

IMPROVED FIELD MEASUREMENTS IN NHTSA's CISS PROGRAM

Mark Mynatt

John Brophy

National Highway Traffic Safety Administration
United States of America

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ABSTRACT

In 2012 the United States Congress issued a directive to the National Highway Traffic Safety Administration (NHTSA) to modernize its nationally representative crash databases and examine the data collected in those programs. In response, NHTSA initiated the Data Modernization Project to affirm its position as the leader in motor vehicle crash data collection and analysis, by collecting quality data to keep pace with emerging technology and evolving policy needs. To ensure the needs of the highway safety community were met NHTSA sought input from users of the data including government, academia, and industry. One of the areas the stakeholders requested upgrades was in the collection of more precise scene diagrams and vehicle measurements in the investigation-based programs. NHTSA's new nationally representative study, the Crash Investigation Sampling System (CISS), will collect scene and vehicle measurements using total station mapping equipment. NHTSA elected to use FARO Technology software to produce scaled scene diagrams and will release files to the public which can be used by most computer-aided design (CAD) software. The purpose of this paper is to describe the CISS scene and vehicle measurement procedures and detail the improvements users of the data can expect in the coming years.

BACKGROUND

NHTSA has operated multiple investigation-based data collection programs with detailed scene, vehicle and occupant injury information: the National Automotive Sampling System (NASS), the NASS-Crashworthiness Data System (NASS-CDS), Special Crash Investigations (SCI), and the Crash Injury Research and Engineering Network (CIREN). Data from each of the programs has been critical in NHTSA's evaluation of vehicle crashworthiness countermeasures such as air bags and seat belts and identifying problem areas where improvements could be made. The focus of these data collection programs have differed somewhat, but they were intended to complement one another.

NASS (1979-1987) was NHTSA's initial nationally representative crash data collection system and served as the forerunner to NASS-CDS. NHTSA re-evaluated its data collection programs in 1988 and elected to divide NASS into two components: NASS-CDS and NASS-General Estimates System (NASS-GES), the latter of which being a police report-based nationally representative sample designed to collect basic statistical information in order to monitor traffic safety trends.

NASS-CDS (1988-2015) was a nationally representative sample of towed light vehicle crashes with an emphasis on the crashworthiness of the

vehicle. NASS conducted detailed investigations of the crash scene, vehicle damage, and injury. The case selection algorithm was designed to give fatal and severe injury crashes a higher probability of selection. Data was collected at 24 sites across the country with an average of 4,500 cases per year between 1999 and 2015.

NASS-CDS case viewers are available at <http://www.nhtsa.gov/NASS>. The statistical data sets are located at <ftp://ftp.nhtsa.dot.gov/NASS/>.

SCI (1972-present) is a collection of approximately 125-150 targeted investigations each year that are used by NHTSA and the automotive safety community to understand the real-world performance of existing and emerging advanced safety systems as well as other unique safety problems occurring on the nation's roadways. The SCI case data and technical reports can be accessed at <http://www.nhtsa.gov/SCI>.

CIREN (1997-present) is a hospital-based study operating at six medical centers across the country, collecting approximately 300 serious injury cases per year. The CIREN process combines comprehensive data elements with professional multidisciplinary analysis of medical and engineering evidence to determine injury causation in every crash investigation conducted. CIREN case viewers and statistical data sets are accessible at <http://www.nhtsa.gov/CIREN>.

INTRODUCTION

In response to a congressional directive to modernize its nationally representative crash databases, the Data Modernization Project concluded that the NASS-CDS program would be retired and replaced with the Crash Investigation Sampling System (CISS). It was also decided that other NHTSA programs collecting detailed investigation-based data - SCI and CIREN - would remain largely unchanged with the exception of Information Technology (IT) infrastructure, improvements to injury information, and the upgrades to vehicle and scene data collection described later in this paper.

The new CISS program is designed to provide many improvements from its predecessor including:

- An updated sample design with new sites for more representative data and smaller statistical margins of error for key estimates,
- Better targeting of newer vehicles and more severe crashes in case selection algorithm,
- Flexibility to increase the number of sites without reselection,
- Consolidating IT infrastructure,
- Obtaining more accurate scene and vehicle measurements,
- Upgrading injury information, and
- Making it easier for end users to access the data.

Although the main focus of this paper is to discuss enhancements in CISS field measurement collection, it is first necessary to briefly describe other program improvements in more detail.

CISS Sample Design

To ensure accurate national estimates of passenger vehicle crashes in the country, NHTSA designed a sophisticated three-stage sample: the first stage is a sample of single counties or a group of counties called the Primary Sampling Unit (PSU); the second stage is a sample of police jurisdictions (PJs) within the PSUs; and the third stage is a sample of crash reports at the selected PJs.

The new sample design improves operational efficiency because the designers took into account the lessons learned in the previous NASS-CDS sample design. One example of this dealt with the size of the PSUs. Some PSUs in NASS-CDS covered very large geographic areas that resulted in excessive driving time for the Crash Technicians collecting field data. As part of the redesign, the goal was to sample

smaller areas to reduce associated travel times and thereby provide more field data collection time and potentially an increased caseload.

Additionally, the new sample design took into account end-user requirements. End users consistently requested data on recent model year vehicles equipped with new and emerging technologies. The new sample was designed to include more recent model year vehicles (previous four model years) which are more likely to be equipped with advanced crashworthiness and crash avoidance technologies. Areas with a higher volume of severe crashes and those with more crashes involving newer vehicles had a greater likelihood to be selected as PSUs.

To further enable CISS to generate cases with newer vehicles and higher severity injuries, a greater granularity in sampling was necessary. Crash reports are now listed into categories referred to as domains (also referred to as strata): Recent Model Year (vehicles that are 4 years old or newer), Mid Model Year (vehicles that are 5-9 years old), and Older Model Vehicles (vehicles 10 years old or older). With these changes, the CISS Pilot Study revealed a higher case selection rate on newer vehicles (47% in CISS versus 33% in NASS-CDS), thereby accomplishing one of the primary objectives of the sample redesign.

There was a significant change in the priority of the police crash reports domain/strata assignments in CISS as compared to NASS-CDS. In NASS-CDS, injury severity took precedence over model year when assigning domain/strata to a crash report. However, the CISS sampling flow chart prioritizes model year of vehicle before severity of injury. This was a deliberate change by NHTSA in an effort to include more new vehicles that will likely be equipped with more advanced crashworthiness and crash avoidance technologies. The priority change was accounted for when crash population estimates and the target allocations were developed.

To reduce missing data in CISS, the system has been designed to replace cases when there is NOT a reasonable expectation that the vehicle, by which the crash was assigned a domain, will be successfully inspected. Reasons for a replacement case include, but are not limited to, the following scenarios:

- The vehicle has been repaired, crushed, sold to another owner, or moved out of the area,
- An owner, insurance company, tow yard, police, or other responsible party denies

permission to inspect the exterior of the vehicle, or

- After following protocols for sufficient contact attempts, the CISS Crash Technician is unable to locate the vehicle or reach those persons necessary to secure permission to inspect the exterior of the vehicle.

Early results on replacement cases have been very promising and could prove to be one of the significant upgrades from NASS-CDS, particularly at PSUs located in urban areas where cooperation has historically been more difficult to attain. The CISS sample design is described in much greater detail in a paper by Chen, et. al, "NHTSA's Data Modernization Project" presented at the 2015 Federal Committee on Statistical Methodology (FCSM) Research Conference [1].

CISS Information Technology (IT)

A significant amount of the resources dedicated to the Data Modernization Project were used to improve the IT components of the various programs sponsored by NHTSA's National Center for Statistics and Analysis (NCSA). One of the major concerns addressed was making the new data system compliant with Federal privacy and security requirements. The new system utilizes Max.gov, which meets stringent authentication requirements. The databases, sensitive documents, and all Personally Identifiable Information (PII) are fully encrypted.

Another goal of the project was to modernize and consolidate the IT infrastructure for multiple legacy systems. The new system was able to more efficiently use scarce resources by eliminating redundancy and utilizing a consolidated server platform in a Federal data center supported by full virtualization. The new IT system also improves flexibility to add/subtract data by using a common variable set for shared elements across programs, making changes much more efficient.

Data in the CISS, SCI, and CIREN programs is now collected in the field by Investigators or Crash Technicians using rugged tablet computers, similar to those used by military and law enforcement personnel. In the past, information was collected largely on paper and then transferred into electronic format causing inefficiencies. Information that will be available to end users in the programs is expected to be much more robust and easier to use than in the previous systems. Although the new IT system required a significant initial investment, the upgrades

should make the NCSA data programs more sustainable moving forward.

CISS Injury Upgrades

Three primary injury areas were addressed in the CISS redesign. First of all CISS, along with SCI and CIREN, have adopted an updated version of the Abbreviated Injury Scale (AIS) to classify injuries. The revision, AIS 2015©, like the versions used by NHTSA since 1976, is produced by the Association for the Advancement of Automotive Medicine (AAAM). AIS 2015 incorporates the needs of its users and the current status of traumatic injury diagnosis and documentation. The revision is the next step in the continual evolution of traumatic injury classification and scaling. Clearer and expanded coding rules encourage improved interrater reliability to support an improved tool for both medical coders and researchers [2].

Secondly, CISS and SCI have added ten data elements to describe injury causation scenarios for seriously injured occupants. In the past CISS and SCI did not provide injury causation. The scenarios are a condensed version of the data traditionally collected in the CIREN program. Because of the large volume of weighted cases in CISS, the addition of this data will be a valuable resource to researchers as they identify crashworthiness areas where further improvements can be made.

Lastly, NHTSA's investigation-based programs will be using state-of-the-art software developed by the Department of Defense Army Research Laboratory to enter and present injury data. The Visual Anatomical Injury Descriptor (VisualAid) software offers many advantages not only during the initial entry of AIS codes and injury causation scenarios, but will also present the injury data with increased detail and in a more user friendly format.

Additional detail is described in ESV paper 17-0173, "Documenting Injuries in NHTSA's CISS Program", Mynatt, et al.

DISCUSSION

After reviewing the Data Modernization feedback from stakeholders it became evident that more precise scene and vehicle data were areas CISS should attempt to upgrade. The majority of the comments related to scene and vehicle documentation received from various organizations,

including auto manufacturers, suppliers, safety advocates, the medical community, and government, were similar. In general, they requested more accurate scene documentation and more detailed descriptions of damage sustained by the vehicle. To address the users' needs, NHTSA elected to make three significant improvements to scene and vehicle data collection in the CISS program: 1) provide more comprehensive crash scene documentation and scaled diagrams; 2) increase the number and precision of vehicle crush measurements; and 3) make the raw measurements collected at the scene available to the public in a format that can be used in most reconstruction and mapping software.

Since NHTSA's other investigation-based programs - SCI and CIREN - also use the same methods to document the crash scenes and vehicles, NHTSA took the opportunity presented by the Data Modernization project to update all the programs simultaneously.

Previous Data Collection Methods

Since the inception of NASS in 1979, and continuing through its final data collection year in 2015, methods used to collect vehicle crush data and document the crash scene had changed very little. Throughout this period, all measurements were collected with a tape measure and then hand-transcribed to a paper form or into a pen-based computer (1997-2007). For scene inspections, there were generally two methods to document the curvature of a roadway: the chord/middle ordinate method and the offset method. Both methods required placing a tape measure on the ground and manually measuring the distance of the middle ordinate or incremental offset values. Obtaining these measurements over long distances usually required the use of 50 meter cloth tape measures and other cumbersome tools while working alone. For safety reasons the tools provided were recommended to be used off the roadway and presented obstacles such as vegetation, ditches, rocks, etc. that skewed the accuracy of measurements.

Similarly for vehicle crush measurements, tape measures were laid alongside the vehicle to establish the original dimensions (length and width) of the vehicle. Crush to the vehicle was then documented using tape measures and incremented rods. In some cases this may have contributed to minor errors in reporting crush, damaged wheelbase, and other required measurements due to the tape measure laying on an

uneven surfaces or vehicles being stored in confined spaces.

NHTSA recognized that these traditional methods for scene documentation and acquiring vehicle crush measurements lacked the desired precision and sought to find a remedy.

Electronic Distance Measuring Device

To address the accuracy issues in data collection, NHTSA took the opportunity to upgrade its field measurement techniques and equipment. The first step was to conduct a time analysis study of the NASS-CDS program, which tabulated the time necessary to complete the tasks required of the field personnel and their processes. The results of study highlighted that the documentation of scenes and vehicles using the manual measurement methods was overly time consuming and an area where efficiencies could be realized. NHTSA then began testing the viability of various technologies that could potentially improve the accuracy of the data and the efficiency of the expended effort.

Tools evaluated ranged from inexpensive hand-held laser tape measures to very expensive 360-degree laser scanners. For the purposes of scene measurements, a product was required that minimized the necessity for the Crash Technician to venture into the road to obtain measurements because the NHTSA programs lack the authority to divert traffic or close the roadway. Safety of the NASS/CISS personnel has always been paramount. NHTSA sought tools that could be paired with software and could produce a precise scaled scene diagram with minimal input from the user. NHTSA concluded that the optimal measurement device and software package should have the following capabilities:

- Document scenes from off the road,
- Require only one person for operation,
- Capture points in all orthogonal axes (X,Y,Z),
- Produce diagrams in both two-dimension and three-dimension,
- Produce standard outputs that could be used in multiple computer-aided design (CAD) software packages,
- Analyze the points documented and produce a scaled drawing of the scene with limited human involvement,
- Document various crush and reference points on damaged vehicles, and

- Be affordable so each Crash Technician could be equipped with the technology.

Prior to procuring any equipment, NHTSA's Office of Regulatory Analysis (ORAE) was enlisted to confirm the cost benefits of moving to an electronic measurement collection platform. It was estimated that the reduction in labor hours would allow NHTSA to recoup the initial investment on the equipment in approximately three years. With all of the above considered, NHTSA elected to procure Nikon Total Station electronic measuring devices coupled with FARO® Blitz software. It should be noted that during the evaluation process the software suite was owned by ARAS 360 Technologies Incorporated. FARO Technologies Incorporated acquired ARAS in February 2015.

Training on the Equipment

After attending training to become familiar with the capabilities and features of the hardware and software, NHTSA's Crash Investigation Division (CID) staff developed new protocols for scene and vehicle documentation in the NHTSA investigation-based programs.

The key to crash data collection is consistency. To ensure new CISS Crash Technicians in the field were trained uniformly on these technologies, NHTSA CID staff conducted all training on the new products and measurement procedures. The entire Crash Technician training process takes approximately six months for each group of trainees and includes five separate weeks at NHTSA's Crash Investigation Training Facility located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma. One week of training was dedicated solely to total station and FARO software and consisted of both classroom and field exercises. By using pre-measured scenes and crashed vehicles, the instructors were able to ensure accuracy among the trainees and consistency between the various sessions of training. The instructor-led training at the training facility was followed with on-the-job training at the PSU field offices. Throughout the remaining training weeks the Crash Technicians were tested and required to show proficiency with the measurement device and software. Figure 1 shows CISS trainees collecting scene measurements using total stations at NHTSA's training center.



Figure 1. CISS trainees collecting scene measurements.

Scene Data Collection

To ensure uniformity, protocols and guidelines were established for documenting scenes and scene evidence. The positioning of the total station device is crucial in scene documentation. Unlike law enforcement, the Crash Technicians cannot setup the device on the roadway, so a safe location where the majority of the physical plant and evidence can be captured is critical. As the trainees progressed, they were also instructed on techniques to merge multiple scenes together when all required data points cannot be obtained from one total station setup location. Guidelines for leveling the device were provided along with a series of 26 steps to set up the instrument to begin scene or vehicle documentation. Code Descriptors (CD) were developed and distributed to all trainees so that a consistency was ingrained throughout the system. These CD ensured a standardized naming convention for points contained in the raw file generated by the Nikon Total Station. Example Code Descriptors include: EP (edge of pavement), LLS (lane line solid), CW (crosswalk), CB (curb), ELV (elevation), GOU (gouge), etc.

The new scene guidelines stipulated that a minimum number of points were to be recorded when documenting a roadway. Crash Technicians are required to record at least five points on road lines to demonstrate any roadway curvature even when they appear straight. Curved roadways and lines often require significantly more points be documented. By doing this, any curvature of the road will be captured and will result in more precise and realistic scene diagram.

In all the investigation-based programs, scene measurements are now collected in three-dimensions (X,Y,Z), although they are presented in the FARO Blitz software in two-dimensions. NHTSA made the decision during design of the system that two-dimension scenes would be sufficient for CISS. Producing scenes in three-dimensions would have required additional computer hardware, more robust and costly FARO 360 HD software, additional training, and more time to complete each scene diagram. NHTSA felt the additional resources required for three-dimension scene diagrams could be better allocated toward more CISS cases. The files provided to the public will have all the data points measured in three-dimensions, and the user can create their own version of a three-dimensional scene in most CAD, mapping, or reconstruction software packages. NHTSA's CID staff is also equipped with the more advanced FARO 360 HD software for use when additional details are needed.

Crash Technicians were instructed during training on how to document various types of crash scenes including intersections, curved roads, off road, and object impacts. Guidance was also issued on documenting specific points on more complex objects. For example, when documenting traffic signals all measurements should be to the middle of the signal (typically the yellow light) to represent the height off the ground for potential use in three-dimensional models. Similarly, stop signs are measured to the point where the bottom of the sign meets the vertical pole or post. To maximize efficiency, Crash Technicians were taught methods to document roadways by adding specific prefixes to the Code Descriptors so the FARO software can connect lines on the scene diagram. By using "Z" and "X" prefix designations on lines, the software will connect the same-named points creating a line on the diagram. By efficiently labeling eight curbs or road edges that make up a four-leg intersection, the software connects all similar named lines together creating the legs of the intersection.

Figure 2 shows the 127 points collected by a CISS Technician using the total station during documentation of an intersection crash scene.

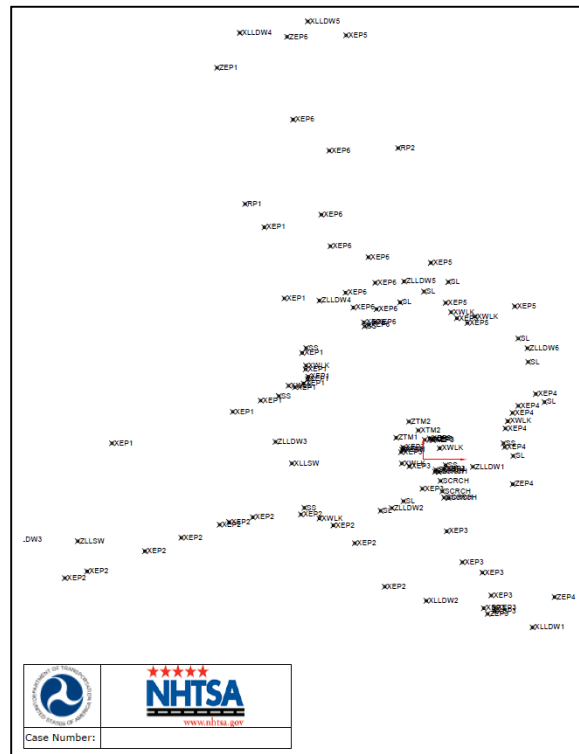


Figure 2. Example of points collected at an intersection crash scene using Nikon Total Station.

Figure 3 is an example of the final diagram of the same scene displayed in Figure 2. The points captured by the total station and named using common code descriptors have been connected by the software and other final features such as traffic signals, north arrows, scales, and callouts giving additional details have been included. Additionally, the position of the two vehicles involved in the crash at pre-crash, impact, post-impact paths, and final rest positions are shown on the final diagram.

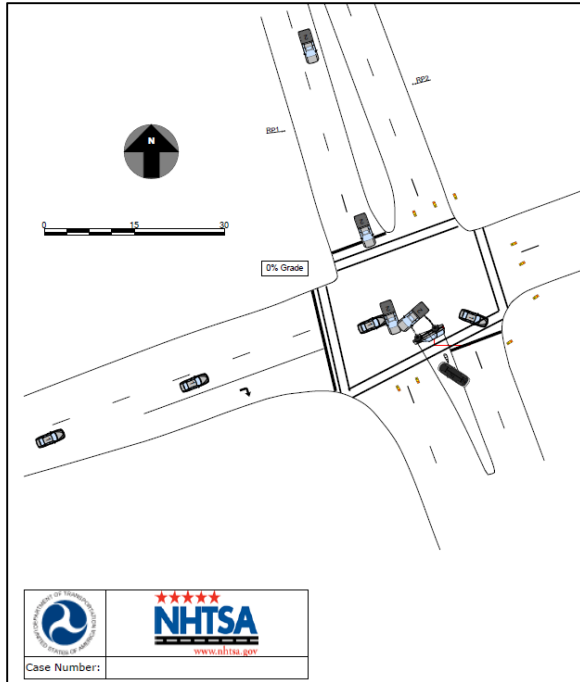


Figure 3. Final scene diagram using the points displayed in Figure 2.

In CISS, some selected crashes occur on limited access or interstate roads where stopping/parking is not permitted or safe. In these cases, the FARO software allows the Crash Technician to use Google satellite imagery to pinpoint the exact position of the crash and trace the scene in the software, resulting in a scaled diagram of the physical scene minus any evidence.

The scene diagram, along with the rest of the case, is devoid of any personally identifiable information. The Crash Technician attaches the following files to the CISS case:

- .nik – the Nikon file generated from points documented
- .blz – a Faro Blitz file generated from drawing the complete scene
- .csv – the comma separated values file where all the scene data is stored as tabular data
- .pdf – a portable document format (Adobe) where the scene diagram can be visible to a wide audience of users

All of these files will be published with the case file on NHTSA’s website, unless the scene was drawn using only the Google imagery feature which eliminates the .nik and .csv file extension types.

Vehicle Data Collection

One of the most appealing features of the FARO Blitz software is its ability to determine vehicle crush based on points collected by the total station. This is done by measuring crush points on the damaged plane of the vehicle in conjunction with undeformed points, such as undamaged axles and center points on planes that did not sustain damage. The points from the damaged vehicle are overlaid on an undamaged model and the difference is calculated by the software to produce crush. Principles for obtaining crush are similar to the previous manual method, in that the damaged vehicle is compared to its undeformed state. However, the efficiency by which this is done now is a considerable upgrade from the earlier systems.

The reliability and accuracy of the scene portion of the FARO software is well documented in validation studies and papers [3,4,5], and is commonly used by law enforcement officers in court. However, since the vehicle module of the software used to establish crush values was relatively new at the time of evaluation, NHTSA’s CID conducted an evaluation to ensure the accuracy of the software. A team of Crash Investigation Specialists from NHTSA traveled to a crash test facility and documented a series of vehicles involved in six crash test configurations: full frontal, side, side pole, frontal small overlap, frontal oblique, and rear impacts. The crush to the vehicles was documented using the traditional manual measurement techniques, and the updated data collection method featuring the Nikon Total Station and FARO software. The crush measurements using the two methods were entered into the WinSMASH reconstruction software used to generate Delta V (change in velocity). These results were compared with the data imaged from the vehicle’s Event Data Recorder (EDR) and accelerometer data available from the crash tests. The evaluation concluded that the updated vehicle measurement procedure was quicker, and resulted in a slight increase in the accuracy of the output compared to manual measurement techniques used in the past.

NHTSA updated its Vehicle Measurement Technique Guide used in the investigation-based programs to assist the field staff in setting up the instrument and obtaining the crush and other vehicle measurements that are ultimately entered into the WinSMASH reconstruction software to generate Delta V. One of the areas that increases the accuracy in the new measurement approach is

the number of crush points collected on a vehicle. The old manual method collected damage at six points along the vehicle's crush profile regardless of damage length, while the new procedure collects crush at 10 cm increments. This often results in a marked increase in number of points documented in the crush pattern. Figure 4 shows a vehicle with side impact damage documented with a total station. In this example, instead of six crush measurements as in the previous measurement method, twenty-three points were collected to document the crush. It should be noted that regardless of the number of crush points collected by the total station at the vehicle, the FARO software consolidates the crush points into six values for use by WinSMASH and other reconstruction software capable of generating Delta V. Figure 5 displays the results from a frontal impact.

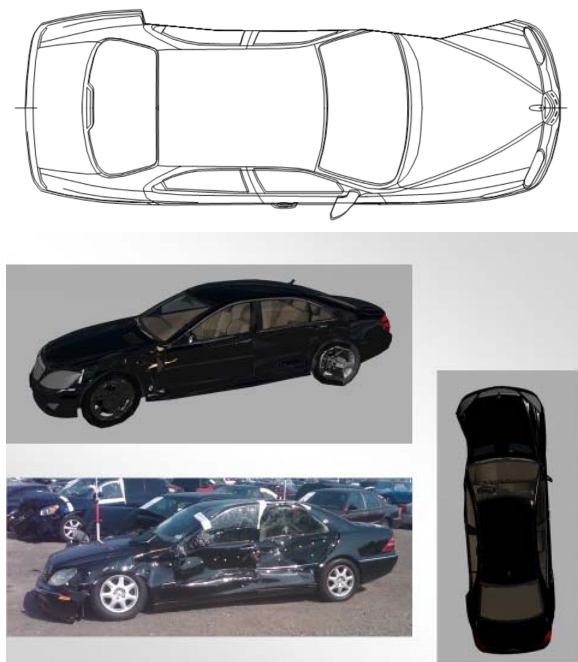


Figure 4. Image of a vehicle with side impact damage and the resulting models using FARO Blitz and FARO 360 HD software.

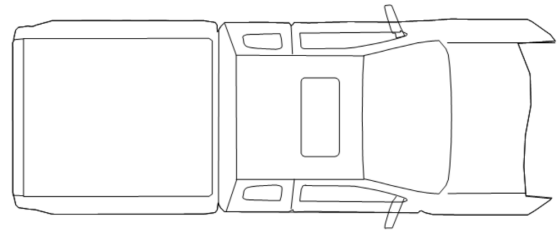


Figure 5. Images of a vehicle with frontal damage and the resulting models using FARO Blitz and FARO 360 HD software.

Early feedback from Crash Technicians that moved to the CISS project from the previous NASS-CDS, as well as SCI Investigators who have used both vehicle measurement methods, has been very positive. They have stated that the new measurement protocols with the electronic measurement device and FARO software not only improves accuracy, but is also more efficient in most cases.

CONCLUSIONS

The Data Modernization Project was initiated to reaffirm NHTSA's position as a leader in investigation-based data collection. One of the chief outcomes was the replacement of NASS-CDS with the CISS program. CISS will have vast improvements over its predecessor in many areas such as sample design, IT infrastructure, and injury data. Additionally, CISS will deliver stakeholders more precise scene and vehicle information, which was one of the most widespread requests of the Data Modernization effort.

NHTSA's move to the Nikon Total Station electronic measurement device coupled with FARO mapping software will provide more

robust and accurate scene information. The scenes in CISS will be measured with a higher degree of accuracy than in previous data collection studies, which gathered measurements manually using tape measures. Scaled scene diagrams can be completed more efficiently than in past studies due in large part to the software's ability to automate the diagramming process, thus reducing the amount of time required to finalize diagrams. However, the most important feature of the improved scene documentation procedure is the reduction in the amount of time the Crash Technicians are in harm's way collecting measurements in or near the trafficway.

NHTSA will make four file types available to the public from scenes documented using total station. Scaled scene diagrams will be produced and the raw data points that were collected will be available in multiple formats. These can be imported into most CAD or mapping software for modeling or reconstruction efforts.

The adoption of new electronic measurement instrument and software allows the crush and other vehicle measurements to be collected with a higher degree of precision than previously in NHTSA's investigation-based programs. Early results suggest the new vehicle measurement techniques are also more time efficient.

REFERENCES

[1] Chen, et. al, "NHTSA's Data Modernization Project", Proceedings of the 2015 Federal Committee on Statistical Methodology (FCSM) Research Conference.

[2] Association for the Advancement of Automotive Medicine website. <http://www.aaam.org>

[3] Kennedy, Mike, Hetherington, Paul, and Luker, Craig (2013) "Rapid Generation of Digital Terrain Models using Total Station Data and Aerial Images or Satellite Imagery", AWP-1-2013. <http://aras360.com>

[4] Kennedy, Mike, Hetherington, Paul (2013) "Accuracy Evaluation of the ARAS HD Angular Momentum Solution in Relation to the RICSAC Staged Crash Events", AWP-2-2013. <http://aras360.com>

[5] Kennedy, Mike, Hetherington, Paul (2013) "Evaluation of the ARAS HD ICATS System in Relation to the RICSAC Staged Crash Events", AWP-3-2013. <http://aras360.com>