Data Collector and Evidence Recorder.	$2,400

Like the Robotic Total Station, the Imaging Station eliminates the need to mechanically aim the EDM at the prism. Auto-tracking the prism via a remote controller is a function of the Imaging Station. The controller functions to re-establish tracking of the prism more efficiently. A search command sent from the remote controller to the command station turns the station to the prism eliminating the need to manually aim the station at the prism and return to the prism lock status.

The use of a tracking laser maintains aim automatically and updates distance measurements. The Robotic variant increases the ability to measure in the reflectorless mode to 2000 meters or approximately 6,500 feet. These distances are to an industry standard grey card. When measuring to a roadway from ground level, a user should expect maximum measurements to about 2,000 feet, which is sufficient to cover a ¼ mile crash site. The measurement time decreases as the instrument is constantly measuring and updating the collector.

The station is motorized horizontally and vertically. As the laser tracks the prisms' movement about the scene, the need to precisely focus and aim the station is eliminated. The addition of a remote controller provides the option for one-person operation at incident scenes. The data collector connects to the remote controller which then connects to the unit via long range Bluetooth. Should connection be lost, the remote controller provides a method to reconnect the devices.

The theodolite is a very precise instrument used to measure horizontal and vertical angles between points. The EDM measures the slope distance between points. The Electronic Total

Station utilizes an infrared light laser reflected from an optical prism to capture distances. This data maintains attributes recognized by the software. The data is input to software designed for creating a scale map and is a visual depiction of the crash scene. The gathered data is used in mathematical formulas to reconstruct the crash.

As with the use of the other variations of the Electronic Total Station, the Imaging Station is more complex and the training is much more involved. The recommendation of basic training needed is a minimum of 40 hours and does not include field projects that should be completed following the basic course. In addition to the basic training and field projects, operators must use the equipment frequently to maintain their proficiency and maintain court acceptance.

Like other variations of the Electronic Total Station, the technician utilizing an Imaging Station can minimize exposure of personnel to the dangers of traffic by carefully selecting the instrument location.

When an Imaging Station arrives at the incident scene in a timely manner, the mapping of the scene can usually be accomplished by the time vehicle removal is complete. In cases where points of evidence remain for measurement, the reflectorless configuration is available to complete the work. The selection of the reflectorless option increases the mapping time as measurements are timed to be recorded between vehicles while the roadway is open to traffic. However, since these measurements are collected while the roadway is open to traffic, the effect on traffic flow is minimized.

Description: Imaging Stations
Imaging Stations combine advanced imaging and high-accuracy surveying, incorporating real-time field imagery with spatial data. Powerful functionality is controlled using software that produces "photography with dimension", a revolutionary and cost effective alternative to laser scanning.

Average Cost: $20,000

Figure 14. Photo. Imaging Stations
Source: TOPCON

Technology Rating Index – as judged by the experts

▼ **Safe, Quick Clearance** ● **Responder Safety** ● **Court Acceptance**

Table 28. How the Experts Rated Imaging Stations

CRITERIA	1	2	3	4	5	TOTALS
Cost of Ownership	2	0	0	4	5	**11**
Availability	3	0	0	0	5	**8**
Amount of Training Required	0	2	3	0	5	**10**
Retraining to Continue Certification	0	2	3	0	0	**5**
Setup and Takedown	0	4	3	0	0	**7**
Opportunities for Enhancements	1	0	3	0	5	**9**
Court Acceptability	0	0	0	0	20	**20**
TOTALS	**6**	**8**	**12**	**4**	**40**	**70**

The following are comments provided by the reviewers about Imaging Stations:

- Responder Safety
  - Allows options for the operator to measure either remotely or from the base. As long as the scene is controlled, the operator remains relatively safe from exposure.
  - Requires the roadway to be kept closed, decreasing safety.
- Safe Quick Clearance
  - Enhances TIM quick clearance.
- Prompt, Reliable Communications
  - Provides for vast amounts of data which can be analyzed in the future.

CHAPTER 6 VIRTUAL DEMONSTRATIONS

Four web-based virtual demonstrations were conducted to present the technologies and usage in compliance with the National Unified Goal for Traffic Incident Management (NUG). These were visual representations of the research results. The demonstrations were used to gather more detailed information and to allow the Federal Highway Administration (FHWA) Government Task Manager, the Expert Panel, and the project team to interact with the contributors of the best practices and technologies. The demonstrations also allowed for follow-up questions regarding the practices, technologies, and lessons learned.

The Team worked with manufacturers and vendors to develop demonstrations utilizing slide presentations, supplemented with video of the methods in use. They were designed to describe the type of technology, ease of set-up, application, and the capabilities provided for law enforcement agencies and reconstruction professionals. The presenters provided information regarding the training requirements, costs to acquire, costs to maintain, and the expected service life.

The demonstrations detailed the technology applications as a part of a Traffic Incident Management program including the best use of the methods to provide a safer working environment for responders and motorists, and to minimize the time that roadways are closed due to crash reconstruction.

The demonstrations included presentations on the:

- Electronic Total Station,
- Reflectorless Electronic Total Station,
- Semi-Robotic Total Station,
- Robotic Total Station,
- Total Station Hybrid,
- 3-D Laser Scanning,
- Photogrammetry,
- Unmanned Aerial Systems,
- GPS Systems

The virtual demonstrations helped the team categorize technologies into three groups – compliance with NUG goals, cost, and availability. When reviewing results, the reader must accept the assumption that the best method for compliance with the NUG may not be readily available and the cost may be a factor. Likewise, technology that is relatively low cost may not allow for compliance with the NUG due to increased exposure of personnel and extended lane or roadway closures.

Several of the technologies reviewed in the Virtual Demonstrations allude to the use of the technology by one officer or operator. While technically the equipment may be utilized by one officer or operator, this approach is not advised due to safety concerns. There is a need for assistance in the investigations to protect personnel from the dangers of traffic. Personnel focus their efforts on the task at hand and may not be able to concentrate on the traffic and other activity around them. It is essential that additional personnel assist with the investigation or provide back-up in the form of extra eyes and ears at the scene of an incident.

CHAPTER 7 CONCLUSIONS

The research into the state-of-the-practice and the evolution of technologies in traffic crash reconstruction leads to a predictable conclusion – selection or upgrades of technology will be specific to each individual agency or interagency need. The needs of an agency for crash reconstruction equipment must be conveyed to those with funding to potentially support the acquisition, operation, training and maintenance of the equipment. The needs should be expressed in terms of benefits and a case made that matches the need with the type of equipment requested. As stated earlier, the dangers to personnel are great and the cost of congestion is rising. Acquiring the best method that minimizes the exposure of personnel to traffic while minimizing the cost to society should be a part of the business case for traffic crash reconstruction technology.

This report is the result of a process of data gathering, analysis, and evaluation of best practices and technology in use today and those that are emerging in the crash reconstruction environment. The information provided in this report should be useful to agencies who have defined a need for crash reconstruction equipment to improve responder and investigator safety at the scene, to collect court acceptable data about the crash event, and to minimize the impact of crash reconstruction data gathering on the flow of traffic. Matching agency needs with available funding is almost always a challenge. The benefits and advantages of each of the technologies described in this report will provide an agency with information they need to develop justification for a solution to their crash reconstruction needs.

Agencies and organizations must examine their needs and resources when making the decision to acquire or upgrade traffic crash reconstruction equipment. The goal is to have the equipment readily available for response to an incident. If the equipment is not readily available the safety of personnel and motorists can be compromised due to extended roadway closures. While the use of Unmanned Aerial Systems appears to be the safest, with the least amount of time necessary to gather the data required for an accurate reconstruction, it is of little use if unavailable or the response time is high. Law enforcement agencies may find that, due to funding and resources, training officers to properly mark and photograph items of evidence at an incident scene and equipping them with quality digital cameras may be the safest and most efficient answer to their needs. This approach would reduce the time that roadways are closed and would allow for more technical investigative techniques to be utilized when it can be done safely. No matter what technology or procedures are used, personnel must be properly trained and competent in its use for court acceptance.

There is no one-size-fits-all solution in traffic crash reconstruction. Each agency should examine their activities and resources to decide what is best for their environment. It is recommended that an agency familiarize themselves with the practices and technologies presented in this report and identify those that best match their organizational practices, requirements, and needs. The benefits and budgetary information provided for each method can then be used to justify expenditures or negotiate budget for purchase, training, operation and maintenance of the system. Each agency will have a different traffic environment, organizational structure, political establishment, and funding constraints. This report collects crash reconstruction technology and best practices data to inform those decisions.

APPENDIX A: EXPERT PANEL BIOGRAPHIES

Each of the Expert Panel members was contacted for input in this project. The needs of the project were explained to them, with the need for expert participation emphasized. The panelists participated in conference calls, as well as completing a survey concerning the technology that they use or are familiar with, and how well the technology supported the goals of the National Unified Goal for Traffic Incident Management (NUG). The experience of the panelists determined which technologies would be examined in the virtual demonstrations.

Mike Anderson

Michael Anderson is employed by the Unified Police Department of Greater Salt Lake, in Salt Lake City, Utah. Prior to the unification of the Department, Michael was a member of the Salt Lake County Sheriff's Office. He has been employed by the Salt Lake County Sheriff's Office / Unified Police Department of Greater Salt Lake for 20 years. For the last 15 years he has been assigned to the Major Crash Unit, or as the unit is now known, the Collision Analysis Reconstruction (CAR) Unit. Michael is the senior member of the CAR Unit team. He is responsible for the funding, grant application and administration, training and equipment updates for the Unit. The CAR Unit is responsible for the investigation and reconstruction of serious injury and fatal crashes in the jurisdictions served by the Unified Police Department of Greater Salt Lake. Michael Anderson is certified by the Accreditation Commission for Traffic Accident Reconstruction (ACTAR). He has been certified by ACTAR for over six years. Michael has taught crash investigation courses for Northwestern University in the past and he currently provides law enforcement training on traffic safety related topics which includes crash investigation training at the advanced level.

James D. (Dave) Bean

James D. (Dave) Bean is currently a Crash Investigation Specialist at the United States Department of Transportation/the National Highway Traffic Safety Administration. He is a retired Police Detective from the Fairfax County Police Department, in Fairfax, Virginia. Dave has 29 years of law enforcement experience.

Dave has previously been designated as the Fairfax County Police Officer of the Year and a past award winner of the International Association of Chiefs of Police, J. Stannard Baker Award for Highway Safety.

Dave Bean is also a founding member of the Fairfax County Police Crash Reconstruction Section and has been assigned to the unit for the last 17 years of his career as a law enforcement officer.

Victoria (Tori) Boldt

Employed by the Sarpy County Sheriff's Office, in Papillion, Nebraska, Victoria (Tori) Boldt specializes in Accident Reconstruction for the Sarpy County Sheriff's Office. She participates in a county wide crash response team providing crash investigation and reconstruction services for six law enforcement agencies in the county.

Tori Boldt has been employed by the Sarpy County Sheriff's Office for eleven years, and has served as a Crash Investigator for ten years. Receiving hundreds of hours of crash specific training, Tori is responsible for the investigation and reconstruction of serious and fatality crashes for the Sarpy County Sheriff's Office.

Tori Boldt received accreditation through ACTAR in 2009. In addition, Tori provides Crash Investigation training at the Nebraska Law Enforcement Training Center.

Tracy Flynn

Tracy Flynn began his career with the Pennsylvania State Police in September 1995. He was promoted to Corporal in 2011. Tracy received training in traffic crash reconstruction in 2007 and he received his ACTAR accreditation in 2012. Tracy is currently assigned to the Bureau of Patrol for the Pennsylvania State Police. He is currently the Collision Analysis and Reconstruction Specialist Unit Supervisor and has held that position since of 2012. In his career, Tracy Flynn has been involved in the investigation and reconstruction of a large number of crashes.

John Graves

John Graves has been employed by the Hillsborough County Sheriff's Office since 1996. He is currently assigned as a Master Detective with the Traffic Homicide Section of the Hillsborough County Sheriff's Office Department of Investigative Services which he has served since 2005. John has received over 600 hours of traffic crash investigation training and has over 13 years of traffic crash reconstruction experience which has qualified him to testify as an expert in criminal court in the field of Traffic Homicide Reconstruction.

Crashes that involve criminal charges and civil court cases are investigated by the Traffic Homicide Section of the Hillsborough County Sheriff's Office Department of Investigative Services. The Traffic Homicide Detectives collect the evidence, photograph and map the scene, and conduct the reconstruction of the events that led up to the crash. The skills of the Traffic Homicide Detectives are often called upon during the investigation of other criminal cases.

John Graves has received training in Advanced Scene Investigation Using Forensic Mapping and CAD from Texas A&M University. He has also received training in Photographic Techniques for Crash Investigations from the Florida Public Safety Institute. John Graves also received certification from the Accreditation Commission for Traffic Accident Reconstruction (ACTAR) in 2007.

Gregory Gravesen

Greg Gravesen began his career in vehicle crash reconstruction in 1992. He holds a Bachelor of Science degree in Criminal Justice from the University of Wisconsin – Platteville. Greg has 24 years of law enforcement experience and is currently a Sergeant with the St. Paul Police Department's Forensic Services Unit.

Greg is an ACTAR certified Accident Reconstructionist with specialized training from institutions such as the Institute of Police Technology and Management (IPTM) at the University of North Florida, Northwestern University Traffic Institute, and several others. Greg is also an

adjunct instructor for IPTM with both the Basic and Advanced Pedestrian and Bicycle Reconstruction courses and Advanced Crash Reconstruction using HVE-CSI.

Greg has testified many times in trials and depositions, and has been qualified as an expert in the fields of Accident Reconstruction, Forensic Mapping and Forensic Animation in both State and Municipal courts. Greg specializes in vehicle crash investigation and reconstruction, pedestrian crash reconstruction, computer simulation & animation, and forensic mapping and scanning. In addition, Greg Gravesen owns and operates a crash analysis consulting business.

Ronald B. Heusser

Ron Heusser received a Bachelor of Science degree in Mechanical Engineering in 1970 from Oregon State University. He has worked as a Civil Engineer for the U. S. Forest Service. Ron has been involved in the business of crash reconstruction for over 29 years.

Ron was employed by the National Transportation Safety Board (NTSB) for over 7 years. Ron's experience with the NTSB included on-scene investigations, crash reconstruction, and report writing. He also served as both Vehicle and Highway Group Chairman for several major crash investigations for the NTSB.

Since July 1992, Ron has been working his own accident analysis company. Ron wrote two Society of Automotive Engineers (SAE) papers on heavy truck braking and he co-authored a major safety study for the NTSB on air brake performance. Ron has taught truck reconstruction courses for state police agencies in Pennsylvania, Michigan, Oregon, North Dakota and Washington. Ron has taught for the Department of Continuing Education at Arkansas State University and the Engineering Extension Service at Texas A&M University.

Keith Jackson

Keith Jackson is currently employed by the Collinsville Police Department in Illinois. He has been in law enforcement for about 8 years and is currently assigned to the Street Crime Unit at the Collinsville Police Department. Keith has received law enforcement-related training as a Field Training Officer, DUI Enforcement, Search and Seizure, Crime Scene Processing, Traffic Crash Reconstruction and Investigations, as well as other law enforcement training.

Keith Jackson received certification as an Illinois Certified Traffic Accident Reconstruction Specialist in the summer of 2012 from the Illinois Law Enforcement Training and Standards Board. He has received additional training in Motorcycle Crash Reconstruction, Pedestrian Crash Reconstruction, Crash Reconstruction/Crime Scene Photography, Mapping and Diagramming, and Human Factors.

Keith Jackson is certified by the Accreditation Commission for Traffic Accident Reconstruction (ACTAR). He has been a member of the Illinois Association of Technical Accident Investigators since 2012 and has attended the annual conference both years.

In 2013, Keith assisted in forming the Metro East Crash Assistance Team to provide traffic crash reconstruction services to law enforcement agencies in three counties of southwest Illinois. This team includes certified accident reconstruction officers from various local agencies, and provides crash reconstruction services at no cost to the requesting agencies. Keith Jackson has been

involved in the reconstruction of approximately 25 to 30 traffic crashes, as well as many other serious crashes during his career.

Matthew S. Jackson, Esq.

Matthew S. Jackson grew up with crash reconstruction and joined a private reconstruction firm, full-time in 2008, after graduating from law school. Since that time, he's received formal and on the job training from the best in the field. He has assisted in the investigation and reconstruction of over 200 crashes and handles all aspects of ground vehicle crash reconstruction. Matthew has over 6 years of full-time Accident Investigation/Reconstruction experience, and also obtained his Accreditation Commission for Traffic Accident Reconstruction (ACTAR) certification.

Walter W. "Bill" Johnson

Walter W. "Bill" Johnson is a Master Police Officer assigned to the Traffic Investigation Unit of the Kansas City Missouri Police Department (KCPD). With 27 years of law enforcement experience, he has been assigned to the KCPD Traffic Investigation Unit, Accident Investigation Section, as an Accident Reconstruction Specialist for over 15 years. Bill has received extensive training in Traffic Crash Reconstruction, Forensic Mapping, and Traffic Incident Management. Bill has been fully accredited as a Traffic Crash Reconstructionist by the Accreditation Commission for Traffic Accident Reconstruction (ACTAR) since 2004. Bill is certified as a Level One Commercial Vehicle Inspector by the Commercial Vehicle Safety Alliance and has received specialized training in the investigation and reconstruction of crashes involving commercial motor vehicles. He is a current member of the Illinois Association of Technical Accident Investigators. Bill has been recognized as an expert in traffic crash reconstruction in both criminal and civil courts. Bill has been an active partner in the Kansas City Area Traffic Incident Management Program since its inception in 2007. With a focus on safe, efficient quick clearance, and concentration on the National Unified Goal, Bill has worked diligently with the many emergency response partners in the Kansas City Metropolitan area to develop and promote responder safety and Traffic Incident Management procedures throughout the Kansas City Metropolitan area.

David Keltner

Dave Keltner is a Master Sergeant with the Illinois State Police. He currently serves as the Traffic Crash Reconstruction Unit's (TCRU) Northern Illinois Supervisor. He has been an Illinois State Police certified Reconstruction officer since January 2002. The ISP Northern Illinois Reconstruction Team investigates an average of 150 fatal crashes a year. He has personally been the lead investigator on over 200 cases in the last decade. In June 2002, he was certified by the Illinois Law Enforcement Training and Standards Board (ILETSB) as a Crash Reconstruction Specialist. He is also certified by Accreditation Commission for Traffic Accident Reconstruction (ACTAR). Dave has over 2,400 hours of crash investigation training along with additional extensive training in critical incident management.

Dave is certified as an instructor by the ILETSB. He instructs Basic Crash Investigation, At-Scene Crash Investigation, Technical Crash Investigation, Vehicle Dynamics, Crash Reconstruction, Traffic Incident Management and Roadway Safety Assessments. He continues to participate in speaking engagements around the region pertaining to crash investigation and scene and case management. He is a member of numerous professional organizations regionally

and nationally. Dave is currently in his second term as President of the Illinois Association of Technical Accident Investigators (IATAI).

Andrew S. Klane

Lieutenant Andrew S. Klane has been a member of the Massachusetts State Police for approximately 26 years. He has been assigned to the Collision Analysis and Reconstruction Section (CARS) for the past 22 years. Lt. Klane has reconstructed over 500 serious injury and fatal motor vehicle crashes. He has testified numerous times as an expert witness in both District and Superior Courts throughout the Commonwealth. Lt. Klane is accredited by the Accreditation Commission for Traffic Accident Reconstruction (ACTAR). Lt. Klane is an instructor in the field of crash investigation for the Massachusetts State Police and the Criminal Justice Training Council. Since his promotion to the rank of Lieutenant in September 2009, Lt. Klane has been the Section Commander of CARS. He is responsible for the Massachusetts State Police's entire reconstruction program and for the supervision of four Sergeants and 18 Troopers that are assigned to the Section. Lt. Klane has been responsible for the selection and implementation of technology to facilitate CARS achieving the Department's quick clearance goals, which he participated in developing. Lt. Klane represents the Massachusetts State Police on the Commonwealth of Massachusetts Traffic Incident Management (TIM) Task Force. HE was a principle party in the drafting of the Commonwealth's uniform response manual (URM).

Annjanette (Angie) Kremer

Angie Kremer received a Bachelor of Science Degree from Michigan Technological University in Civil Engineering and is a registered Professional Civil Engineer in the State of Michigan. Angie serves as the Traffic Incident Management (TIM) Engineer for the Michigan Department of Transportation (MDOT). She oversees the areas of TIM and Work Zone Safety & Mobility and her responsibilities include policies, procedures, and programs for MDOT related to these areas. Angie teaches classes/workshops to emergency personnel for responder safety, quick clearance and traffic incident management techniques. She is also an advisor for the national TIM Network and is Co-chair of the Michigan Traffic Incident Management Team for the Governor's Traffic Safety Advisory Commission.

Prior to her current position, Angie worked as the Traffic and Safety Engineer for the Marshall Transportation Service Center (TSC) with the Michigan Department of Transportation (MDOT). While working in that position, Angie's duties brought together roles of the traditional traffic & safety areas along with a new focus of operations. Angie's other areas of work expertise include the areas of Utilities, Permits, and Planning.

Angie is one of two representatives for MDOT on the ENTERPRISE Pooled Study for Rural Intelligent Transportation Systems (ITS). She is also a member of the Michigan Chief of Police – Safety Committee and on the Michigan Association of Traffic Accident Investigators (MATAI). Angie is also the only representative for transportation on the International Association of Chiefs of Police for the TIM Sub-Committee.

Brian Reeves

Brian Reeves is a Traffic Accident Reconstructionist and has been investigating crashes since 1994. He began his career with the Warrensburg Missouri Police Department in 1994. In 1998, Brian became a member of the Springfield Missouri Police Department.

Since Brian began his career, he has investigated well over 1,000 non-injury and injury crashes. In 2008, Brian was assigned to the Traffic Section at the Springfield Police Department where his responsibilities were focused on traffic-related activities only. Since he began the specialized assignment in the Traffic Section, he has taken on the added responsibility of being the lead investigator in several fatality crashes. In addition, he has assisted with several other fatal crash investigations.

Prior to this specialized assignment, Brian had been assigned to a Driving While Intoxicated Enforcement Team. During this assignment of three years, he received a Command Commendation for his efforts along with recognition by National Highway Traffic Safety Administration (NHTSA) and Mothers Against Drunk Driving (MADD).

After being assigned to the Traffic Section, Brian earned his ACTAR Accreditation and has since been placed on the ACTAR Governing Board of Directors. Since 2008, Brian has been called to testify regarding his investigative findings in both criminal and civil court. He has continued his training by receiving considerable instruction since becoming a Reconstructionist. This training has included MapScenes Capture, Commercial Motor Vehicle Accident Investigation, and Total Station training.

Brian has been imparting his knowledge to others by instructing at the Safety Center at the University of Central Missouri in Warrensburg, Missouri. He also assists attorneys and insurances companies by reviewing cases and providing crash reconstruction services through a private firm.

Nathan Shigemura

Nathan Shigemura is certified as an Accident Reconstructionist by the State of Illinois and holds full accreditation as a Traffic Accident Reconstructionist from the Accreditation Commission for Traffic Accident Reconstruction (ACTAR). He is co-owner of a traffic crash reconstruction and analysis company based in Illinois.

Nathan Shigemura retired in 2002 as a sergeant from the Illinois State Police, where his duties included Crash Investigation Instructor, Traffic Crash Reconstructionist and Supervisor of the Statewide Traffic Crash Reconstruction Unit.

Since 1989, Nathan Shigemura has been an adjunct faculty member of the Institute of Police Technology and Management (IPTM) for whom he teaches courses in all levels of traffic crash investigation and reconstruction worldwide.

Nathan Shigemura received a Bachelor of Science degree in Electrical and Electronic Engineering (BSEE) from the University of Illinois, Chicago in 1975. Prior to joining the Illinois State Police, Nathan was employed as a hardware/software design engineer.

Nathan Shigemura is a member and past president of Illinois Association of Technical Accident Investigators IATAI. Nathan is also an active member of the Society of Automotive Engineers (SAE) and the Fraternal Order of Police.

Nathan Shigemura is the author of Mathematics for the Traffic Accident Investigator and Reconstructionist, published by IPTM in 1996. He is a co-author, with John Daily, of Fundamentals of Applied Physics for Traffic Accident Investigators; Volume 1 of the Traffic Accident Reconstruction Series published by IPTM in 1997. And he is co-author, with Andrew Rich, of Balancing Collision Forces in Crush/Energy Analyses published by IPTM in 2007.

Thomas Simon

In June of 2007, Thomas Simon was promoted to Sergeant by Arizona Department of Public Safety (DPS) and reassigned to a Phoenix Highway Patrol squad, responsible for patrolling during the third shift in the Metro Central District. During this assignment, Simon supervised 6-8 Highway Patrol officers as they investigated numerous high profile arrests, collision investigations involving felony charges, and an extraordinary amount of impaired driver investigations. Simon supervised the patrol squad until November 2012, when he was selected as a Sergeant in the Vehicular Crimes Unit (VCU) within the Major Crimes District, where he remains assigned. Thomas Simon has attended many advanced level collision investigation and reconstruction courses, interview and interrogation, Electronic Data Recorder and Drug Recognition Expert courses. He also prepares and presents training to new officers at the DPS Advanced Academy as well as other law enforcement agencies throughout Arizona.

Presently, the DPS VCU uses a GPS-based station, an Imaging Station and a 3-D Laser Scanner in conjunction with software for collision and crime scene mapping.

Scott Skinner

Scott Skinner is currently employed by the Oregon State Police, as the Statewide Collision Reconstruction Program Coordinator for the Oregon State Police. His current rank is Sergeant and he is stationed in Ontario, Oregon. His current assignment allows him to work full-time as a Collision Reconstructionist. He is responsible for managing the Collision Reconstruction Unit of the Oregon State Police and its 40 program members. He also peer reviews many of the collision reconstruction reports that are prepared by Oregon State Police officers statewide. Scott has been a sworn Oregon State Police officer since June 17, 1985. Scott holds an Associate of Science degree in Criminal Justice and Law Enforcement. He also holds an Advanced Law Enforcement Certificate from the Board of Public Safety Standards and Training. Scott received his initial training in the field of Collision Reconstruction from the Institute of Police Technology and Management (IPTM.), University of North Florida in 1993. He has been accredited by the Accreditation Commission for Traffic Accident Reconstruction (ACTAR) since October 1994. Scott continues to be accredited and in good standing with ACTAR, by maintaining at least the minimum requirement of 80 continuing education units every 5 years.

APPENDIX B: TECHNOLOGY RANKINGS

As a part of this project, each technology was rated on Responder Safety, Quick Clearance, and Court Acceptance. From the information developed during the research, including the surveys and the Virtual Demonstrations, the technology was ranked in each of these categories.

Due to the difference in the evaluation criteria in each category, each type of technology received a different rating in the following ranking, according to the National Unified Goal for Traffic Incident Management (NUG). Reviewer comments are provided in support of each criteria.

RANKING IN ORDER

1. Unmanned Aerial Systems (UAS).
    a. Responder Safety.
        i. Decreases risk of injury since UAS can be flown from off the roadway.
        ii. Improves responder safety since it can be used after the collision has been cleared.
        iii. Lowers risk to investigators by reducing on-scene crash investigation time.
    b. Safe Quick Clearance.
        i. Has the potential to rapidly document collision and crime scenes and re-open roadways in far less time that is currently experienced.
        ii. One of the quickest methods of documenting scenes.
        iii. Measurements can be made at an office location without being on the roadway.
    c. Prompt, Reliable Communications.
        i. Data transforms via photogrammetry software. Once that is complete, data sets easily transfer.
        ii. Photos may document how the scene was actually cleared.

2. Reflectorless Electronic Total Station.
    a. Responder Safety.
        i. Optimal, fairly available measurement device. In many cases, enables measurements to be taken some distance from the roadway and out of traffic.
        ii. Lowers exposure risk since no officer need be in the roadway.
        iii. Reduces on-scene crash investigation time.

b. Safe Quick Clearance.
    i. Allows relatively quick scene clearances, compared to tape measures, etc. Captures scene detail required for diagrams and reconstruction analysis.
    ii. Reduces time necessary to set up and take down, as well as reduced time to measure; all reducing time to return to a normal traffic pattern.

c. Prompt, Reliable Communications.
    i. Data is easy to share.
    ii. Information can be shared with anyone who has a compatible program that will communicate with the total station.

3. Semi-Robotic Total Station.

a. Responder Safety.
    i. Risk and exposure to traffic is less than mechanical and Electronic Total Station. User can set up in a safe area and avoid traffic.
    ii. Reduces risk to investigators, reduces on-scene crash investigation.
    iii. Reduces on-scene crash investigation time.

b. Safe Quick Clearance.
    i. For closed scenes, shaves time off the already quick clearance time of other total station instruments by cutting out the need to find and focus on areas of interest through scope.
    ii. Set up can be heavily dependent on the individual operator's expertise in using it. For those properly trained, set up is not time-consuming and subsequent measurements can be taken quickly and with more precision and accuracy than the roller wheel or tape methods.
    iii. Captures scene detail required for diagrams and reconstruction analysis.
    iv. Reduces time necessary to set up and take down, as well as reduced time to measure; all reducing time to return to a normal traffic pattern.

c. Prompt, Reliable Communications.
    i. Data is easy to share.
    ii. Information can be shared with anyone who has a compatible program that will communicate with the total station.

4. Robotic Total Station.

a. Responder Safety.
    i. Less risk and exposure to traffic than mechanical and Electronic Total Station. User can set up in a safe area and avoid traffic.
    ii. Reduces risk to investigators, reduces on-scene crash investigation.
    iii. Reduces on-scene crash investigation time.

b. Safe Quick Clearance.
    i. For closed scenes, shaves time off the already quick clearance time of other total station instruments by cutting out the need to find and focus on areas of interest through scope.
    ii. Set up can be heavily dependent on the individual operator's expertise in using it. For those properly trained, set up is not time-consuming and subsequent measurements can be taken quickly and with more precision and accuracy than the roller wheel or tape methods.
    iii. Captures scene detail required for diagrams and reconstruction analysis.
    iv. Reduces time necessary to set up and take down, as well as reduced time to measure; all reducing time to return to a normal traffic pattern.

c. Prompt, Reliable Communications.
    i. Data is easy to share.
    ii. Information can be shared with anyone who has a compatible program that will communicate with the total station.

5. Hybrid Total Station.

a. Responder Safety.
    i. Less risk and exposure to traffic than mechanical and electronic total station. User can set up in a safe area and avoid traffic.
    ii. Reduces risk to investigators, reduces on-scene crash investigation.
    iii. Reduces on-scene crash investigation time.

b. Safe Quick Clearance.
    i. For closed scenes, shaves time off the already quick clearance time of other total station instruments by cutting out the need to find and focus on areas of interest through scope.
    ii. Set up can be heavily dependent on the individual operator's expertise in using it. For those properly trained, set up is not time-consuming and subsequent measurements can be taken quickly (and with more precision and accuracy) than the roller wheel or tape methods.
    iii. Captures scene detail required for diagrams and reconstruction analysis.
    iv. Reduces time necessary to set up and take down, as well as reduced time to measure; all reducing time to return to a normal traffic pattern.

c. Prompt, Reliable Communications.
    i. Data is easy to share.
    ii. Information can be shared with anyone who has a compatible program that will communicate with the total station.
    iii. Data collection and sharing is mostly flawless. The data formats are usually compatible with most of the diagramming programs used in the industry.
    iv. Information constantly reviewed and analyzed for building safer roads and traffic patterns as well as adjusting law enforcement activities in those areas.

6. Imaging Station.
    a. Responder Safety.
        i. Less risk and exposure to traffic than mechanical and electronic total station. User can set up in a safe area and avoid traffic.
        ii. Reduces risk to investigators, reduces on-scene crash investigation.
        iii. Reduces on-scene crash investigation time.
    b. Safe Quick Clearance.
        i. For closed scenes, shaves time off the already quick clearance time of other total station instruments by cutting out the need to find and focus on areas of interest through scope.
        ii. Set up can be heavily dependent on the individual operator's expertise in using it. For those properly trained, set up is not time-consuming and subsequent measurements can be taken quickly and with more precision and accuracy than the roller wheel or tape methods.
        iii. Captures scene detail required for diagrams and reconstruction analysis.
        iv. Reduces time necessary to set up and take down, as well as reduced time to measure; all reducing time to return to a normal traffic pattern.
    c. Prompt, Reliable Communications.
        i. Data is easy to share.
        ii. Data collection and sharing is mostly flawless. The data formats are usually compatible with most of the diagramming programs used in the industry.
        iii. Information constantly reviewed and analyzed for building safer roads and traffic patterns as well as adjusting law enforcement activities in those areas.
        iv. Provides for vast amounts of data which can be analyzed in the future.

7. Photogrammetry.
    a. Responder Safety.
        i. Scene can be mapped quickly.
        ii. Reduces risk to investigators; reduces on-scene crash investigation time.

b. Safe Quick Clear.
    i. One of the fastest methods to create an accurate diagram, thus greatly accelerates clearance times.
    ii. Measurements and photographs in one step.
c. Prompt, Reliable Communications.
    i. Output easily imported into diagramming software packages.
    ii. Information extracted at a later time.

8. 3-D Laser Scanning.
    a. Responder Safety.
        i. Reduces risk to investigators; reduces on-scene crash investigation time.
        ii. Allows the user to scan at a distance, out of harm's way.
        iii. Need roadway closed if moderate to heavy traffic.
    b. Safe Quick Clearance.
        i. Takes longer to scan scenes if detail (no gaps) is desired. Enormous scene detail and topography information captured. Sometimes low contrast evidence is not clearly captured.
        ii. Allows a lot of data to be collected in a short period of time. Movements of the instrument for viewpoints sometimes increases time needed.
    c. Prompt, Reliable Communications.
        i. Collects vast amounts of data which could be used for various study purposes in the future.
        ii. Software is often proprietary and doesn't work well with other programs. The technology is constantly improving.

9. GPS Systems.
    a. Responder Safety.
        i. Has positive and negative attributes regarding Responder Safety. Easily used as a one-person unit; however that person can become unaware of the hazards around them when their full attention is given to the operation of the unit. It greatly reduces the time spent on-scene collecting data over the Reflectorless and Robotic Total Stations.
        ii. Reduces on-scene crash investigation time.
    b. Safe Quick Clearance.
        i. Set up time is low; scenes cleared more quickly.
        ii. Increases speed of data collection, clearing the scene faster.

c. Prompt, Reliable Communications.
    i. Communications are not possible with satellites in some situations such as buildings, terrain, and foliage blocking sight line to satellites. There are places it cannot be used due to the line of sight obstructions.
    ii. Information gathered is the same as the Total Stations and therefore has the same ease and restriction on the sharing of the data.

10. LiDAR Systems.
    a. Responder Safety.
        i. Allows for roadway mapping without being in traffic.
        ii. Allows for measurements across/away from moving traffic, reducing possible exposure.
    b. Safe Quick Clearance.
        i. Clearance rates decrease for simple scenes. Clearance rates increase for complex scenes.
        ii. Can improve clearance times since some of the evidence can be measured after the roadway is open to traffic.
    c. Prompt, Reliable Communications.
        i. Allows for very accurate measurements which support detailed reports.
        ii. Information can be shared with anyone who has compatible software.

11. Electronic Total Station.
    a. Responder Safety.
        i. Reduces exposure to traffic when compared to manual measurement.
        ii. Requires some exposure to traffic for prism pole operator.
        iii. Reduces risk to investigators; reduces on-scene crash investigation time.
    b. Safe, Quick Clearance.
        i. Set up can be heavily dependent on the individual operator's expertise in using it. For those properly trained, set up is not time-consuming and subsequent measurements can be taken quickly and with more precision and accuracy than the roller wheel or tape methods.
    c. Prompt, Reliable Communications.
        i. Very easy to share data.
        ii. Data typically stored in a format that is easily shared between parties but somewhat dependent on the knowledge of the individual storing the data. An individual not properly trained could produce a nearly indecipherable data file.

12. Mechanical Measurement Tools.
    a. Responder Safety.
        i. Requires personnel close to road and roadway evidence to take measurements.
        ii. Increases exposure of personnel to dangers of traffic.
    b. Safe Quick Clearance.
        i. Takes a longer period of time to make each measurement, cannot gather as many measurements as other methods.
        ii. Takes longer and is less accurate. The value of prosecutorial information depends on accuracy needed but is generally lower than other options available.
    c. Prompt, Reliable Communications.
        i. Information cannot be shared easily unless it is stored in a computer program for later use.
        ii. Reliable, but slow and prone to error.

COURT ACCEPTANCE

Ranking in order:

1. Mechanical Measurement Tools.
    - Ranked high in court acceptability. Historically sound process.
2. Electronic Total Station.
    - Evaluating experts rated at the highest rating for court acceptability.
3. Reflectorless Electronic Total Station.
    - Evaluating experts rated at the highest rating for court acceptability.
4. Semi-Robotic Total Station.
    - Evaluating experts rated at the highest rating for court acceptability.
5. Robotic Total Station.
    - Evaluating experts rated at the highest rating for court acceptability.
6. Total Station Hybrid.
    - Evaluating experts stated that it is accepted in court proceedings.
7. Photogrammetry.
    - Evaluating experts rated at very high for court acceptability.
8. LiDAR Systems.
    - Evaluating experts stated that it is accepted in court proceedings.
9. 3-D Laser Scanning.
    - Evaluating experts rated at very high for court acceptability.

10. GPS Systems.
    - Evaluating experts rated at very high for court acceptability.
11. Imaging Station.
    - Not rated as highly for court acceptability due to the limited use to date.
12. Unmanned Aerial Systems.
    - Not rated as highly for court acceptability due to the limited use to date.

COST

Ranking in order:

1. Mechanical Measurement Tools.
2. Photogrammetry.
3. LiDAR Systems.
4. Electronic Total Station.
5. Reflectorless Total Station.
6. GPS Systems.
7. Semi-Robotic Total Station.
8. Robotic Total Station.
9. Imaging Station.
10. Total Station Hybrid.
11. 3-D Laser Scanning.
12. Unmanned Aerial Devices.

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