TRANS-SAFE

TRANSFORMING ROAD SAFETY IN AFRICA

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Radical improvement of road safety in low- and medium-income countries in Africa

D1.4 - In-depth database: structure, tools and methods

Author: Università degli Studi di Firenze (UNIFI)

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Summary Sheet

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Responsible Author(s)	N. Baldanzini; S. Piantini
Contributing Partner(s)	J. Záhořík; A. Neven; H. Dirix; T. Bońkowski
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LIST OF ABBREVIATIONS

Acronyms	Full meaning
AAAM	Association for the Advancement of Automotive Medicine
AACN	Advanced Automatic Crash Notification
ABS	Anti-lock Braking System
ACEM	Association of European Motorcycle Manufacturers
AEB	Autonomous Emergency Braking
AGL	Above Ground Level
AGPS	Assisted GPS
AIS	Abbreviated Injury Scale
ANOVA	Analysis of Variance
ARSO	African Road Safety Observatory
AU	African Union
CAD	Computer Aided Diagramming
CADaS	Common Accident Data Set
CARE	Community database on Accidents on the Roads in Europe
CDC	Crash (or Collision) Deformation Classification
CIREN	Crash Injury Research and Engineering Network
CISS	Crash Investigation Sampling System
CoG	Centre of Gravity
COLM	Conservation Of Linear Momentum
CRP	Close-range photogrammetry
DaCoTA	Road safety Data Collection, Transfer and Analysis
DBMS	Database Management System
DGPS	Differential GPS
DoE	Design of Experiment
DXF	Drawing Interchange Format
EDM	Electronic Distance Measurement Instrument
EDR	Event Data Recorder
EES	Equivalent Energy Speed

EMS	Emergency Medical Services
ERSO	European Road Safety Observatory
ESP	Electronic Stability Program
ETS	Electronic Total Station
EuroNCAP	European New Car Assessment Programme
FAA	Federal Aviation Administration
FARS	Fatality Analysis Reporting System
FE	Finite Element
FEM	Finite Element Method
GCP	Ground Control Point
GEBOD	Generator of Body Data
GIDAS	German In-Depth Accident Study
GIS	Geographical Information System
GNSS	Global Navigation Satellite Systems
HM	Human Model
HSIS	Highway Safety Information System
ICD	International Classification of Diseases
IGLAD	Initiative for the Global Harmonization of (in-depth) Accident
InSAFE	In-depth Study of road Accident in FlorencE
IPC	Involved Physical Component
iRAP	International Road Assessment Programme
ISS	Injury Severity Score
KE	Kinetic Energy
MAIDS	In-Depth investigation of motorcycle accidents
MAIS	Maximum Abbreviated Injury Scale
MB	Multi-Body
MBS	Multi-Body System
MMUCC	Model Minimum Uniform Crash Criteria
MOPSO	MultiObjective Particle Swarm Optimization
NASS-CDS	National Automotive Sampling System Crashworthiness Data System
NCGA	Neighbourhood Cultivation Genetic Algorithm
NHTSA	(United States) National Highway Traffic Safety Administration

NISS	New Injury Severity Score
NSGA-II	Nondominated Sorting Genetic Algorithm
POI	Point of Impact
POR	Point of Rest
PPE	Personal Protective Equipment
PTW	Powered Two-Wheeler
RAIDS	Road accident in-depth studies
RASSI	Road Accident Sampling System
RDBMS	Relational Database Management System
RTC	Road Traffic Crash
RTCIP	RTC investigation programs
RTK	Real Time Kinematic
SaaS	Software as a Service
SAE	Society of Automotive Engineers
SfM	Structure-from-Motion
SSATP	Africa Transport Policy Program
TDC	Truck Deformation Classification
TLS	Terrestrial laser scanning
ToF	Time-of-Flight
TRL	Transport Research Laboratory
TSRC	Transport Safety Research Centre
UAS	Unmanned Aerial Systems
VIN	Vehicle Identification Number
VRU	Vulnerable Road User
WAAS	Wide Area Augmentation System

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EXECUTIVE SUMMARY

The TRANS-SAFE Deliverable 1.4 provides an exhaustive framework with the objective of improving road safety through the implementation of effective and comprehensive in-depth crash investigation methodologies and advanced data management strategies. Although data collection for national databases still has to be improved to solve well known issues (e.g., underreporting of low severity crashes), Africa should benefit from experiences worldwide and consider the implementation of in-depth crash investigation programs to develop specific knowledge and support the improvement of road safety. Such programs may be developed at local scale and with a variety of approaches, adaptable to different budgets, but still able to provide invaluable information.

Thus the main objective of Deliverable 1.4 is to establish a systematic and comprehensive methodology for in-depth road traffic accident investigations, tailored to the African context. The proposed approach is designed to be adaptable and accommodate varying levels of resource availability and complexity. This document is conceived as a handbook to provide guidelines for optimal crash investigation and reconstruction, establishing minimum data structures for in-depth crash analysis, and enhancing the utilisation of tools for crash investigation, data collection, and reconstruction.

In the first part of the report a state-of-the-art review of global best practices is presented, encompassing pivotal areas such as the data collection standards, which are compared with national and in-depth datasets to identify critical variables for crash analysis. The review also addresses the evaluation of cutting-edge tools for crash scene investigations, including photogrammetry, LiDAR, UAVs, and robotic stations, and how to generate high quality data while ensuring compliance with legal and ethical standards. In the second part the report provides comprehensive guidelines for the investigation of road traffic crashes, with particular emphasis on the composition and skills required of the investigative team. For the investigation the creation of multidisciplinary teams is recommended, encompassing experts in road engineering, vehicle mechanics, and biomechanics. The inclusion of a traffic psychologist would also be beneficial. However, different size and composition options are presented to optimise costs, based on the requirements of the investigation. In addition, suggestions are given on the following key topics: sampling and weighting strategies, which are of pivotal importance in order to ensure the representativeness of crash datasets and to adjust for biases in sample collection; investigation protocols, which are required for the analysis of road traffic crash scenes, vehicle inspections, the collection of injury data and the interviewing of involved parties; recommendations for crash reconstruction, highlighting how the integration of advanced software tools with advanced instruments such as UAVs and 3D laser scanning for accurate scene mapping can bring innovation and high-quality results. Lastly, in order to facilitate consistent and effective data collection, the deliverable defines a data structure, which can be implemented with three, progressively expanded, sets of variables. Selection, coding and allocation of variables to one of the data categories (crash-related, road-related, vehicle-related, and person-related variables) is made to facilitate the future comparison with already existing in-depth crash databases.

This document delivers a comprehensive picture on the main topics of an in-depth crash investigation program, to allow novice researchers to quickly gain knowledge in the domain. In addition, different implementation options are given for the main areas of the program, to enable a highly customizable implementation based on the specific context.

1. INTRODUCTION

The Deliverable 1.4 of the TRANS-SAFE project focuses on creating a structured framework for an in-depth road crash investigation programme. Such a programme is intended to investigate *in-depth* a limited number of crashes to gain more insight in the causes and contributory factors, the kinematics and dynamic of the crash, the human perception before the crash and the behaviour in the pre-crash phase, the effect of safety devices or personal protective equipment –if present –, the injuries sustained by the people involved and their evolution in the short term. All this information contributes to gain understanding in road crashes and to design actions to improve road safety.

In-depth data collection is more detailed, but also more time and resource intensive compared to data collection performed to feed data into national databases. Because of these specificities, in-depth data collection is not a substitute for the national data collection, but a complement to it. Thus, in-depth data collection programs are typically run-on smaller areas (e.g., a city or a district) and the results are projected to national level by linking to the national statistics.

The primary goal of this deliverable is to establish a scalable structure for in-depth crash investigation that can be adapted according to the level of complexity and available financial resources, allowing for both high-detail and cost-effective approaches. The structure of this document is organized into four main chapters. Chapter 2 offers an analysis of the current state of the art in several key areas for effective crash investigation, including guidelines and procedures, the definition of a minimum data structure, tools for data collection, and an overview of crash reconstruction techniques and methods for result assessment. These elements form the foundational components needed to build a thorough investigation framework. Chapter 3 introduces the proposed TRANS-SAFE programme structure. This chapter outlines crucial aspects of the programme, including "Sampling and Weighting Procedures," investigation procedures, necessary tools, as well as detailed profiles of the investigation teams and their operational roles. This section aims to provide a comprehensive proposal that covers both practical implementation and resource allocation for road crash investigation teams. Finally, Chapter 4 defines the structure of the dataset and database, setting the groundwork for data storage, access, and analysis to support ongoing and future investigations. This structure ensures the secure, organized, and standardized management of data crucial for effective crash investigation and research. With this deliverable, the TRANS-SAFE project aims to advance road safety by enhancing crash investigation practices and optimizing data management to support robust road crash research and analysis.

About TRANS-SAFE

The TRANS-SAFE project involves national, regional, and city level demonstrations to test different types of innovative and integrated Safe System solutions, complemented by a comprehensive toolbox, capacity development, policy support and replication activities. To maximize impact, the project brings together in a consortium, highly committed cities, road safety agencies and experts from both Europe and Africa. Building on numerous synergistic projects, networks, and a strong technical experience among partners, the consortium will deliver on project objectives through highly effective and innovative approaches to sustainable road safety development, thereby ensuring that road safety systems and interventions from this project deliver on the recommendations of the Road Safety Cluster of the African-EU Transport Task Force, adopted in 2020. The consortium members have experience and expertise in Africa-related research as well as development-related research in collaboration with local actors in various countries of Africa at many levels. Ultimately, the project will help deliver on the Joint EU-Africa Strategy (JAES) and advance countries' progress towards the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs). TRANS-SAFE leverages on existing partnerships to collaboratively design sustainable interventions that aim to radically transform road safety systems in Africa.

2. STATE OF THE ART REVIEW

Setting up an in-depth crash investigation program requires the knowledge of several topics and instruments. A few studies have already been implemented worldwide, and some are still running. Reviewing implementation strategies of previous programs will optimize the definition of the proposal tailored for the African context. In the following sections all the key topics required for the definition of an in-depth crash investigation program will be reviewed pointing out the key features for the implementation.

2.1. GUIDELINES AND PROCEDURE FOR OPTIMAL IN-DEPTH CRASH INVESTIGATION

The Road Strategy for Accidents in Transport (RO-SAT) Working Group of the European Commission remarked upon the importance of all types of Road Traffic Crash (RTC) investigation programs, such as statistical/national data collection, intermediate-level investigations, in-depth investigations as well as special cases, encouraging "to devote the necessary resources to cover all levels of the investigation employing permanent, professionalized, and in case of in-depth studies also multidisciplinary, independent investigating bodies". Furthermore, the Working Group also recognized that, "neither the collection of statistics nor police or other intermediate-level investigations (based on police or insurance reports) are enough to fully and deeply learn from accidents", and recommends that in-depth, independent multidisciplinary investigations should be a core ingredient of road traffic safety policies (Monclus J., 2006).

Jeavons and Runacres (Jeavons and Runacres, 2020) listed the following general recommendations about RTC investigation programs (RTCIP).

- It should be established as an impartial investigator, independent from the judicial investigation process operated by the police.
- It should have sufficient legal powers to function effectively (investigate cases; access crash sites; identify, collect, and collate evidence; undertake physical tests on material evidence; interview witnesses including the response services and other investigators).
- It undertakes multi-disciplinary investigations relating to the road environment, vehicle, and human factors aspects of crashes and delivers recommendations relating to all of these aspects.
- It should have access to national statistics to utilize and conduct its analyses.
- It should be provided with access to police RTC files such as reports, findings, notes, measurements, plans, test results and interview transcripts.
- It will be important that an RTCIP is of sufficient size as an organisation to undertake its allotted functions, duties, and tasks. The staff should be heavily oriented toward technical

investigators. To reduce the financial budget, especially in its initial phase, the RTCIP could potentially comprise a relatively small organisation, tasked with investigating a limited number of RTCs. Moreover, it could operate with a small team of full-time investigators, calling upon external specialists from industry, academia, research institutes and private sector organisations when required.

2.1.1. Data quality

Data quality and under-reporting are two of the main issues to be considered either during the development of a data collection system or during its maintenance. Crash data management typically involves more than one person working on the same crash case: in a structured programme, frequently who collects crash data is not the same person who entered the data into the database.

A must have feature of a crash investigation team is “to be as accurate as possible when collecting data” and, especially in real-time collections, “to be able to work under pressure” which, nevertheless, might adversely affect the data collection. This could be addressed by planning specific training and by the use of datasheets and checklists containing the most important information to be acquired and how to collect them.

Training should mainly address the following:

- how to interact with people present at the crash scene,
- knowing what kind of information to gather and by which procedure,
- knowing all tools available and how and when to use them, as well as
- knowing how to conduct the collection of witness testimony.

Additionally, the investigator also should have basilar skills in impact kinematics, biomechanics, and injury coding to avoid not useful over-detailed collection.

Quality problems could also come out from the data entry staff, causing a high chance to have of data mismatching due to human error (although unintentional) frequently caused by either too long data collection forms/procedure or unclear variable definitions (Austroads, 2005; OECD, 2007; Vallet et al., 1999; Ward, 2006; WHO, 2010).

The OECD also suggests assessing the under-reporting level and data quality of a dataset by comparison with other crash databases, usually matching hospital, and police data. One of the most valid comparison ways should be to use of sensitive data of casualties (i.e., personal identification codes). However, countries do not typically allow access to sensitive data. Therefore, even though less accurate, a valid alternative could gather from the use of other crash characteristics, such as time, date, and location. Nonetheless, this is the best way to estimate the data quality and the proportion of under-reported cases in conjunction with a regular monitoring (Austroads, 2005; IRTAD, 2011; OECD, 2007; PIARC, 2023; WHO, 2010).

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WHO (WHO, 2010) and IRTAD (IRTAD, 2011) provide details on methods for assessing data quality and under-reporting rates. The most important steps to improving data quality include:

- Review definitions (e.g., variables should be simple to understand and apply).
- Strengthen reporting requirements (e.g., by making it a legal requirement for at least crashes involving injuries).
- Improve data collection tools (e.g., reporting tools, most updated investigation instruments, codding procedures).
- Collect accurate location information.
- Improve training of either crash investigators or data entry staff.
- Quality assurance measures.

2.1.2. Confidentiality and Ethics

Different authorizations will be needed according to the data collection programme type. For example, if the RTC program is mainly an on-the-scene data collection, informed consent from all the people involved in the crash it might be enough. Vice versa, if the RTC program also taps into other data sources (i.e., police and hospitals), then specific authorizations from each external organization should be required.

To have the most accurate crash picture as possible, the team is going to manage and/or exchange sensitive data such as gender, age, injury patterns, driving circumstances (alcohol and drug consumption), photographs and video recording, vehicle data (plate and VIN), and coroner report (in case of fatal on-scene crashes), and medical examination such as X-ray, CT scan and MRIs.

Therefore, the RTC investigation program design must take into account the national regulations on data protection. For example, according to the EU regulations, the processing of personal data is only permitted if the person concerned has consented to this, beyond any doubt, and the processing is required for accomplishing a contract position or a contract-related position of trust with the person in question.

The following are some recommendations (Vallet et al., 1999).

- During the in-depth investigation of a RTC, personal and vehicle data are required. The type and volume of this information mainly depend upon the data collection approach used. But in any case, the investigation programme will encounter sensitive data. Ethical approval concerning the data processing management and its data maintenance should be needed.
- Define a procedure on how to manage and store the data collected both in electronic and paper versions, with a particular reference to sensitive data.
- The data collected have to be entered into a database anonymized. This aspect also involves faces and vehicle plates present in videos and photographs.

- All the staff employed in the program as investigators and/or data entry should sign a non-disclosure agreement (NDA) not to pass any kind of information, verbal or written, to anyone not directly involved in the research program.
- Statements from all the people involved should be documented. According to that, the investigation team is going to ask for his/her consent for scientific purposes.

2.1.3. Data Collection typologies

Data collection can be performed with different approaches, which may be selected to tailor the general organization of the program to the available resources. In the following the different approaches are presented and the possible Pros/Cons are highlighted.

Retrospective

A retrospective study is a data collection where the time factor is not usually a big concern. It is performed from several hours to some days after the crash. Data are usually collected by people external to the team (e.g. police) and conveyed to the crash investigation team later on.

However, the procedure has to cover the following three main aspects, each having their respective specialists:

- roads
- vehicles
- injuries.

Roads should be investigated within 2-3 days later the crash to avoid loss of evidence. Vice versa, vehicles can be inspected later and away from the crash scene. Injuries are typically collected by asking for police information as to which hospital the injured occupant has been taken to and then requesting the hospital for access to the medical records. For fatal cases should be requested to the coroner for a post-mortem.

The advantages of the approach are:

- the possibility to choose a specific crash type to be collected and allow possible sampling variations
- the investigation team can carry out its tasks during office hours
- the accident alert can occur with a certain degree of freedom in timing.

The two last points clearly contribute to a cost reduction.

Vice versa, some disadvantages are:

- the delay between the crash and the investigation process that would affect the data availability and quality

- the possible lack of information restricting the options for collision analysis
- the possible increment of human errors because the data collection is performed by people external to the team(s), whose procedures cannot be precisely controlled (Vallet et al., 1999).

On the scene (on-time)

The on-the-scene or on-time studies are crash investigations performed immediately after the event. The investigation team moves to the crash scene as quickly as possible after it occurs and, ideally, before the vehicles involved have been removed.

In this way, the team can take detailed crash information relative to environment, vehicles, and injuries, although a more detailed investigation is still needed later on. Some advantages are the possibility to collect more detailed, high-quality and reliable data thanks to a collection performed by a specialized team and because most of these data are only available at the crash scene.

Vice versa, some disadvantages are the following. Teams could have difficulties in reaching out the status permission to reach the crash scene as fast as the rescue services (ambulance, police and fire brigade). For that reason, it may be necessary for teams to travel or work closely with their local emergency services in order to arrive in a safe and timely way. The investigation could delay the operations to restore normal traffic, as well as it does not permit making an a priori choice of the crash types to be studied. However, the major disadvantage is the higher staffing cost due to the need to cover a bigger data collection range (up to 24 hours per day), as well as the setting up of the notification system which usually requires a close collaboration with the emergency services, which could not be easy to obtain (Vallet et al., 1999).

Hospital-based

A hospital-based study concerns a systematic register type collection, for which a given population must be clearly defined (seriously injured, fatalities, head injuries, etc.). Data are mainly medical; therefore, environment and vehicle information are mainly absent or anyway less important. Since a trauma register has to be systematic and exhaustive, the collaboration of the different medical departments should be requested.

Some advantages are the simplicity of the selection criteria, and the possibility to reduce the issue linked to the department collaboration, for example, conducting the collection in a specific hospital department such as the intensive care unit or neurologic unit and so on. Other advantages are the fact that the data collection staff are also hospital staff and therefore they do not require extended training. On the other hand, the main disadvantage is the limited quantity or absence of crash data. It is generally easy to know the type of road user involved (such as car occupant, pedestrian, etc.) but it could be difficult to have reliable information about, e.g., the use of restraint systems and so on. Moreover, depending on local legislation, the registry is often closely regulated, and this can complicate the setting up of the system and the information exchange (Vallet et al., 1999).

2.1.4. Sampling strategies and weighting procedures

Sampling strategies

A representative sample is a sample whose results can be generally applied to a wider population (target population), and it should reflect the characteristics of the target population from which it has been taken, or, at least, the difference between the sample and the population should be as low as possible (Zůvala et al., 2021). For example, including an out-of-proportion number of severe and fatal accidents in the development of risk curves, fatality risks may be overestimated unless appropriate weighting procedures are applied (Rosén et al., 2011).

There are two main methodologies.

- “Probability sampling” methods – that acquire the sample randomly from the target population, and where every sampling unit has the same probability of being selected. A list of sampling method in this category is the following: simple random sampling, stratified random sampling and group sampling. The randomness of probability sampling guarantees the representativeness of the sample.
- “Nonprobability sampling” (or non-random) methods – such as quota sampling, snowball sampling and convenience sampling.

However, to predict the population behaviour from a sample, the sample structure must imitate the population composition as precisely as possible (Zůvala et al., 2021).Nonetheless, it might not be possible to achieve a truly random sample, even in the case of using the “probability sampling” methods due to the data collection process.

We will try to clarify it with an example from the GIDAS crash investigation programme. GIDAS adopts a probability sampling strategy where, theoretically, every member of the target population has the same probability of being selected. The target population is all police-recorded accidents involving personal injuries which occur within a predefined geographical area of the Hannover and Dresden cities. The method ensures to generate a random selection of crashes since the target population generates itself in the context of a randomized process. The investigations take place daily for two six-hour time intervals (shifts) following a 2-week cycle, after being alarmed by the police, rescue services, or fire department headquarters. However, because not 100% of crashes managed by the three alerters are notified to the GIDAS, this method is affected by biases due to unbalanced sampling concerning the severity of crashes (crashes with slightly injured persons are underestimated compared to crashes with persons killed), implying that the GIDAS's sample, if taken as is, is not nationally representative (Hautzinger, 2005).

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Weighting procedures

To generate a nationally representative dataset, weighting procedures are needed to adjust for this bias. Various methods exist, such as:

- cell-weighting,
- poststratification,
- raking (Iterative Proportional Fitting, IPF), and
- hypercube weighting.

Cell weighting is one of the most accurate but not easy to use. Hypercube clustering is frequently used to identify weighting factors, but small samples or empty cells in datasets are problematic. Poststratification can improve the efficiency of estimators but needs enough data in each post-stratum. Raking method, even generally less accurate, presents a higher flexibility in the amount of required information. Among them, the IPF Raking method can be successfully used for those countries with sparse crash data (Zůvala et al., 2021; Bethlehem., 2009; Kreiss, 2015; Hautzinger, 2005; Thongnak et al., 2022).

Another example of sampling strategy and weighting methodology comes from the Crash Investigation Sampling System (CISS) by NHTSA (2019) which uses a stratified three-stage sample design and weighting procedures.

A more straightforward method for comparing in-depth datasets with national datasets is to utilise specific variables present in both datasets which are highly correlated with as many as possible other crash characteristics (Hautzinger, 2005).

These may include the location of the crash (urban, rural or highway) or the severity of the crash, which can be collected using the same sample modalities used in the national dataset. Once the variables have been identified in both datasets, a variety of strategies may be employed. As an example, two potential procedures may be employed:

- The number of urban road crashes at the national level can be divided by the number of cases present in the in-depth dataset for a specific year.
- The product of the number of urban road crashes at the national level and the total number of cases present in the in-depth dataset (all cases, not only urban) can be divided by the product of the number of urban road crashes in the in-depth dataset and the total number of cases present in the national dataset for a specific year.

2.1.5. Crash Investigation Team

The investigation team should have high experience and multidisciplinary skills on at least the following road safety subjects:

- Environment
- People
- Vehicles.

A team of three people with expertise in road engineering, vehicle engineering and biomechanics, and trauma management would be recommended, plus, if possible, an extra fourth human factors expert such as a human factor engineering, ergonomics, or psychologist.

The advantages of working in a team are the improvement of the quality and the accuracy of the data collection, offering a quicker investigation of crash causes, the generation of more points of view (especially crucial in complex cases), the possibility to provide a peer review support to identify or code tough elements of a crash.

Regrettably, having so high expertise can be expensive and even not always easy to recruit. To overcome this issue, a possible solution is the employment of "less qualified" personnel but, in any case, well-trained on the most important aspects of the crash data collection process. At the same time, the team size can also be reduced to only two investigators.

The following are some recommendations for the composition of the crash investigation team and its operating activity (Atalar, 2012; Vallet et al., 1999):

- Build a balanced team by selecting the appropriate expertise
- Constant training and skill updating to ensure high quality of data collection and the coding of the information
- A glossary of terms constantly updated should be in place with a clear, precise understanding of the terminology and conventions used
- Data must be collected using objective methods
- Checks should be used to ensure conversion of the data into an electronic format is correct
- Feedback loops should be established throughout the system to allow for errors to be corrected and new conventions or training identified at the earliest possible stage
- Define a Team Leader
- Define a Case Leader.

A Team Leader is typically the team coordinator, responsible for the recruitment and management of the team, ethical and data handling agreements, reporting on team progress, conducting case review meetings with their investigation team, organising all necessary investigation tools, quality control checks, etc.

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A Case Leader should be the most experienced team member on that shift mainly responsible for the organization of the shift, the data collection and entry into the database for cases that are started during the shift. The case leader usually assigns tasks, checks if notified cases fulfil the sampling criteria, handles any kind of problem that may arise during the investigation process (e.g., physical, or emotional issues), liaise with all individuals contributing to the case, and so on.

During an on-scene investigation, the team must speak with the police, fire brigade and first aid responders, witnesses and all road users involved in the crash. Take photos of the accident location and vehicles, identify the fast changeable marks and traces, measure all relevant parameters of the accident scene, etc. However, to save time, vehicles can be also examined retrospectively, with the team asked to take photos, and measurements and check passive safety system deployment.

Nonetheless, the least common denominator that joins all investigation phases, whether on-scene or retrospectively, is the filling of specific forms useful to guide the operator in the collection of the data requested.

2.2. DEFINITION OF THE MINIMUM DATA STRUCTURE

At national and transnational level, the minimum data structure of a traffic crash database serves as a fundamental tool for identifying potential risk factors associated with crashes and for developing targeted interventions to mitigate the risks. By identifying trends and patterns in crashes, stakeholders can better understand the root causes of these crashes and take appropriate measures to prevent them from occurring in the future. The minimum data set can serve as a powerful tool, making it possible to identify and quantify road safety problems throughout a country, evaluate the efficiency of road safety measures, determine the relevance of community actions, and facilitate the exchange of experience in this field (Segui-Gomez, 2021).

In a different way from earlier collection, the in-depth road crash databases can play a pivotal role in enhancing road safety by offering a plethora of data concerning the causes and consequences of road traffic crashes. This is because they are designed to answer more specific questions. For example, the understanding of the manner in which a body region sustains injuries under specific conditions (gender, age, weight and height, body-to-point impacted, impact speed, energy, accelerations, etc.), or again the way in which a specific vehicle or person-related safety feature (seat belt, air-bag, chassis, Anti-Lock Braking - ABS, Autonomous Emergency Braking – AEB, helmet, etc.) responds to or avoids a collision to protect its occupants.

However, in comparison to national road traffic datasets, these initiatives are typically implemented at a more limited geographical scale, often at the metropolitan level, due to the greater complexity of data collection and the associated resources required for its acquisition, as reported in section 2.1.

Nevertheless, the usefulness of these databases depends largely on the quality and comprehensiveness of the data collected. In practice, there is a continuum between the level of detail and the quantity of crash data. Identified effective practice acknowledges that no single crash injury database will provide enough information to give a complete picture of road traffic injuries or to fully understand the underlying injury mechanisms (IRTAD, 2011). To this end, the minimum data structure of an in-depth crash database is a set of essential data elements or variables that must be collected and recorded to provide sufficient information for conducting comprehensive analyses of crashes (WHO, 2010).

2.2.1. Review of Different National Road Crash Data Sets

The significance of road safety decisions is heavily reliant on the quality of data and linked to the robustness and completeness of the data used to inform it. Thus, the development of a comprehensive and efficient database that includes a minimum set of variables is paramount in ensuring accurate analysis of crashes. The importance of standardized data collection in crash reporting is crucial. To achieve greater uniformity in data collection across countries, guidelines for a minimum national set of standardized data elements have been developed in Africa, the European Union (EU), and the United States. The EU developed the Common Accident Data Set (CADaS) in 2008 with a last update in the 2023 (Care Team, 2023). The United States developed the Model Minimum Uniform Crash Criteria (MMUCC) in 1998 and updated it several times after that (MMUCC, 2024). In Africa, African Road Safety Observatory (ARSO) recommended crash-related minimum data set at a country level adapted from CADaS (mini CADaS), and a smaller data set to be shared between countries, designated as MiniARSO (Segui-Gomez, 2021). The implementation of these standardized data collection guidelines allows for more effective analysis of crash data and the development of targeted interventions to reduce the number and severity of crashes on the road.

A Critical review of national traffic crash databases from Africa, the EU, and the US as well as an in-depth analysis of selected traffic crash databases, was conducted to identify the most important variables and establish the minimum data structure to be proposed for an in-depth crash investigation program.

EU Level

For years, crash data have been collected in the EU countries according to their own national systems. At the European level, disaggregate crash data have been available since 1991 in CARE – the community database on road accidents resulting in death or injury. The lack of data uniformity among and within EU countries hinders the exploitation of CARE's potential. With this situation in mind, the recommendation for CADaS, consisting of a minimum set of standardized data elements, was developed (De Meester, 2011). The minimum data elements selected for CADaS were based on extensive research into both the data sources and the systems available in 25 European countries and the stakeholders' needs and priorities. CADaS consists of 73 variables and 471 values. The selection of these variables and values resulted from the balanced co-consideration of some basic criteria, taking into account that variables and values must be comprehensive, concise, and valuable for road accident analysis at the EU level, the level of detail of the variables and values should correspond to all data useful for macroscopic data analysis and that each country should have the possibility to choose alternative level of detail of the various variables and values. Data which are impossible or very difficult to be collected are not retained in the CADaS. However, the future perspective of using certain variables and values was also taken into account, even though those data are not currently collected by most of the countries. Existing CARE variables and values are of first priority within CADaS and additionally, CADaS variables and values refer to casualty road accidents. CADaS is a standardized approach to collecting and reporting crash data in Europe. The minimum data structure recommended by CADaS includes the following four Categories (Care Team, 2023):

- A, for Accident-related variables,
- R, for Road related variables,
- U, for Traffic Unit (vehicle and pedestrian) related variables,
- P, for Person related variables.

United States (National Level)

The United States has specialized safety databases at the national level such as the Fatality Analysis Reporting System (FARS) and the Highway Safety Information System (HSIS). FARS includes fatal injuries suffered in traffic crashes collected from all U.S. states (FARS, 2011). HSIS contains crash, roadway inventory, and traffic volume data from seven states (HSIS, 2012). The inclusion of severe injuries in the FARS system has been discussed recently, and this discussion has not concluded. These databases serve safety research at the national level more than road safety management in individual states. Each state has its own safety database that may but does not have to follow the MMUCC (MMUCC, 2024).

MMUCC is the result of years of discussion among many safety experts. It does not present coding values for the data element attributes, so states are able to design the content, format, data collection system, and data coding conventions to meet their needs. It is also important to highlight that since MMUCC is a minimum data set, states may collect additional data if they believe it is necessary to enhance decision-making. It has 111 data elements. Seventy-seven of these elements are to be collected at the scene and include date/time, weather, location, vehicles involved, sequence of events, etc. Ten more elements are derived from the previous elements, and include severity, fatalities, and presence of alcohol. Additional driver information and facility information compose the remaining 24 elements, which are designed to be integrated once the incident is entered into an enterprise database system.

According to the MMUCC, the minimum data structure for in-depth crash databases should include the following variables:

- Crash data elements such as date, time, and location of the crash
- Injury information, including the severity and location of injuries sustained
- Roadway characteristics, including road type, surface conditions, and lighting
- Vehicle information, including make, model, and year, as well as a vehicle identification number (VIN) and license plate number
- Driver and occupant information, including age, sex, and seat belt use

- Contributing factors, including driver-related factors such as alcohol use or speeding, and environmental factors such as weather or road conditions
- Crash diagram, showing the location and direction of travel of each vehicle involved in the crash.

African level

In Africa, a process began in 2017 to define a common set of indicators to be collected, analysed, and monitored by African countries, as part of their efforts to improve road safety in Africa. Some of these indicators will be collected individually at country level and serve country level decision-making. A smaller subset of indicators could be reported in aggregate form to regional or global road safety observatories and inform other decisions. This data-focused effort runs in parallel with the effort led by the Africa Transport Policy Program (SSATP) to establish an African Road Safety Observatory to act as a platform for faster and more homogeneous strengthening of road safety data in the 54 African countries under the African Union (AU). ARSO recommended crash-related minimum data set at a country level that were adopted from the EC's CARE Common Accident Data Structure to develop a database structure called MiniCADaS (hereafter referred to as ARSO) and a minimum dataset (25 indicators) to be shared between countries (MiniARSO) in July 2018 (Segui-Gomez, 2021).

ARSO recommended crash related data set has 47 variables in the following four categories.

- Crash-related variables
- Road-related variables
- Vehicle-related variables
- Person-related variables.

2.2.2. Review of Different In-depth Road Crash Data Sets

In the context of in-depth road crash investigation programmes, a number of datasets are available worldwide, which have been developed over time in accordance with evolving standards and requirements. For reference, the following is a non-exhaustive list of some in-depth data sets currently available and ongoing worldwide:

- IGLAD - Initiative for the Global Harmonization of (in-depth) Accident (Worldwide)
- CIREN - Crash Injury Research and Engineering Network (US)
- GIDAS - German In-Depth Accident Study (Germany)
- RAIDS - Road accident in-depth studies (UK)
- RASSI - Road Accident Sampling System (India)
- InSAFE – In-depth Study of road Accident in FlorencE (Italy)

In addition to the aforementioned datasets, a number of European research projects may be referenced in the development of an in-depth road crash database, tailored to the specific topics of interest. For reference, the following is a non-exhaustive list:

- DaCoTA - Road safety Data Collection, Transfer and Analysis (EU research project)
- MAIDS - In-Depth investigation of motorcycle accidents (EU research project)

A critical review of in-depth road crash data sets from all over the world has been conducted with the objective of identifying the most important variables and then establishing the minimum data structure for an in-depth crash investigation programme.

IGLAD - Initiative for the Global Harmonization of Accident Data (IGLAD)

IGLAD is a worldwide in-depth crash investigation program designed to improve road and vehicle safety through standardized data collection. Launched by Daimler AG, ACEA, and various research institutions, IGLAD was formalized as a working group within the FIA Mobility Group in 2010. The goal is to establish a common framework for crash data, facilitating comparisons across international datasets and providing a global, standardized accident dataset. This initiative also aligns with the objectives of the European Road Safety Action Programme and the Decade of Action for Road Safety, aiming to support road safety policy development and intervention effectiveness assessments. The IGLAD dataset includes accidents with at least one injured person and currently comprises up to 124 variables per accident, categorized into crash, road, vehicle, and person-related data. Data contributions are made by 14 providers across 12 countries—including Germany, Italy, Australia, France, China, and the USA. Since the project's inception, it has progressed in phases: Phase 1 began with cases from 2007, while Phase 2 ran from 2014 to 2016, gathering 3,100 cases from 11 countries. Phase 3, starting in 2017, expanded the dataset to nearly 5,000 accident cases by 2018, covering periods such as 2015-2016 and beyond. This extensive dataset serves as a key resource for international road safety improvement (IGLAD, 2024; IGLAD Technical Working Group., 2021).

CIREN – Crash Injury Research and Engineering Network

CIREN is a collaborative research initiative sponsored by the United States NHTSA. It aims to enhance the understanding of crash injury mechanisms and improve vehicle safety through detailed data collection and analysis. CIREN integrates medical and engineering data from severe motor vehicle crashes to identify injury patterns and risk factors (Scally et al., 1999;Elliott et al., 2010; Plevin, 2017; Flannagan & Rupp, 2009). One of the key benefits of CIREN is its ability to provide in-depth medical data, including injury location, severity, and medical imaging, which are crucial for biomechanical injury evaluation. Studies using CIREN data have shown that Advanced Automatic Crash Notification (AACN) systems can significantly reduce mortality by providing timely information to Emergency Medical Services (EMS), allowing for quicker and more appropriate (Plevin, 2017). Additionally, combining CIREN data with other databases like the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) helps reduce bias and improve the accuracy of injury risk assessments (Elliott et al., 2010) (Flannagan & Rupp, 2009). CIREN data has also been instrumental in identifying specific injury patterns in different crash scenarios: e.g. the type of vehicle damage distribution in head-on crashes can influence the severity and type of injuries sustained by drivers (Tencer et al., 2005;Conroy et al., 2008). The database consists of multiple discrete fields of the NASS data set concerning severe motor vehicle crashes, augmented with medical and injury variables such as co-morbidity, medical images, disabilities, vital signs, physiologic measurements, injury location, etc., while, from the engineering point of view, in addition to NASS data, some of the main variables collected are delta-V, the crash type, the Crash Deformation Classification (CDC), intrusions quantification, occupant contacts, etc. for over 1000 collected data on every crash investigated (CIREN, 2024; Plevin, 2017;Elliott et al., 2010; Flannagan & Rupp, 2009). Each injury is then linked to crash intrusions, contacts, biomechanical descriptors (e.g. sheer mechanism) and human drawing maps. Labels and drawings are layered over the standard drawings to clarify positions and mechanisms. These are very useful for the bioengineer who requires a detailed localization of an injury in order to effectively analyse the mechanics and discover new relationships. In this way the injury layers may be added together or "clustered" so that patterns over several patients may be analysed. This process enables repetitive injury patterns to be highlighted. The case is then presented to a review board meeting where the experts validate the case findings.

GIDAS – The German In-Depth Accident Study

GIDAS, established in 1999, is a joint research effort between the Federal Highway Research Institute (BASt), the Research Association of Automotive Technology (FAT), Hannover Medical School (MHH), and the Technical University of Dresden (TUD). The study focuses on collecting comprehensive data on traffic accidents involving personal injury in two main areas: Hannover and Dresden, including their surrounding regions. The accident investigation teams, which work on a rotating schedule throughout the year, gather detailed information on accident conditions, vehicle and equipment details, vehicle damage, injuries to involved parties, and the response by rescue services. The data collection occurs at the accident scene and includes direct interviews with those involved, as well as collaboration with police, hospitals, and emergency services to gather retrospective details. Each documented accident undergoes a simulation-based reconstruction covering all stages—from the initial phase and vehicle response through to the collision and final rest positions. Key variables such as braking deceleration, initial and collision speeds, and impact angles are calculated. In total, GIDAS documents up to 3,000 encoded parameters per accident, creating a thorough database representative of road accidents across Germany (Babisch et al., 2023; GIDAS Homepage, 2024).

RAIDS – Road accident in-depth studies

RAIDS represents a significant initiative in the field of road safety in the UK, with a particular focus on the investigation and data collection aspects of road traffic accidents. The objective is to provide comprehensive analyses of road traffic accidents, with a view to enhancing road safety. The programme encompasses a number of key aspects, including the gathering of comprehensive data from real-life crash sites, vehicles, and other contributing factors to accidents. This encompasses vehicle damage, environmental conditions, driver behaviour, and other variables. Furthermore, RAIDS is a collaborative endeavour involving police, vehicle engineers, medical professionals and road safety experts, with the objective of attaining a comprehensive understanding of the underlying causes of road traffic accidents. The findings are intended to inform policymakers and stakeholders, influencing the development of legislation, safety features and improvements to road infrastructure. Additionally, the data collected is integrated into national road safety strategies, enabling the formulation of targeted interventions aimed at reducing road traffic collisions and fatalities (RAIDS, 2024).

RASSI – Road Accident Sampling System India

RASSI is a comprehensive methodology developed to conduct on-site crash investigations and collect in-depth accident data on road accidents in India. This initiative was driven by the urgent need to understand the primary factors involved in serious road accidents, which have been on the rise in India, leading to severe injuries and fatalities. The RASSI project is an international collaborative effort involving safety researchers and vehicle manufacturers, aimed at improving the safety of highways and automobiles for all road users. The RASSI methodology involves several critical steps to ensure the collection of nearly 700 high-quality crash data suitable for detailed analysis, such as: photographing the crash site and vehicles, examining crash vehicles, injury coding as well as determining critical crash data like driving and collision speeds, Delta-v and the energy absorption from vehicle deformation pattern. Regarding the injuries, the coding process is performed using the Abbreviated Injury Scale (AIS) and Maximum Abbreviated Injury Scale (MAIS) (Rameshkrishnan, 2013; Padmanaban, 2013).

InSAFE – In-depth Study of road Accident in FlorencE

InSAFE is an in-depth road crash investigation programme established in 2010. Its objective is to identify the causes and effects of severe injuries resulting from road crashes. A collaborative network was established between the Department of Industrial Engineering at the University of Florence, the Careggi University Hospital with its Intensive Care Unit of the Emergency Department and the local Police forces. The research programme is managed by the Mobility and Vehicle Innovation Group (MOVING) of the University of Florence. The programme's primary objective is to analyse the causes of road traffic accidents and the mechanisms of injury, in order to gain insights into the factors contributing to road trauma and to improve traffic safety policies. The InSAFE team operates within the metropolitan areas of Florence and Prato, with a particular focus on fatal and severe road traffic accidents. The dataset includes over 1300 crash-related variables. This data collection includes not only crash-specific data, but also medical information, allowing for a multidisciplinary approach to the analysis of crash outcomes. Each injury is coded using theAIS (2015 version) and localised on a three-dimensional human body model derived from computed tomography slices. Finally, the MAIS for body regions and the person, the Injury Severity Score (ISS) and the New Injury Severity Score (NISS) are calculated for each case. Thanks to the collaborative network that has been established, the team is able to collect crash-related data from: police reports, scene investigations, photographs and video footage, witness statements, injury records and detailed vehicle inspections. The team is thus able to collect a comprehensive set of data that combines field observations, vehicle assessments and medical evaluations. These data are ultimately used to reconstruct the crash event, analyse injury patterns and identify risk factors associated with different crash scenarios (Piantini et al., 2013; InSAFE, 2024; Piantini S, 2012).

DaCoTA – Road safety Data Collection, Transfer and Analysis

DaCoTA is a research project funded by the European Commission under the Seventh Framework Programme (FP7), aimed to improve road safety policy and management across the European Union by enhancing the quality, accessibility, and comparability of road safety data. Led by the Transport Safety Research Centre at Loughborough University, DaCoTA's core objective was to establish a comprehensive data framework that integrates various forms of traffic, accident, and behavioural data, creating a robust evidence base for policy-making. DaCoTA supported the European Road Safety Observatory (ERSO) by advancing data collection protocols and analytical tools that ensure consistency in how data is gathered and reported across member states. The project has developed a validated protocol covering over 1500 variables, addressing crash causation, accident scene data, and injury characteristics. DaCoTA also established a data warehouse accessible to stakeholders, incorporating road accident data from the EU CARE database, exposure data, and safety performance indicators. This platform provides policymakers with real-time, high-quality data for effective safety interventions. In addition to developing a standardized data framework, DaCoTA has created a pan-European accident investigation network. This network harmonizes in-depth accident investigation methodologies and trains teams across 19 EU countries, facilitating a more nuanced understanding of crash dynamics and injury mechanisms. DaCoTA's pilot studies have provided practical insights into various crash scenarios, supporting targeted safety initiatives like Euro NCAP ratings and road safety audits. DaCoTA's contributions to road safety data management enable better assessment of risks, identification of high-priority areas, and support for evidence-based road safety strategies. By enhancing data accuracy and fostering cross-border collaboration, DaCoTA plays a crucial role in advancing EU road safety goals and promoting safer road environments across Europe (Thomas, 2013).

MAIDS – In-Depth investigation of motorcycle accidents

MAIDS is an in-depth road crash investigation project, carried out between 1999 and 2001 and supported by the Association of European Motorcycle Manufacturers (ACEM) and the European Commission, represents a major effort to investigate motorcycle accident causation across Europe. Its primary objective was to collect comprehensive data on motorcycle crashes to inform safety improvements. The study was carried out across five European countries (Italy, France, Germany, Spain, and the Netherlands) and followed a common methodology developed by an international committee, ensuring consistent data collection and analysis. The MAIDS methodology is comprehensive and multidisciplinary, including on-scene accident investigation, detailed data on human factors, environmental conditions, and vehicle characteristics. The data collected encompassed over 2000 variables per accident, covering accident typology, mechanical factors, and injury analysis. Additionally, the project included a concurrent exposure study that involved interviewing motorcyclists at petrol stations, allowing researchers to compare accident data with exposure data. A total of 921 accidents were investigated in depth, with over 900 control cases analysed. The findings from MAIDS highlighted key risk factors for motorcycle accidents, such as collision with other vehicles at intersections, and common injury patterns, supporting the development of targeted safety measures. The project also introduced stringent quality control processes to ensure data accuracy and harmonization across countries, with both internal and external review mechanisms. Through its standardized approach, the MAIDS project has significantly contributed to the body of knowledge on motorcycle safety in Europe, providing a basis for developing evidence-based countermeasures (ACEM, 2003).

2.2.3. A comparison of National and In-depth Data Sets

National road crash databases provide crucial data for understanding road safety challenges, guiding policy decisions, and designing effective prevention programs. Central to these datasets are accurate crash locations, descriptive narratives, and detailed classification information, as well as data related to the road, the vehicle, and the individuals involved. Together, these elements offer a comprehensive picture of each road crash. The integration of these data components underscores the essential role of crash databases in advancing road safety, despite variations in data collection methods. Robust crash data enables researchers and policymakers to develop more effective safety interventions, contributing to a reduction in road traffic incidents globally.

In contrast, in-depth datasets provide a more detailed examination of road traffic crashes, incorporating a multitude of variables that facilitate a deeper understanding of the underlying patterns and causal relationships. These datasets may include factors such as weather conditions, driver behaviour, and vehicle specifications, which are often absent in national datasets. By employing advanced statistical techniques and methodologies, in-depth datasets allow to uncover correlations and trends that inform more nuanced safety measures. The richness of this data provides valuable insights that can enhance the efficacy of prevention programmes and targeted interventions.

Later, a comparative analysis of national and in-depth road traffic datasets, classified according to the aforementioned categories, will be presented.

Crash Related Information from national and in-depth data sets

- **Crash location** - The accurate collection of crash location data is crucial for identifying road safety problems, designing effective prevention programs, evaluating engineering interventions, creating detailed crash maps, and linking data across different databases. However, this data element can also be the most challenging and complex to collect. The EU CADaS system uses GPS coordinates to record the location of a crash. This approach leads, in some cases, to incorrect location data. One potential source of error when a GPS unit is used includes blockage or reflection of satellite signals by tall buildings. Despite this challenge, all major crash databases recognize the importance of crash location and utilize GPS coordinates. MMUCC and ARSO use route names, GPS coordinates, and LRS (linear reference system) to ensure accurate and consistent reporting. In the context of an in-depth crash investigation program, the utility of crash location data becomes even more pronounced. Accurate crash location information is pivotal for a comprehensive analysis of traffic crashes, as it enables to pinpoint the exact geographic context in which crashes occur. This allows for the identification of high-risk locations or patterns that may not be evident from a broader national dataset.

- **Crash Narrative** - The crash narrative, which provides a detailed description of the events leading up to the crash, is a crucial component of police reports and is valuable for both crash classification and identifying contributory factors. While tabular-structured data provide essential information, the narrative text contains critical details that cannot be found in structured data alone. To extract useful information from narratives, text-mining techniques can be employed to identify patterns and crash contributory factors. In contrast, in the US, MMUCC crash database have allowed users to search text within police reports. However, the EU CADaS and ARSO currently do not require the inclusion of narratives in crash databases, which may limit the potential for identifying important contributing factors which cannot be found in structured tabular data of the database either. The crash narrative is essential in in-depth crash investigation programs, particularly during the crash reconstruction process. By providing detailed accounts of events leading to a crash, narratives enrich the data with qualitative insights that structured data cannot capture. They allow investigators to correlate physical evidence with the actions of individuals involved, enhancing the accuracy of incident reconstructions. Additionally, narratives highlight contributory factors such as driver behaviour and environmental conditions that may not be reflected in quantitative data. Ultimately, integrating crash narratives into the reconstruction process fosters a more comprehensive understanding of road traffic incidents, leading to informed safety interventions and strategies.
- **Crash Classification** - The classification and description of crashes represent a key distinction among various crash databases, as illustrated in Table 1. To implement effective road safety improvements, it is crucial to consider the multiple factors that contribute to crashes. The U.S. MMUCC system acknowledges this complexity by examining multiple events leading up to a crash, including vehicle direction and manoeuvres. In contrast, the ARSO and the European Union's CADaS primarily classify crashes based on collision type and vehicle manoeuvres, recording only the first event and thus missing the full chain of actions that lead to a crash. Despite these differences, there is consistency across databases in how collision types are defined. Categorizing crashes based on collision types and contributing circumstances allows for the identification of specific causes related to different crash types, such as driver inattention in rear-end collisions or failure to yield at intersections. This classification further facilitates the examination of injury profiles, as different crash types often result in varying severities of injuries. Ultimately, crash classification offers a structured framework for understanding the complexities of traffic incidents, enabling targeted prevention strategies and informed policy decisions aimed at enhancing road safety and reducing injury risks.

Table 1 Summary of Crash Information in the National data sets

Variable	EU CADaS	US. MMUCC	ARSO
Crash location	GPS coordinates	Highway name &Linear referencing. GPS-GIS coordinates	Route name &Linear referencing. GPS-GIS coordinates
Crash narrative	No	Alternatively used	No
Crash sketch	No	Yes	No
Crash type	Yes	All the events are recorded in the traffic unit section	Yes
Collision type	Yes	8 descriptors	Yes
1st harmful event	only the 1st event is recorded	Non collision (8), Collision (9), and Collision with fixed object (21) descriptors	No
Contributing Circumstances	No	Environmental circumstances (6 descriptors, 3 subfields), road circumstances (11 descriptors,3 subfields)	No
Weather condition	7 descriptors	10 descriptors	8 descriptors
Light condition	6 descriptors	7 descriptors	6 descriptors
Reported crashes	Only injury crashes	All severities including	Only injury crashes
Property Damage Only	Not reported	Damage >= $1,000	Not reported
Number of non-fatal injury levels	2	4	2
Definition of non-fatal injury levels	**Serious**: hospitalized for more than 24 hrs. **Slight**: hospitalized for less 24 hrs.	(A) Suspected Serious Injury (B) Suspected Minor Injury (C) Possible Injury (O) Property Damage-Only	**Serious**: hospitalized for more than 24 hrs. **Slight**: hospitalized for less 24 hrs.
Fatalities	Died within 30 days	Died within 30 days	Died within 30 days

Road, Vehicle, and Person-Related Information from national and in-depth data sets

- **Road-related information** – The databases show a high level of consistency in the road-related information they collect, as demonstrated in Table 2. However, the U.S. MMUCC database includes a particularly valuable variable, "Road-related contributing circumstances," which can reveal underlying causes of crashes not immediately evident from other structured data elements. This variable provides crucial insights into the factors influencing crash occurrence on roadways, making it a significant asset for researchers and policymakers. By incorporating this information, MMUCC enables a more comprehensive understanding of road-related crash factors and supports the development of targeted road safety improvements. Road-related information plays a central role in analysing crash causes and severity. Key data points, such as road type, curvature, gradient, surface conditions, and visibility, directly impact driver behaviour and vehicle dynamics, influencing both crash likelihood and injury outcomes. Road characteristics can also create risky conditions that contribute to crash causation.
- **Vehicle–Related Information** - Among all examined databases, the U.S. MMUCC recommendations for traffic unit data are the most comprehensive. These data elements capture not only the sequence of events leading up to and during a crash but also identify the most severe event, providing a detailed understanding of crash dynamics that can inform more effective safety measures. Additionally, the MMUCC includes a key variable, "Vehicle contributing factors," which aids in identifying crash causes related to vehicle status and defects. This information is particularly valuable for pinpointing potential safety issues in specific vehicle models or components and guiding targeted vehicle safety interventions. Vehicle-related data—such as type, age, weight, safety features, and maintenance status—provides essential context for assessing a crash's dynamics and identifying contributing factors. In crash reconstruction, these details allow analysts to evaluate how specific features, like braking capacity, stability control, or crash avoidance systems, might have influenced the event. For example, knowing whether a vehicle had anti-lock brakes or lane-keeping assistance helps reconstruct scenarios where these systems could have altered the crash outcome
- **Person–Related Information** - The U.S. databases contain extensive person-related data, including the injury status of all individuals and detailed actions of drivers and pedestrians, while the EU CADaS and ARSO databases capture fewer person-related elements than the MMUCC. The MMUCC emphasizes recording driver actions at the time of the crash, identifying up to four actions per driver, and has introduced a field specifically for speeding-related behaviour due to its impact on crash rates. Person-related information is crucial in crash reconstruction and cause analysis, providing insights into human factors that may have influenced the incident. This data includes characteristics such as age, gender, experience, physical condition, and behaviours (e.g., alcohol use, seatbelt use, or distraction). In reconstruction, these details help assess reaction times, decision-making, and manoeuvres, while seatbelt and helmet data inform injury severity and protective measure effectiveness. In cause analysis, person-related data identifies behavioural risk factors linked to certain crash types. Younger drivers may be more involved in high-speed collisions, while older drivers may

struggle with incidents requiring quick responses. Data on impairment or distraction highlights risky behaviours, supporting targeted interventions to improve road safety.

Table 2 Summary of Road, Vehicle, and Person-Related Information in National data sets.

Variable	EU CADaS	US. MMUCC	ARSO
Crash site pictures	No	No	No
Contributing circumstances	No	Road—11 descriptors with 3 subfields Motor vehicle—14 descriptors with 2 subfields	No
Speed limit	Yes	Yes	Yes
Work zone related	Yes	Yes (5 subfields)	No
Surface conditions	6 descriptors	10 descriptors	6 descriptors
Relation to junction or interchange	7 descriptors	11 descriptors	7 descriptors
Road curve	Yes	Yes (3 subfields)	Yes
Road segment grade	Yes	Yes	Yes
Traffic unit type	Yes	18 descriptors	Yes
Traffic unit manoeuvre	Yes	14 descriptors	Yes
Sequence of events	No	Non collision (16), collision (9), and collision with fixed object (21) descriptors (4 subfields)	No
Most harmful event	No	Non collision (8), collision (9), and collision with fixed object (21) descriptors	No
Age	Date of birth	Date of birth	Date of birth
Gender	Yes	Yes	Yes
Nationality	Yes	No	Yes
Injury status	4 descriptors	5 descriptors	4 descriptors
Driver action at time of crash	No	19 descriptors (4 subfields)	No
Pedestrian action prior to crash	No	11 descriptors	No
Pedestrian location at time of crash	5 descriptors	13 descriptors	5 descriptors
Violation codes	No	Yes	No
Alcohol level	Yes	Yes	Yes
Drug test results	Yes	Yes	Yes
Safety equipment	Yes	Yes	Yes
Seating position	Yes	Yes	Yes

2.2.4. Summary of the comparison of national and in-depth data sets

The MMUCC recommendations for traffic unit data are more comprehensive and detailed compared to the EU CADaS and ARSO, containing a larger number of variables and attributes that capture a more complete picture of crash events and their contributing factors. However, the CADaS focuses on recording the most critical variables that are necessary to establish the causes and outcomes of a crash. The ARSO database is derived from the CADaS database and shares similarities in terms of variable descriptions, data level, and values. However, it differs from CADaS in that it contains fewer datasets and variables. In essence, ARSO can be considered a scaled-down version of CADaS, hence its name "Mini CADaS." Despite their differences, both CADaS and MMUCC databases have their strengths. The MMUCC recommendations could serve as a valuable reference for other crash databases seeking to improve their data elements. Furthermore, although the MMUCC is more comprehensive, it includes some redundant variables that evaluate certain parameters directly without cross-referencing to other crash elements in the database. This can lead to challenges in capturing all the necessary data (77 variables) at the crash scene. On the other hand, CADaS has a smaller number of data elements that can be efficiently and uniformly collected to investigate crashes in-depth. Thus, CADaS can also serve as a guide for defining the minimum in-depth database structures necessary for different countries to establish a comprehensive picture of crash events. From the perspective of in-depth datasets, there is considerable variation in the number of variables collected per case. To cite one example, the iGLAD database comprises just over 100 variables (124), whereas the GIDAS database collects over 2,500 variables per case. Nevertheless, an examination of the primary databases, their codebooks, and data collection procedures does not yield any definitive guidelines for the development of this specific type of dataset. It thus seems reasonable to conclude that the iGLAD dataset represents the minimum level of detail, whereas the one developed in the DaCoTA project represents the maximum. It should be noted, however, that there is no definitive upper limit, as the number of variables is contingent upon the specific objectives of the research and the available economic resources. As at national level, in-depth datasets are typically divided into four categories: accident, road, vehicle and person.

The primary challenge, however, lies in the number of variables that are actually collected, rather than in those that can be stored. It would be illogical to have a database with the capacity to store thousands of variables while the investigation team is only able to collect a few dozen. In light of these considerations, the international iGLAD dataset seems to represent the optimal compromise for the development of a minimum data set that can be defined as both in-depth and suitable for a meaningful international comparison of results (Table 3).

Table 3 Comparison of national and in-depth road crash datasets.

	National (police-reported) crash data				In-depth crash data						
	CADaS EU	MMUCC US	ARSO AFRICA	Mini ARSO AFRICA	IGLAD	DaCoTA	GIDAS	CIREN	InSAFE	RASSI	MAIDS
Crash-related	13	18	9	8	21	66	-	-	230	-	-
Road-related	25	15	9	9	4	125	-	-	150	-	-
Vehicle-related	18	36	11	4	58	835	-	-	660	-	-
Person-related	21	40	18	4	41	234	-	-	360	-	-
Total	**77**	**109**	**47**	**25**	**124**	**1260**	**2500+**	**1000+**	**1400**	**400+**	**2000+**

2.2.5. Type of variables in the minimum data structure

The variables included in the minimum data structure of an in-depth crash database vary depending on the specific objectives, scope, and level of detail in different databases. It is accepted that more variables and values may be necessary to better describe and analyse a road crash phenomenon than is provided in the minimum set of data elements. Flexibility in the set of data elements makes it possible for countries to add more when it is necessary (Martensen et al., 2021).

The criteria utilized in CADaS for selecting data variables and values serve as valuable references in defining the criteria for selecting data variables and values in this specific data structure. Along with this, common accident data collection databases in Africa adapted the criteria in CADaS to an applicable context, for defining the minimum data elements included in the data system (Thomas et al., 2019). Accordingly, by adapting the criteria in CADaS, the following selection criteria are used for defining the minimum data elements to ensure that the chosen variables and values align with the needs and objectives of this project.

- Data elements and values must be useful for road crash analysis at both national and international levels. These elements should be routinely collected when a road crash occurs.
- The level of detail of the variables and values corresponds to all data useful for macroscopic data analysis and for a detailed reconstruction of the scene of the crash (in-depth analysis).
- Data elements and values should be comprehensive and concise. Each variable must include description and scope (importance to road safety) attribute values, their definitions, and the data format.

- All variables and values refer to casualty road crashes, i.e., all road crashes involving at least one moving vehicle and one person injured or killed as a consequence of this crash. Not-injured participants in an injury crash can optionally be recorded. Material damage-only crashes are not considered.

The data structure has the following four categories:

- Crash-related variables
- Road-related variables
- Vehicle-related variables
- Person-related variables

These variables will be discussed further in detail in section 4.1 of this report.

2.3 TOOLS FOR CRASH INVESTIGATION AND DATA COLLECTION

2.3.1 Crash investigation tools

This section is dedicated to exploring the different tools used for crash investigation. Initially, a brief overview of each tool will be provided. Afterwards, the U.S. Department of Transport's research from 2015 will be used to rate the technology (James, 2015). To conduct their research, the department analysed information available on the internet and solicited feedback from traffic crash reconstructionist, professional organizations, and equipment vendors. Surveys were also administered to reconstruction professionals to gather information on how they utilized technology in their work. These practices varied from simple to technically complex. The technologies were rated in several areas including cost of ownership, availability, amount of training required, retraining to continue certification, setup and takedown, opportunities for enhancement, and court acceptability. The rating system used a range of 1 to 5, with 1 being the lowest score and 5 being the highest score. For areas of technology that the experts had little to no experience, a score of not applicable (N/A) was used. The scores in the tables were determined by multiplying the number of responses in each category by the rating scale. The data was further refined by converting the results to percentages, allowing for an examination of which tools received the highest scores across all categories from the experts in the field. It is important to note that the values in the tables were intended to provide a comparison of expert responses in each category, and the percentages in each row add up to 100%.

The following criteria were used to rate the technologies:

- **Cost of Ownership**: This category considers the cost of the technology versus its benefit to the collection of prosecutorial information. A score of 1 indicates high cost and low benefit, while a score of 5 indicates low cost and high benefit.

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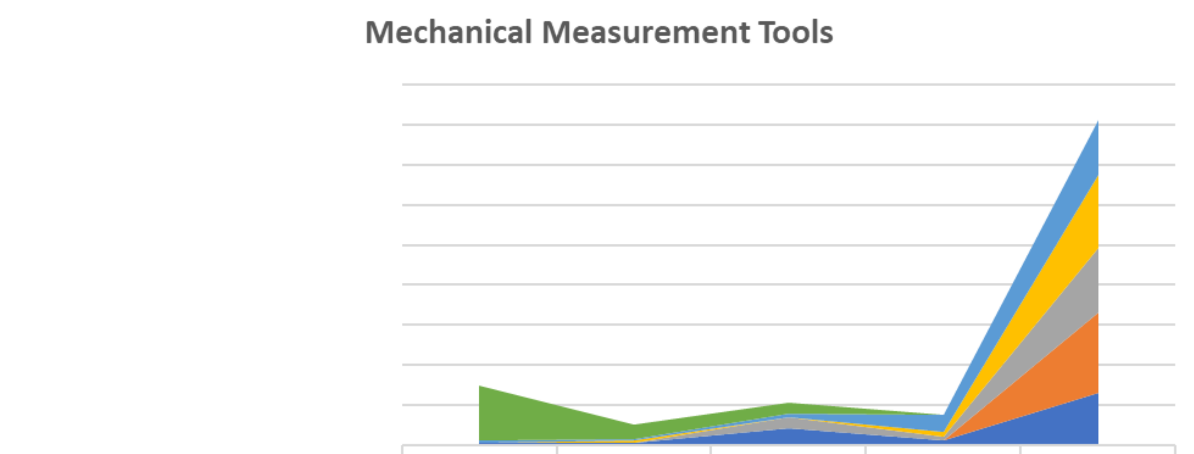
- **Availability**: This category determines whether the technology is available for all crash investigation teams in a jurisdiction. A score of 1 indicates no availability, while a score of 5 indicates always available.
- **Amount of Training Required for Usage**: This category rates the amount of training required to use the technology and attain certification. A score of 1 indicates a burdensome amount of training, while a score of 5 indicates little amount of training required.
- **Retraining to Continue Certification**: This category assesses how often retraining is required to maintain certification on the technology. A score of 1 indicates monthly retraining, while a score of 5 indicates annual or longer retraining.
- **Setup and Takedown**: This category measures the time required to set up the equipment and store it for future use. A score of 1 indicates a long setup/takedown time, while a score of 5 indicates a short setup/takedown time.
- **Opportunities for Enhancement**: This category evaluates whether the technology accommodates future enhancement. A score of 1 indicates no future enhancements, while a score of 5 indicates a high number of enhancements.

Mechanical Measurement Tools

The use of mechanical measurement tools in traffic crash investigations is a common practice. These tools consist of a measuring tape, a rolling measuring device, or a combination of the two. A carpenter's level is also often employed to determine the grade(s) of the roadways, providing highly accurate results when used properly by well-trained investigators. To create a diagram of the crash scene, additional equipment such as a protractor, compass, and various types of curves are required. These tools are used to record baseline measurements at the crash scene and are straightforward to use with minimal training. However, accuracy can be difficult to attain on curved roadways, and manual recording is subject to human error (James, 2015).

Basic instruction, which usually takes 4-6 hours, is sufficient for investigators to create a basic diagram of the crash scene using mechanical measuring tools. Additional training is required for more complex crash investigations, with recognized entry-level courses varying from a few hours to over 40 hours, and advanced courses ranging from 40 hours to 80 hours.

While these tools can provide highly accurate results, their use increases the exposure of officers and investigators to the dangers of traffic and extends roadway clearance time. Furthermore, obtaining accurate measurements on curved roadways and roadways with significant changes in elevation can be difficult. Reviewers have raised concerns about the safety of personnel required to take measurements close to the roadway evidence, and the time required to make each measurement, which is longer than other methods. The value of prosecutorial information also depends on the level of accuracy needed, which is generally lower than other options available. Finally, the use of mechanical measuring tools can be slow and prone to error, although the information collected can be considered reliable. Sharing information collected with these tools is difficult unless it is populated into a computer program for later use.



	1	2	3	4	5
Opportunities for Enhancements	68%	18%	14%	0%	0%
Set Up and Takedown	3%	3%	4%	22%	68%
Retraining to Continue Certification	0%	3%	0%	6%	91%
Amount of Training	0%	0%	14%	5%	81%
Availability	1%	0%	0%	0%	99%
Cost of Ownership	3%	3%	22%	6%	66%

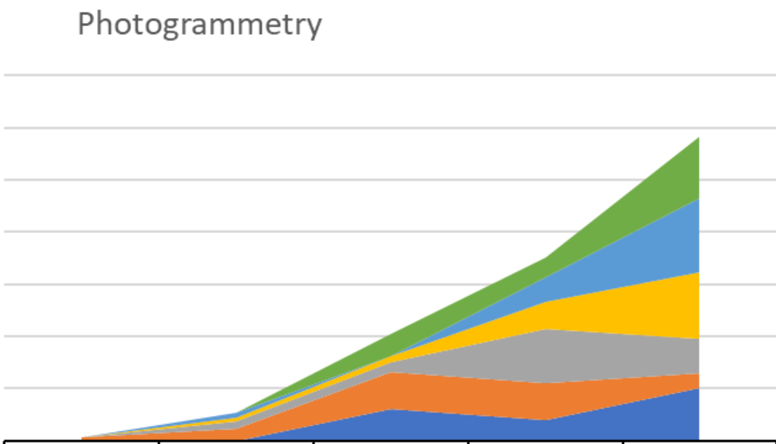
Figure 1 Mechanical Measurement Tools.

Photogrammetry

To capture points of evidence, the investigator acquires sufficient photographs of the objects of interest, with each point of evidence ideally observed in at least 3 images from different perspective viewpoints to support accurate measurements. 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 (James, 2015)

Training to become proficient in the use of photogrammetry is recommended for at least three days, which is less extensive than the training necessary for the Electronic Total Station. To maintain proficiency and court acceptance, the investigator must use the photogrammetry system. While someone who is not familiar with photogrammetry or evidence identification can take the photographs, the use of photogrammetry software to process the data requires the investigator be familiar with the process and be proficient.

Photogrammetry can aid in the quick clearance of traffic crashes, with digital cameras being more readily available and accessible than other types of technology. However, photogrammetry is limited by weather conditions, and the investigator must be able to see the evidence measured. While the at-scene time may be reduced by using photogrammetry, the processing of the data for 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, but 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.



	1	2	3	4	5
Opportunities for Enhancements	0%	0%	21%	19%	60%
Set Up and Takedown	0%	4%	0%	24%	71%
Retraining to Continue Certification	0%	4%	6%	26%	64%
Amount of Training	0%	6%	10%	52%	32%
Availability	3%	12%	35%	35%	15%
Cost of Ownership	0%	0%	30%	20%	50%

Figure 2 Photogrammetry.

Light Detection And Ranging (LiDAR)

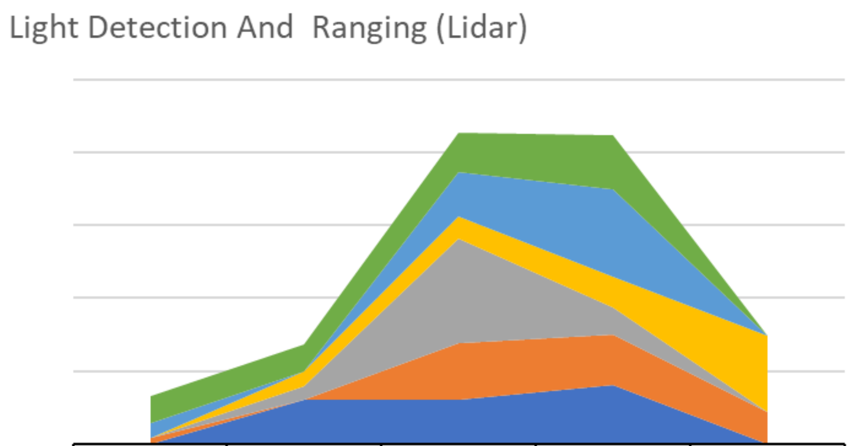
LiDAR systems have been used in traffic crash investigation and reconstruction for some time. They consist of a LiDAR unit and a data collector and use remote sensing technology to measure distances by illuminating the target with a laser and analysing the reflected signal to determine the distance. LiDAR is routinely used by law enforcement as a speed measuring tool, but for traffic crash reconstruction, it is used to measure distance rather than speed (James, 2015).

The use of LiDAR systems in traffic crash reconstruction is complex, and operators must undergo a minimum of 40 hours of basic training, as well as field projects, to maintain their proficiency. The LiDAR can be handheld or tripod-mounted, but tripod-mounted systems are recommended due to the instability introduced by handheld configurations. The unit must be used with a graphic controller to avoid measurement errors.

LiDAR measurements can be captured using a prism, reflectors, or reflector less mode. Reflective mode measurements may require the use of reflectors or prisms, but reflector less mode measurements can be captured without any additional equipment. The reflector less mode can lengthen mapping time as measurements must be timed to be recorded between vehicles while the roadway is open to traffic, but it minimizes personal exposure to traffic.

LiDAR systems may be limited by weather conditions, with rain reducing the effective range. However, they allow for roadway mapping without being in the traffic, reducing possible exposure and improving clearance times for complex scenes. LiDAR also allows for very accurate measurements supporting detailed reports and information sharing with anyone who has compatible software.

Overall, the use of LiDAR systems in traffic crash reconstruction can provide reliable and accurate data, but it requires specialised training and equipment and can be time-consuming. However, it can also improve responder safety and clearance times, making it a valuable tool for accident investigation and reconstruction.



	1	2	3	4	5
Opportunities for Enhancements	18%	18%	27%	36%	0%
Set Up and Takedown	10%	0%	30%	60%	0%
Retraining to Continue Certification	0%	11%	16%	21%	53%
Amount of Training	0%	10%	71%	19%	0%
Availability	4%	0%	39%	35%	22%
Cost of Ownership	0%	30%	30%	40%	0%

Figure 3 Light Detection And Ranging (LiDAR).

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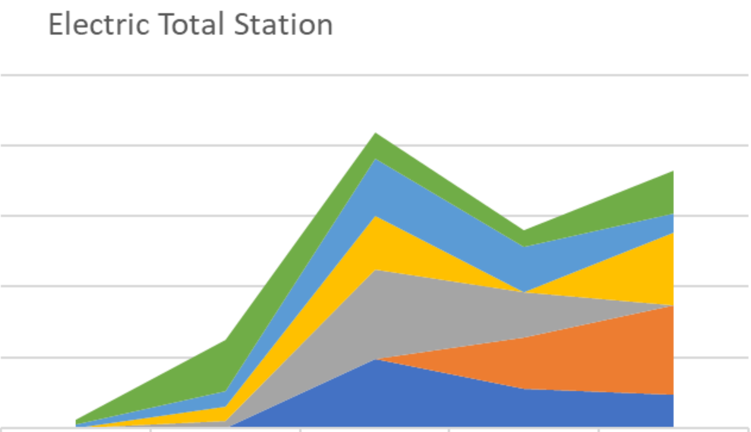
Electronic Total Station

Crash reconstructionist have been using Electronic Total Station (ETS) since the early 1990s to create a map of a crash scene. ETS comprises four components: the theodolite, the Electronic Distance Measurement Instrument (EDM), an optical prism, and a data collector. The theodolite measures horizontal and vertical angles between points, while the EDM measures the slope distance between points. The reflected light from an optical prism is used to capture distance and angles from the theodolite, and this data is combined with graphic attributes recognised by the software to generate an accurate scale map of the scene (James, 2015).

The use of ETS requires much more extensive training than the mechanical measuring process, with a minimum of 40 hours of basic training and field projects. In addition, the operators must use the equipment frequently to maintain proficiency.

Although the data collected using ETS is very precise, its use increases the exposure of officers and investigators to the dangers of traffic. The measurements must be obtained with the use of an optical prism located directly over the evidence to document or map, and this process can be slow depending upon the intricacy of the accident site and the skill level of the personnel operating the equipment.

However, the use of ETS reduces exposure to traffic when compared to manual measurement means and reduces risk to investigators, thereby reducing on-scene crash investigation time. 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. The data format is also easily shared between parties, although it is somewhat dependent on the knowledge of the individual storing the data.



	1	2	3	4	5
Opportunities for Enhancements	3%	36%	18%	12%	30%
Set Up and Takedown	3%	11%	41%	32%	14%
Retraining to Continue Certification	0%	10%	38%	0%	51%
Amount of Training	0%	5%	63%	32%	0%
Availability	0%	0%	0%	36%	64%
Cost of Ownership	0%	0%	49%	28%	23%

Figure 4 Electronic Total Station.

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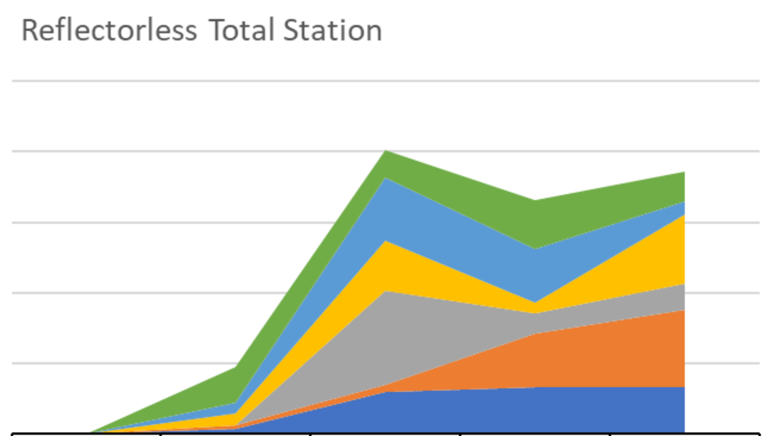
Reflectorless Total Station

The Reflector less Electronic Total Station is a variation of the Electronic Total Station that has been in use for crash scene reconstruction in the United States since around 2001. It has four components, including the theodolite, EDM, an optical prism, and a data collector. The Reflector less version has the added functionality of reflector less measurements up to 350 meters or 1150 feet, making it a more efficient and safer tool for gathering data (James, 2015). The theodolite is a precise instrument that measures horizontal and vertical angles between points, while the EDM measures the slope distance between points. The ETS uses reflected light from an optical prism to capture distance and angles from the theodolite for each point measured, which, combined with graphic attributes recognised by the software, generates an accurate scale map of the scene. The reflector less Total Station adds the ability to record measurements with the EDM without the use of an optical prism, which eliminates the need to hold the prism pole over the point, and the EDM utilises a laser rather than an infrared signal to measure the slope distance. Training on the reflector less Electronic Total Station is more detailed than the mechanical measuring process, and the recommendation for basic training is a minimum of 40 hours. Using the reflector less Electronic Total Station can minimise personal exposure to traffic, as the technician can carefully select the instrument location and record measurements in the reflector less mode, which greatly reduces the exposure risk of officers in the roadway. It also reduces on-scene crash investigation time, allows for quick scene clearance, and prompt and reliable communication of data.

Overall, the reflector less Electronic Total Station is an optimal and reliable measurement device for crash scene reconstruction, making it a great tool for responders to use in minimising their exposure to traffic while also increasing their efficiency and accuracy in gathering data.



	1	2	3	4	5
Opportunities for Enhancements	0%	26%	19%	34%	21%
Set Up and Takedown	0%	8%	45%	38%	9%
Retraining to Continue Certification	0%	8%	35%	8%	49%
Amount of Training	0%	0%	67%	15%	19%
Availability	0%	3%	5%	38%	55%
Cost of Ownership	0%	3%	30%	33%	33%

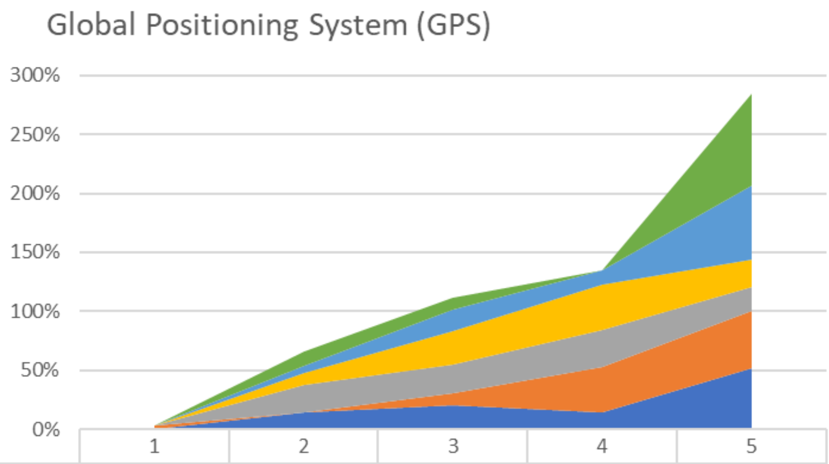
Figure 5 Reflector less Total Station.

Global Positioning System (GPS)

The Global Navigation Satellite Systems (GNSS) are widely used for GPS mapping and traffic crash reconstruction. These systems consist of two units: a rover and a base, which communicate with each other using a Class II Bluetooth connection. The use of GPS Systems for crash reconstruction has become more affordable, and the systems available now are capable of centimetre accuracy when used in the carrier phase GPS mode (James, 2015). However, the use of GPS Systems requires training to become proficient. The recommended basic training is a minimum of 40 hours. Additionally, the introduction of a new Real Time Kinematic (RTK) GPS system has emerged, which offers a pair of GPS antenna (base and rover) that utilise class 1 Bluetooth range. This system requires nearly clear sky above the base and rover antenna but allows for one antenna to serve as the base unit, supporting a multidisciplinary approach to scene documentation.

The use of GPS Systems has positive and negative attributes when it comes to responder safety. While it greatly reduces the time spent on-scene over the reflector less and Robotic Total Stations, the operator can become unaware of the hazards around them when their full attention is given to the operation of the unit. However, set-up time is low, and scenes are cleared more quickly, increasing data collection speed.

It's important to note that communications with satellites are not always possible in some situations such as buildings, terrain, and foliage blocking sight line to satellites. There are also places where it cannot be used due to line-of-sight obstructions. The information gathered from GPS Systems is the same as the Total Stations and has the same ease and restriction on the sharing of the data.



	1	2	3	4	5
Opportunities for Enhancements	0%	13%	9%	0%	78%
Set Up and Takedown	0%	6%	19%	13%	63%
Retraining to Continue Certification	0%	10%	29%	38%	24%
Amount of Training	0%	24%	24%	32%	20%
Availability	3%	0%	10%	39%	48%
Cost of Ownership	0%	14%	21%	14%	52%

Figure 6 Global Positioning System (GPS).

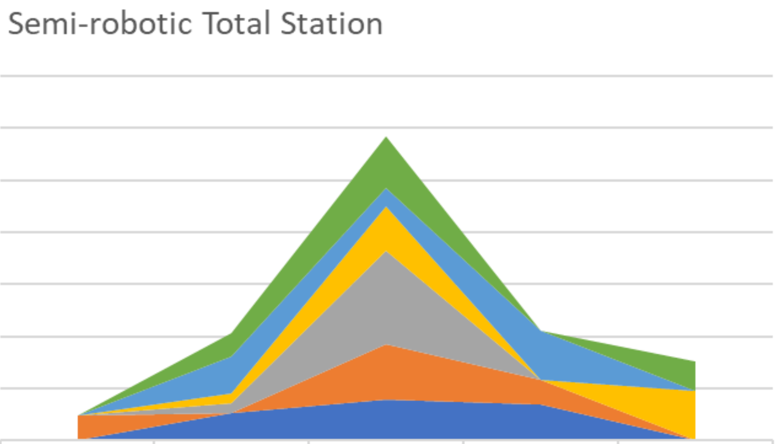
Semi-robotic Total Station

The Semi-Robotic Total Station is a device used in traffic crash reconstruction since the early 2000s. It consists of four components, including a theodolite, an EDM, an optical prism, and a data collector. Unlike its predecessor, the Electronic Total Station and reflector less variant, the Semi-Robotic Total Station does not require mechanical aiming of the EDM at the prism but instead uses a tracking laser to maintain aim automatically and update distance measurements. This feature increases the ability to measure in the reflector less mode to 500 meters or approximately 1640 feet (James, 2015).

The collected data provides attributes recognised by the software and 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 is motorised horizontally and vertically, eliminating the need to focus and aim the station precisely. The use of a Semi-Robotic Total Station requires more complex training than the mechanical measuring process. The recommended basic training necessary is a minimum of 40 hours, not including field projects that should be completed following the basic course.

The Semi-Robotic Total Station provides a safer option for technicians by minimising their personal exposure to traffic. The operator can carefully select the instrument location and record measurements in the reflector less mode. The mapping time may be lengthened as measurements are timed to be recorded between vehicles while the roadway is open to traffic.

However, these measurements are collected while the roadway is open to traffic, minimising the effect on traffic flow. The Semi-Robotic Total Station offers several advantages over other total station instruments, including lower risk and exposure to traffic, reducing the quick clearance time, and prompt, reliable communications. However, the set-up is heavily dependent on the individual operator's expertise in using it. For those properly trained, the 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. The data is easy to share, and information can be shared with anyone who has a compatible program that will communicate with the total station.



	1	2	3	4	5
Opportunities for Enhancements	0%	22%	50%	0%	28%
Set Up and Takedown	0%	35%	18%	47%	0%
Retraining to Continue Certification	0%	10%	43%	0%	48%
Amount of Training	0%	10%	90%	0%	0%
Availability	24%	0%	53%	24%	0%
Cost of Ownership	0%	26%	39%	35%	0%

Figure 7 Reflector less Total Station Semi-robotic total station

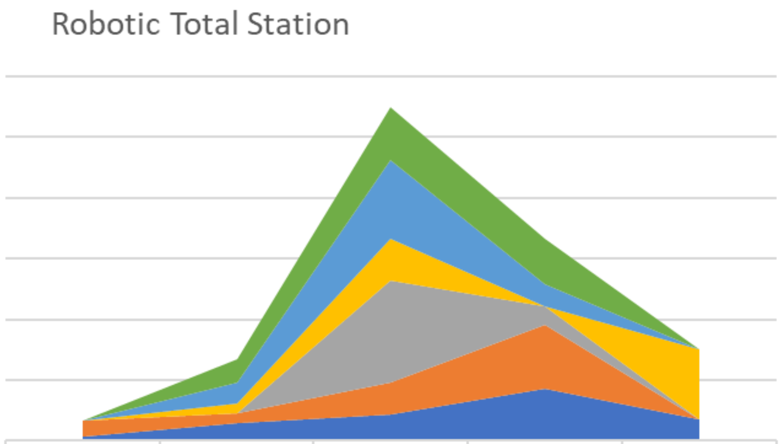
Robotic Total Station

The Robotic Total Station is a variant of the Electronic Total Station that has been used for traffic crash reconstruction since the mid 2000's. It consists of five components: Motorised Theodolite, Electronic Distance Measurement Instrument, Optical Prism, Data Collector, and a Repeater. This instrument eliminates the need to mechanically aim the EDM at the prism and uses surveying principles to create a map of a crash scene. The fully Robotic Total Station provides an added function of auto-tracking the prism via a remote controller, which re-establishes tracking of the prism more efficiently (James, 2015).

The Robotic Total Station increases the ability to measure in the reflector less mode to 100 meters or approximately 3280 feet. The measurement time is reduced since the instrument is constantly measuring and updating the collector. The addition of the repeater provides the option of one person operation at incident scenes. The collected data is given attributes which are recognised by the software, and the data is transferred into diagramming software designed to create a scale map of the scene.

The Robotic Total Station is a complex instrument, and the training is much more involved. The basic training necessary is recommended to be a minimum of 40 hours, and operators must use the equipment frequently to maintain their proficiency. The technician can minimise 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.



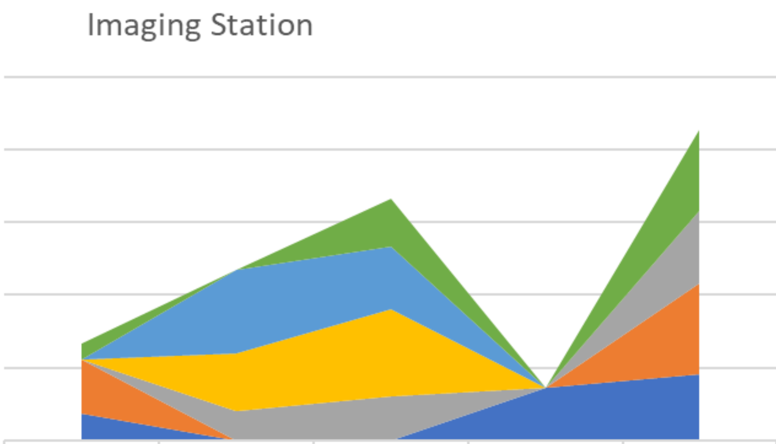
	1	2	3	4	5
Opportunities for Enhancements	0%	19%	43%	38%	0%
Set Up and Takedown	0%	17%	65%	17%	0%
Retraining to Continue Certification	0%	8%	35%	0%	58%
Amount of Training	0%	0%	84%	16%	0%
Availability	13%	9%	26%	52%	0%
Cost of Ownership	4%	14%	21%	43%	18%

Figure 8 Robotic Total Station.

Imaging Station

The Imaging Station is a powerful tool for mapping crash scenes, utilising advanced technology to make the process more efficient and accurate. With its built-in camera and predictive software, it can intelligently scan an area of interest and quickly identify the points that need to be measured to model the observation. The use of a tracking laser and remote controller allows for one-person operation, minimising the exposure of personnel to the dangers of traffic. However, the training required for operating the Imaging Station is more complex than for other variations of the Electronic Total Station, with a minimum of 40 hours of basic training recommended, as well as field projects and frequent use to maintain proficiency (James, 2015).

While the Imaging Station can enhance responder safety and quick clearance of crash scenes, it does require the roadway to be closed during mapping, which can decrease safety. The vast amounts of data gathered by the Imaging Station can be analysed in the future, providing reliable communications and valuable insights for crash reconstruction. Overall, the Imaging Station is a valuable tool for traffic crash reconstruction, allowing for more efficient and accurate mapping of crash scenes while minimising exposure to personnel and minimising the impact on traffic flow.



	1	2	3	4	5
Opportunities for Enhancements	11%	0%	33%	0%	56%
Set Up and Takedown	0%	57%	43%	0%	0%
Retraining to Continue Certification	0%	40%	60%	0%	0%
Amount of Training	0%	20%	30%	0%	50%
Availability	38%	0%	0%	0%	63%
Cost of Ownership	18%	0%	0%	36%	45%

Figure 9 Imaging Station

Three-dimensional (3-D) Laser Scanning

A 3-D Laser Scanner is a device used in traffic crash reconstruction that consists of a phase shift, a time-of-flight laser measuring device, or both. The scanner is placed on a tripod and, while rotating horizontally, spins a mirror vertically to make measurements by indiscriminately distributing a laser beam. The scanner captures what is in the line of sight and allows for operation by one person, reducing the number of personnel exposed to the dangers of traffic. The device can record as many as a million measurements per second and is equipped with a high-definition digital camera to accurately document the crash scene (James, 2015).

The 3-D Laser Scanner produces a point cloud, which is a large amount of data that needs to be analysed to determine where, for example, a curb transitions into the roadway surface. The end product is a photo-like product that can be imported into computer-aided diagramming software. The collected data enables the investigator to observe the crash scene from various perspectives within the scan.

Specialised training is necessary to become proficient in the use of the 3-D Laser Scanner. Law enforcement investigators recommend a minimum of 40 hours of training to become proficient in the use of the software and equipment, including basic training and application in traffic crash reconstruction.

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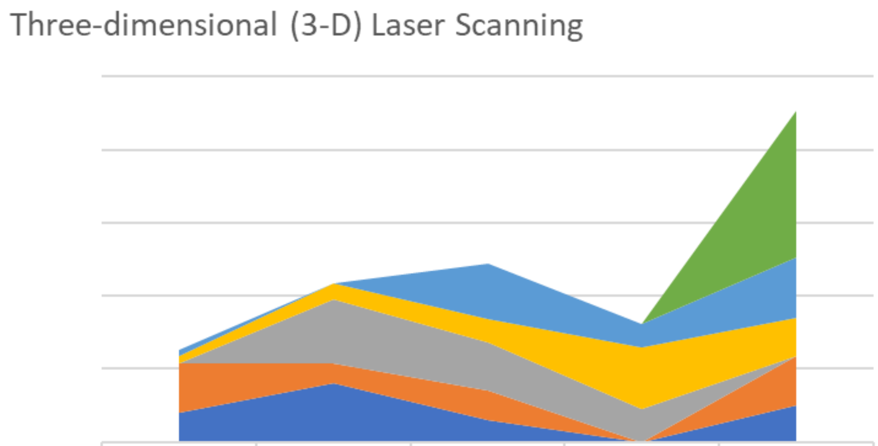

	1	2	3	4	5
Opportunities for Enhancements	0%	0%	0%	0%	100%
Set Up and Takedown	4%	0%	38%	17%	42%
Retraining to Continue Certification	5%	11%	16%	42%	26%
Amount of Training	0%	44%	33%	22%	0%
Availability	33%	13%	20%	0%	33%
Cost of Ownership	20%	40%	15%	0%	25%

Figure 10 Three-dimensional (3-D) Laser Scanning

Unmanned Aerial Devices

The use of Unmanned Aerial Systems (UAS) is gaining acceptance in the field of traffic crash reconstruction. UAS is a remotely piloted aircraft carrying a precision high-definition camera. It is designed to fly under 400 feet Above Ground Level (AGL) and is gaining popularity due to its ability to reduce the time needed for crash scene investigation, decrease risks to responders, and improve responder safety (James, 2015).

The aircraft is designed to be reliable and maintainable by the user in compliance with accepted practices. A UAS uses a programmed Ground Control Point (GCP) or RTK GPS flight path, and the area of interest is identified on an online, live map. The flight path is calculated for current wind conditions for the most efficient flight path, and safety measures are included, such as maintaining line of sight by a trained observer and the pilot utilising a ground control station.

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. The camera's gimbal mount provides assurance for stable geo-referenced photographs, and each photograph is recorded and geo-tagged with precision measurements obtained by the on-board RTK GPS.

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. In the United States the use of UAS is regulated by the Federal Aviation Administration (FAA), and the final operating rules will require more training than is now

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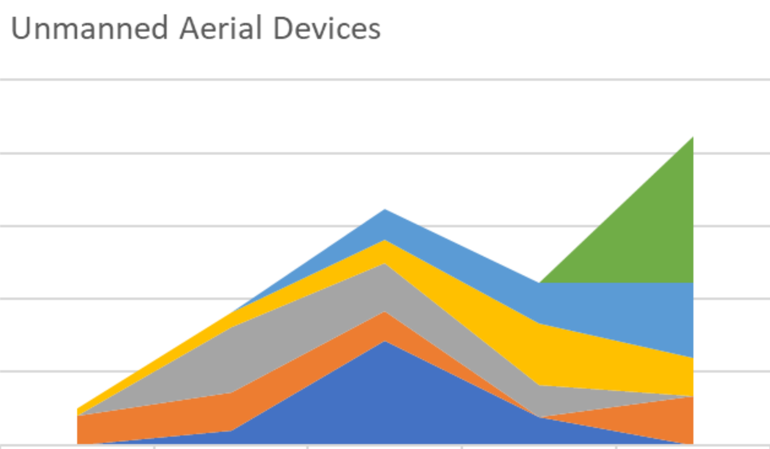
required to become proficient with other types of technology given the aerial aspect of utilising the National Air Space to achieve the NUG and TIM goals.

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 use of UAS will reduce the time needed for crash scene investigation. Mapping can usually be completed in a matter of minutes, and these systems allow the crash scene to be mapped without personnel in the roadway exposed to the dangers of traffic.

The use of UAS 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 UAS 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.

In summary, the use of Unmanned Aerial Systems is gaining acceptance in the field of traffic crash reconstruction due to its ability to reduce on-scene time, decrease risks to responders, and improve responder safety. The FAA continues to evaluate the integration of UAS into the national air space system, and efforts are underway to revise the requirements for operation, with changes constantly monitored.



	1	2	3	4	5
Opportunities for Enhancements	0%	0%	0%	0%	100%
Set Up and Takedown	0%	0%	21%	28%	52%
Retraining to Continue Certification	5%	11%	16%	42%	26%
Amount of Training	0%	44%	33%	22%	0%
Availability	20%	27%	20%	0%	33%
Cost of Ownership	0%	10%	71%	19%	0%

Figure 11 Unmanned Aerial Systems.

Hybrid Total Station

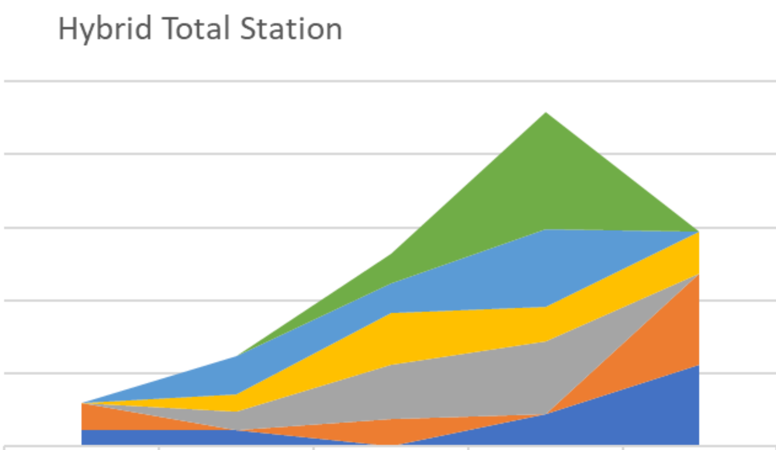
The Total Station Hybrid is a type of Electronic Total Station that combines the functionality of a Robotic Total Station with RTK GPS technology. It is composed of seven components: the motorised theodolite, EDM, optical prism, data collector, a repeater, a GPS antenna, and a data pack (James, 2015).

The Total Station Hybrid uses polar coordinate measuring on all three axes assisted by RTK GPS, which operates more accurately than other GPS technologies such as Assisted GPS (AGPS), Differential GPS (DGPS), and Wide Area Augmentation System (WAAS).

One of the main advantages of the Total Station Hybrid is that it supports one-person operation and beyond line-of-sight measurements, which is not possible with traditional Electronic Total Stations that are capable of line-of-sight measurements only. The robotic functionality eliminates the need to mechanically aim the EDM at the prism, and the Total Station Hybrid provides the function of auto-tracking the prism via a remote controller, which eliminates the need to manually aim the station at the prism and return to a prism lock status.

Another advantage of the Total Station Hybrid is its reflector less mode, which allows the instrument to measure distances up to 1000 meters or approximately 3280 feet without the use of an optical prism. Additionally, the Total Station Hybrid is motorised to rotate horizontally and vertically, and the added functionality of the RTK GPS provides the ability to measure evidence points beyond line of sight of the station.

The data collected by the Total Station Hybrid is used to create a scale map of the crash scene, which can be used in mathematical formulas to reconstruct the crash. However, the Total Station Hybrid is more complex than other Electronic Total Stations, and operators must undergo a minimum of 40 hours of basic training, complete field projects.



	1	2	3	4	5
Opportunities for Enhancements	0%	0%	20%	80%	0%
Set Up and Takedown	0%	27%	20%	53%	0%
Retraining to Continue Certification	0%	12%	35%	24%	29%
Amount of Training	0%	13%	38%	50%	0%
Availability	19%	0%	19%	0%	63%
Cost of Ownership	11%	11%	0%	22%	56%

Figure 12 Hybrid Total Station.

Smartphone LIDAR Scanner

In the current consumer technology landscape, smartphones have become an essential device in daily life, offering features beyond communication. Depth sensors such as LiDAR scanners for iOS devices and time-of-flight depth cameras (ToF cameras) for Android have emerged as powerful tools with transformative potential. Initially used to enhance photography and augmented reality, these sensors have found new applications in scientific exploration.

Android smartphones were among the first to introduce depth sensors and augmented reality applications with the Lenovo Phab 2 Pro launch in 2016. The Tango Project, championed by Google, played a critical role in this revolution by using depth sensing, motion mapping, and area learning technologies to pave the way for augmented reality on Android smartphones. Although ARCore eventually replaced this project, it marked a significant milestone in the evolution of smartphones.

In 2020, Apple released its LiDAR-equipped iPad Pro 2020 and iPhone 12 Pro, signalling a new smartphone depth sensor field era. These devices have been instrumental in scanning and modelling indoor and outdoor environments, catalysing research and innovation.

Costantino et al., (2022) recently conducted a study to evaluate smartphone depth sensors. The research methodology comprised two phases. In Phase 1, the team conducted 3D LiDAR surveys using smartphone depth sensors, specifically the ToF camera for Android and the LiDAR scanner for iOS. These surveys aimed to capture 3D point clouds of various objects. Tailored applications, 3D Live

Scanner Pro for Android and 3D Scanner App™ for iOS, were used to execute these scans, offering variable resolutions: 2 cm for the Huawei P30 Pro, 1.5 cm for the iPhone 12 Pro, and 1 cm for the iPad 2021 Pro.

Phase 2 involved segmenting the acquired point clouds to isolate the scanned objects. The team used mathematical descriptors to gauge the quality of the 3D models and visual analysis to identify any anomalies within the point clouds. For this purpose, the CloudCompare software emerged as a potent tool for data analysis.

The study delved into the outcome of an exhaustive evaluation of the performance of smartphone depth sensors, encompassing ToF cameras and LiDAR, across Android (Huawei P30 Pro) and iOS (iPhone 12 Pro and iPad 2021 Pro) devices in constructing precise 3D point clouds. The quality of these point clouds was assessed via visual analysis and the application of three key eigenfeatures: surface variation, planarity, and omni variance. Several challenges inherent to smartphone-generated point clouds were exposed, including surface splitting, loss of planarity, and inertial navigation system drift issues. The research found that the accuracy achievable from such scanning operations typically falls within the 1-3 cm range, assuming the absence of significant scanning problems.

The study's results were categorized into laboratory and field tests in real-world conditions. Notably, the paper dedicates substantial attention to the outstanding point clouds produced by iOS devices, namely the iPhone 12 Pro and the iPad 2021 Pro. The paper recognizes the scarcity of depth sensors in the smartphone market as a significant hurdle but anticipates that market demands will fuel rapid advancements in this technology in the coming years.

This study emphasises the immense potential of smartphone depth sensors, such as ToF cameras and LiDAR, as invaluable tools for scanning objects and urban environments. These devices offer several advantages, including their lightweight and portable nature, ensuring that a scanning tool is always at one's disposal, and the ease of sharing generated models with others.

Looking to the future, the potential of scaling up to capture larger structures and the need to develop new applications capable of handling more complex scenarios. The journey of smartphone depth sensors in 3D scanning and modelling has just begun, promising a transformative path.

Looking at a practical example, Recon-3D is an innovative iPhone application that uses LiDAR scanning technology to capture precise 3D data tailored for forensic applications. Similar apps in the market provide aesthetically pleasing 3D models, but Recon-3D distinguishes itself with its unwavering commitment to accuracy. To date, Recon-3D is the most rigorously tested and validated app in its category.

The comprehensive Recon-3D training program is conducted entirely online and spans 4 hours. It equips users with the knowledge and skills to harness the iPhone's LiDAR capabilities and ensure 3D point cloud data accuracy. Upon successful completion of the course, attendees who have actively participated in exercises and completed the final assignment will receive certification as a testament to their acquired expertise.

This app is highly recommended for scanning vehicles, exteriors and interiors, and roads within approximately ±25 meters. Recon-3D generates meticulous point clouds that seamlessly integrate with crash reconstruction software and facilitate the preservation of critical forensic evidence, including deformations, blood traces, the condition of a vehicle's interior, road skid marks, crash points, debris positions, and more. The accuracy level of Recon-3D's point clouds is within ±2 millimetres, making it an invaluable tool for forensic investigations (Recon-3D).

2.3.2. Crash data collection tools

IMAAP Fatal

iMAAP is a modern evolution of MAAP, a software solution distributed by TRL (Transport Research Laboratory) since the 1980s. It is a widely used off-the-shelf crash data system. iMAAP is designed to harmonize with the contemporary technological landscape while addressing the needs of professionals who rely on it for accident analysis. Its primary mission is to mitigate the challenges of road injuries through comprehensive crash data management, analysis, and reporting.

With iMAAP, road safety professionals can conduct in-depth accident data analysis, identifying issues and challenges. This empowers them to set measurable and realistic safety objectives within specific timeframes. iMAAP facilitates the creation of countermeasure programs complete with associated costs and timelines. Professionals can adjust strategies as necessary, and iMAAP offers tools to evaluate the effectiveness of implemented interventions and continuously monitor evolving accident trends.

Critical features of iMAAP include its foundation in cutting-edge technologies, ensuring swift and efficient integration into various client IT environments. The Software is user-friendly, with uniform and intuitive screens to facilitate ease of use. It offers role-based access for multi-users and multi-department scenarios, ideally suited for federal or national-level deployment. It also links seamlessly to various external data sources, including driver's license and vehicle registration databases, road information systems, asset management records, and health injury databases. Furthermore, iMAAP is compatible with multiple database platforms, such as SQL Server, SQL Server Express, PostgreSQL, and Oracle. Its Geographical Information System (GIS) functionality easily handles proprietary and internet mapping formats. The Software ensures configurable access controls for sensitive data, simplifies Stick Diagram analysis, and offers custom accident prediction capabilities through its SafeNet module.

Additionally, a comprehensive audit trail traces all system functions, while enhanced security protocols provide robust protection. iMAAP also boasts media file and photo storage capabilities and is available in Software as a Service (SaaS) mode, making it highly adaptable. With multilingual support and strict compliance with international and regional cloud security regulations, including G-Cloud UK Government Standards, Cyber Essentials Plus Cyber Threat Protection (UK), MeitY India, and ISO 27001, iMAAP is a pioneering solution in accident analysis software systems.

For an even more specialized approach, the iMAAP Fatals Database is available as a secure, in-depth collision investigation platform. iMAAP Fatals Database is an advanced, secure, and tailored collision investigation platform developed by TRL. It is designed to support the principles of a safe systems-based approach to in-depth road safety analysis. The platform is crafted with more than three decades of international collision research and ongoing contributions to in-depth collision research for entities such as the Department for Transport (DfT), Highways England, and Transport for London (TfL), embodying a wealth of knowledge and expertise.

The adoption of iMAAP Fatals is rooted in the platform's capacity to augment existing data sources, including STATS19, and TRL's dedicated Collision Research Team's work. The specialized data capture tool empowers road safety professionals to conduct meticulous investigations into fatal road traffic collisions, transcending superficial analyses. The investigations aim to uncover the fundamental causes of collisions, ultimately yielding actionable safety intelligence.

Distinguished by their vast experience and in-depth knowledge, the Collision Research Team at TRL actively participates in real-time road traffic collision events alongside emergency services. Their approach is fundamentally distinct from law enforcements, as their primary goal is to ascertain the root causes of collisions, rather than apportion blame.

To facilitate a comprehensive understanding of collisions' origins and extract actionable safety insights, the database meticulously records nearly 300 data fields encompassing crucial factors. These include the collision environment, involved vehicles, details about occupants, vehicle movements, vehicle interactions, causation factors, and countermeasures. This structured framework underpins safety analysis and ensures compatibility with future projects of varying scope. It integrates with other in-depth collision programs in the UK, including the Transport Safety Research Centre (TSRC) and the International Road Assessment Programme (iRAP).

ADaMS – Accident Data Management System

ADaMS is a web-based information system for collection, management and analysis of road traffic crash data. It supports activities of entities involved in data collection and treatment, namely:

- National road safety centres. Ministries in charge of road safety and road infrastructures.
- Local authorities.
- Police forces.
- Health services (e.g. hospitals, emergency services, ...).

ADaMS® is a fully web-based software capable of managing a large number of road traffic crashes and of analysing them through GIS formats. Being interfaceable with GPS, it allows for the exact location of road traffic crashes on map. ADaMS, designed to guarantee complex and stringent IT and security standards, so that sensitive data stored into a central database are fully protected. Advanced backup functions eliminate the risk of potential loss of data. It provides advanced features for road traffic crash data collection, storage, management, analysis, and reporting. Its modules are very intuitive and supports all normal activities of usual road safety stakeholders. It has also in-depth data analysis functions (including black-spots, road section analysis).

2.3.3. Benchmark and cost analysis

Table 4 Benchmark and cost analysis

Tool	Cost as per Source
Mechanical Measurement Tools	US DoT Best Practices: • Measuring tape $30 to $50 • Measuring wheel $70 to $120 • Assorted additional equipment $100
Photogrammetry	US DoT Best Practices: • Digital SLR Camera and lens. $1,000 • Photogrammetric markers (40). $500 • Software Basic version. $1,000 • Software Professional version. $2,595 Artec Metrology Kit: • Combined photogrammetry's optical measurement with 3D scanning. Entry $27,400; Professional $42,700.
Light Detection And Ranging (Lidar)	US DoT Best Practices: • Light Detection and Ranging (LiDAR), Angle Encoder, and Software. $7,000
Electronic Total Station	US DoT Best Practices: • $8,000 to $10,000 • (varies widely)
Reflector less Total Station	US DoT Best Practices: • 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
Global Positioning System (GPS)	US DoT Best Practices: • 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
Semi-robotic Total Station	US DoT Best Practices: • 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

Tool	Cost as per Source
Robotic Total Station	US DoT Best Practices: - 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
Imaging Station	US DoT Best Practices: 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
Three-dimensional (3-D) Laser Scanning	US DoT Best Practices: - Three-dimensional (3-D) Laser Scanning. $60,000 to $200,000 - Annual calibration. $5,000 - Artec Metrology Kit: Combined photogrammetry's optical measurement with 3D scanning. Entry $27,400; Professional $42,700.
Unmanned Aerial Devices	US DoT Best Practices: - 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
Hybrid Total Station	US DoT Best Practices: - Theodolite, Electronic Distance Measurement Instrument (EDM),OpticaPrism, 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

2.4 CRASH RECONSTRUCTION TECHNIQUES AND RESULT ASSESSMENT

2.4.1. Crash reconstruction models

There are various mathematical equations useful to investigate a traffic crash and obtain, e.g., the vehicle pre-crash velocity. The physical principles most used are the conservation of momentum and the conservation of energy (Kirk, 2000; Brach., 2005; Brach., 1991; Rose, 2018).

Conservation Of Linear Momentum (COLM) – It can be used to determine the pre-impact speed of the vehicles involved in the crash (v_i), and it is based on the knowledge of the following six parameters: the post-crash vehicles trajectory defined by the angle between the vehicle heading and line passing from the centre of gravity (CoG) of the vehicle at the point of impact (POI) and the point of rest (POR), the post-crash vehicles speed ($\overline{v_i}$), and the pre-crash vehicle's trajectory gained from overlapping damage on vehicles. Its main limitations are due to the assumption that the vehicle's post-crash motion takes place with the wheels blocked and in constant contact with the road surface, and that does not hold for shallow angle collisions, because shallow angle collisions are very sensitive to the preimpact angles.

$$m_1 v_1 + m_2 v_2 = m_1 \overline{v_1} + m_2 \overline{v_2}$$

Conservation of energy – It is frequently used in accident reconstruction to determine the pre-crash vehicle speeds as a function of mechanisms by which the vehicle's initial kinetic energy was dissipated by mechanisms such as crushing, braking, sliding, etc. and states that the total pre-crash kinetic energy is equal to the energy dissipated by the deformation of the vehicle structures plus the total post-crash kinetic energy of the vehicles involved.

Considering the translational and angular velocities of a body on a plane, the kinetic energy (KE) can be expressed by the equation

$$KE_1 + KE_2 = E_d + \overline{KE_1} + \overline{KE_2}$$

While the energy dissipated by the deformation of the vehicle structures (deformation energy, Ed) can be calculated, e.g., by one of the following methods: (Brach & Brach, 1987; Campbell, 1974; McHenry, 1975; McHenry R.R., 1986).

2.4.2 Crash Investigation and Reconstruction Software

To keep the mathematical models as simple as possible and easily solved, it is a common practice to make simplifying assumptions about the physics of the crash event (e.g., by using one- or two-dimensional models).

However, to increase the accuracy of modelling the physics of the crash, it is necessary to increase the complexity of the mathematical models, including, just as an example, tire-road contact, how the external forces and the intervention of active safety systems such as ABS (Anti-lock Braking System) or ESP (Electronic Stability Program) act on vehicle dynamics. That usually results in solving complex nonlinear equations. More recent advantages are also the possibility to easily import point cloud and use them to measure the vehicle deformation and calculate their absorbed energy (deformation energy).

For this reason, it is the common practice to engage in the use of a software reconstruction tool. Hereafter the most used software in the field of crash reconstruction is listed. The following list is about crash reconstruction software programmes:

- PC-Crash (PCC)
- Virtual CRASH (VC)
- Analyzer Pro (AP)
- WinSMASH (MH)

While this second list is about digital images and/or 3D point cloud editing and processing software programmes:

- CloudCompare (CC)
- Metashape (AM)
- Photomodeler (PM)
- 3DF Zephyr (3DF)

PC-Crash (PCC) – is probably the most widely used and validated crash reconstruction software in the world and is a powerful calculation tool tailored to the specific needs of reconstructionist. Latest versions have a complete 3D CAD with point cloud management, implements simulation of active safety systems such as ABS, ESP and AEB, incorporates a FEM module, a Crash-Test Database, an EES Database, etc. It uses a 6-degree-of-freedom (translation and rotation on the three main axes of symmetry) extension of the Kudlich-Slibar collision model. From the latest versions, it implements artificial intelligence functions for image processing and analysis. Up to now, this function has been used for improvement of image resolution (the resolution enhancement algorithm increases the definition quality of road markings and road edges for better identification of the road surface), automatic contouring (the algorithm automatically recognises the profile of a vehicle within a photo and extracts it) and the estimation of EES values (it performs the estimation by comparison of the damage reported by the vehicle with those reported by cars in crash tests or in crashes whose deformation energy has been estimated).

Virtual CRASH (VC) – is a validated crash reconstruction software subjected to a large diffusion in last decade both in the US and European market. The software can also be used for forensic investigations, biomechanics issues and work safety in general such as falling from height or downstairs, forklifts rollover investigation, etc. Virtual CRASH uses a Kudlich-Slibar impulse-momentum rigid body dynamics model to simulate collisions between vehicles. This model is based on Newton's Laws of physics, and it is a fully real three-dimensional simulation tool with true three-dimensional vehicle dynamics modelling built in. It also offers the possibility to create composite objects of three-dimensional shapes which can all interact with each other and have a 3D movement in the environment terrain. The software can import total station or RTK GPS measurements, aerial images, and point clouds to help create your 3D environment. It also incorporates EDR data to drive animation motion sequences simply copying and paste data into the EDR tool that allows users to input either speed or acceleration time-series data to quickly generate animated motion.

Analyzer Pro (AP) – provides an expansive toolkit for creating high precision and complex crash sketches that can be accurately scaled to meet user expectations. It also shows a robust image processing capability. The kinematics module allows either the calculation of standard scenarios or more complex collision involving, e.g., multiple vehicles, allowing the user to investigate priority violations. The software is also able to import data from tachographs and EDRs, GPS and all the prevalent measuring devices as well as most recent formats like FIT or GPX employed in many sports watches. Moreover, it is automatically able to calculate for a range of avoidance scenarios, synchronizing traffic light depictions, investigating for diverse visibility conditions, etc. The kinetics module allows for the calculation of exchanged forces and how they result on human being. Indeed, it is possible to assess passenger stress for cervical spine examinations in case of multiple rear-end collisions. The video module automatically identifies moving objects in videos and determining (estimate) their velocities.

MSmac3D (MH) – is a wide validated crash reconstruction software that merges two powerful programs for crash reconstruction and vehicle dynamics: the SMAC and the HVOSM software. SMAC program simultaneously models the forces and moments of the collision as they occur while also modelling the tire forces and moments. Much more sophisticated and objectively accurate than other software since it is able to model the crushing of the vehicle every millisecond of the entire duration of the collision, so it predicts the area and magnitudes of the damage while also modelling the trajectory movements of the vehicle. HVOSM program further enhances SMAC and makes it 3D providing the vehicle dynamics before, during and after the collision interaction. MSmac3D also includes great 3D graphics which can import scene measurements (whether clouds, DXF, google maps, etc.), and many other auxiliary tools to help evaluate, analyse, and illustrate the reconstruction.

CloudCompare (CC) – is an open-source 3D point cloud (and triangular mesh) editing and processing software (GNU licence) for Windows, iOS and Linux platforms, which processes point clouds and triangular meshes. Born to compare point clouds from laser scanner surveys, it was later implemented into point cloud processing software with some rather advanced algorithms. CloudCompare can deal with huge point clouds on a standard laptop. It allows to compare a point cloud and a triangular mesh.

Metashape (AM) – is a stand-alone software that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales. The software allows to process images from RGB or multispectral cameras, including multi-camera systems, into the high-value spatial information in the form of photogrammetric point clouds, textured polygonal models, georeferenced true orthomosaics and DSMs/DTMs. Images can be co-processed with LiDAR points to exploit advantages of both data sources. Metashape allows for fast processing, providing consistent and highly accurate results both for aerial and close-range photography (up to 3cm for aerial, and up to 1mm for close-range photography), as well as for LiDAR databased surface reconstruction.

Photomodeler (PM) – provides accurate measurement and diagramming for many accident reconstruction and forensic tasks. The software produces accurate drawings, maps, CAD data, 3D models, and remapped photos. The user can employ a standard digital camera (e.g., DSLR) to capture accurate 3D data using photogrammetry technology, making it a solution anyone can use to achieve professional results. Photomodeler can measure small or large objects and scenes and integrate with other measurement data sources (laser scanners, total stations).

3DF Zephyr (3DFLOW) - allows photogrammetry to be useful in multiple scenarios, enabling different objectives and needs to be met using a complete all-in-one software suit. 3DF Zephyr allows to automatically perform 3D reconstructions using images and video data acquired with any sensor and using any acquisition technique. E.g., it is possible to use different cameras, lenses and focal lengths during the same survey or scanning session. The software is also able to import, record and analyse laser scan data (native file formats supported). In terms of output, Zephyr creates precision orthophotos, DSMs, DTMs and NDVI maps. Generate sections, contour lines and paths. 3D models, drawing elements and video animations can be exported in all common file formats.

More Advanced software programmes

Most advanced software is usually used for a deeper understanding of among other uses vehicle crashworthiness and injury biomechanics and in the development of new safety devices such as airbag, seat belt and their pre-tensioner, child retention systems, cyclist, and motorcyclist helmets, etc. However, due to their demand for high expertise, high-performance hardware, time-consuming and high prices, it makes these systems usually used for scientific research and industrial R&D purposes. Multibody and finite element methods are the main ones.

Simcenter Madymo (Siemens) - is the most used multibody software in the world for analysing and optimizing vehicle safety designs. Focusing on occupants as well as vulnerable road users such as pedestrians or motor/cyclists, Madymo offers an extensive database of crash dummy and human body models together with advanced solutions for seat belt and airbag simulation. It is used to cut costs in building and testing prototypes, leading to a faster time to market, minimize the risks associated with making design changes late in the development phase, correlate precisely with real crash test results

Funded by
the European Union

for new or improved vehicle models and components and allow safety designers to apply Design of Experiments (DoE) methods and run multiple design variables simultaneously. Crash dummy models and human body models are extensively validated.

LS-DYNA (Ansys) - is the most used explicit finite element simulation program in the world and is capable of simulating the response to fast dynamics loads. Its many elements, contact formulations, material models and other controls can be used to simulate complex models with control over all the details of the problem. Among others, the main applications include crashworthiness and airbag simulations, impact simulations, vehicle crash and occupant safety.

VPS (ESI Group) – is a worldwide software for finite element simulations of impact scenarios. Similarly to LS-DYNA, it is capable of predicting mechanical response of complex bodies (vehicles, occupants, VRU's) to external loading. It enables performing detailed analyses accident scenarios including vehicular deformation and occupant/VRU injury risk (ESI Group, 2024).

In Table 5 current prices for an annual license of the cited software are listed. Prices are indicative since they vary annually and they are also subjected to changes in commercial strategies.

Table 5 Software tool prices.

Tool	Name	Price [$]
Crash reconstruction	PC-Crash	5000
	Virtual CRASH	3200
	Analyzer Pro	Packages: 4300 – 4800
	Msmac3D	
3D point cloud editing	CloudCompare	open source
	Metashape	3500
	Photomodeler	Packages: 1000 – 3000
	3DF Zephyr	Packages: free - 4500

2.4.3. Recent Studies on Crash Reconstruction

UAV aerial photography and 3D laser scanning to collect accident data

The study conducted by Chen (2021) aimed to provide an improved method for traffic accident reconstruction using geomatics techniques and numerical simulations. The study used a combination of different techniques, including UAV aerial photography, 3D laser scanning, multi-body system simulations, and finite element simulations using the THUMS model to predict injuries. The study reconstructed the case of a 70-year-old woman who was hit by a red Ford Mondeo while crossing the pavement and died. The primary objective of the investigation was to determine how much of the deceased's injuries were caused by the traffic accident. The study used a DJI Phantom4 RTK drone to capture images of the accident site using UAV aerial photography. The researchers used a structured-light scanner to document the external findings of the body. The velocity of the vehicle was calculated using surveillance video footage, and a Faro Focus 3D S120 laser scanner was used to create a 3D model of the vehicle. The study used MADYMO program for a Multi-Body System (MBS) simulation to reconstruct the car-to-pedestrian collision. The injury risk evaluation was based on the FE simulation, which provided brain injury parameters, including von Mises and maximum shear stresses at the cerebellum, cerebrum, and brain stem.

Tools and methods used in this study:

- Unmanned Aerial Vehicle (UAV): A DJI Phantom4 RTK drone was used to capture images of the accident site using UAV aerial photography.
- 3D laser scanning: GO!SCAN 50, a hand-held structured light scanner, was used for creating an accurate and high-resolution model of the deceased.
- Surveillance Video Analysis: The smart player played 25 frames per second, and the velocity of the vehicle was calculated using a formula.
- Faro Focus 3D S120 laser scanner: This scanner was used to create a 3D model of the vehicle.
- MBS simulations: MADYMO program was used for a MBS simulation to reconstruct the car-to-pedestrian collision.
- Finite Element (FE) simulations: LS-DYNA software was used for FE simulation, and the THUMS v4.02 a.m.50 pedestrian model was used to model the pedestrian.
- Nondominated Sorting Genetic Algorithm-II (NSGA-II): It was used for optimization of the MBS simulation.
- Context Capture 4.0 software: It was used for automatic calculation and post-processing to generate a 3D model of the accident site.
- Geomagic Studio 2014 software: It was used to transform the point cloud data into a polygon model.

Indiana Unmanned Aerial System Crash Scene Mapping Program

UASs have revolutionized the field of photogrammetry, offering an efficient and cost-effective approach to mapping, surveying, and inspection tasks across various industries (Desai et al., 2022) In the realm of crash scene mapping, UAS enables public safety agencies to quickly document crash scenes and clear an incident, ultimately leading to reduced road closure times and lower likelihoods of secondary crashes. The state of Indiana's Criminal Justice Institute has spearheaded a UAS-based crash scene mapping program that utilizes precision and scale markers, camera types, and a comparison with terrestrial measurements to ensure accurate outcomes.

Several measurement techniques have been used to investigate and document crash scenes, ranging from traditional tape measurements to advanced 3D laser scanning and photogrammetry techniques. While 2D and 3D measuring techniques have their respective advantages, UAS-based photogrammetric mapping techniques have proven to be cost-effective and offer a high level of spatial accuracy. Moreover, the use of low-cost commercial UAS has enabled several state Department of Transportations to explore the cost-effectiveness of practical applications of UAS in solving real-world transportation problems.

The study analysed over 250 crash scenes to determine the accuracy of UAS-based photogrammetric mapping techniques. The analysis revealed that the scale errors were within 0.05 ft (1.5 cm), with a median scale error of 0.0165 ft (0.5 cm) and 90% of scale errors being 0.13 ft (3.9 cm) or lower. The FC2403 camera model equipped on a number of UAS in the DJI Mavic series was found to be the most frequently used camera for mapping crash scenes, with the XT705, ZenmuseZ30, and FC2403 cameras having the least errors.

The UAS-based photogrammetric mapping technique was compared with terrestrial measurements in a crash scene mapping exercise in Tippecanoe County. The UAS was able to quickly map the crash scene in 8 minutes, capturing an area of 3.8 acres at an altitude of 120 ft. The exercise resulted in a 5-hour road closure and 8-mile-long queues, underscoring the importance of using UAS-based photogrammetric mapping techniques to expedite crash scene documentation and reduce road closure times.

In this study, the specific tools and methods used include:

- UASs equipped with various camera models for photogrammetric mapping of crash scenes.
- Terrestrial laser scanning (TLS) for 3D reconstruction of crash scenes.
- Close-range photogrammetry (CRP) and Structure-from-Motion (SfM) algorithms for 3D reconstruction of crash scenes.
- Traditional tape measurements and electronic total stations for 2D measuring techniques.
- Processing software for UAS-based photogrammetric mapping.
- Boxplot and frequency chart for data analysis.
- Scale measurements marked on the scene to determine the errors in scale measurements.
- Comparison with terrestrial measurements for evaluating the accuracy of UAS-based photogrammetric mapping.

Accident Reconstruction of Bus–Two-Wheeled Vehicle

Gao et al., (2022) present a comprehensive approach to accident reconstruction analysis that integrates impact kinematics and human biomechanical injury mechanisms. The authors propose a novel accident reconstruction model comprising a Facet vehicle model and a rigid-flexible coupled human model.

The Facet vehicle model is a FE mesh of hollow materials that can accurately simulate the deformations of a vehicle during a collision. The authors built the Facet model using 3Dmax, HYPERMESH, and MADYMO by setting the relevant grids and nodes. To ensure accuracy and save computation time, the authors used the Facet model to simulate accidents involving buses. The contact coupling calculation was made more realistic by defining the equivalent elastic-plastic stiffness curve of the vehicle collision, which relates the contact force and penetration. MADYMO software was used to establish connections and relative motions between different parts of the Facet model, such as the windshield and wheels.

The rigid-flexible coupled human model was constructed by combining the TNO international standard MB HM and the HUMOS international standard FE HM. The human body was divided into four parts: head, trunk, upper limbs, and lower limbs, and then combined using a MB and a FE local human body model. The head FE model was a three-dimensional model composed of human tissues, such as bones and skin, and was used to analyse head injuries during a bus-two-wheeled vehicle collision. The authors validated the model through local blunt and accident simulation experiments, which confirmed that the contact characteristics of the model matched those of the human body.

To achieve the study's objectives, various tools and methods were employed. In Case 1, photogrammetric methods were used to determine the initial parameters of the accident, and MADYMO software was used to simulate the accident. The simulation employed the MB and FE coupling contact algorithm to set the contact characteristics between people, vehicles, and roads, and a female head FE combined HM was used for the head injury. In Case 2, the photogrammetric method was used to determine the speed and orientation of the bus, and a three-dimensional reconstruction of the accident scene was performed. MADYMO software was used to simulate the accident, and a 50th percentile male rigid-flexible coupled model was used as the human model, while an ordinary bicycle model was used as the two-wheeled vehicle model.

The simulation results revealed that both accidents were caused by speeding vehicles and blind spots for bus drivers. In Case 2, the simulation results matched the injury report of the cyclist's concussion and the autopsy results.

The study uses several tools and methods, including:

- MB modelling method: Used to describe the trajectory of the vehicle during the collision.
- FE modelling method: Used to analyse the mechanism of human injury and the condition of vehicle damage.
- Co-simulation method: Used to model the human-vehicle-road coupling in accident reconstruction to analyse the physical process of a human-vehicle collision, the vehicle damage condition, and the human biomechanical injuries.
- MADYMO 7.5 software: Used to construct two vehicle models: a Facet model for the bus and a rigid-flexible coupled model for the human body.
- Facet model: A finite element mesh of empty materials, which was attached to a reference space, rigid body, or deformed body.
- Rigid-flexible coupled human model: Constructed by combining the TNO international standard MB HM and the HUMOS international standard FE HM. The human body was split into four parts: head, trunk, upper limbs, and lower limbs.

- Contact coupling calculation: Defined the equivalent elastic-plastic stiffness curve of the vehicle collision, which relates the contact force and penetration.
- Photogrammetric method: Used to measure the initial relative position and initial collision speed of the bus and the two-wheeled vehicle before the accident.
- Simulation results: Validated the model's accuracy with real-world data such as CCTV footage or injury reports.

Multiobjective optimisation algorithm for accurate MADYMO reconstruction of vehicle-pedestrian accidents

This study aimed to investigate the accuracy of accident reconstruction using multiobjective optimization algorithms. The research investigates the optimal design of initial collision parameters in vehicle-pedestrian accidents, considering multiple factors simultaneously (Zou et al., 2022). The study uses three multiobjective optimization algorithms: Nondominated Sorting Genetic Algorithm II (NSGA-II), Neighbourhood Cultivation Genetic Algorithm (NCGA), and MultiObjective Particle Swarm Optimization (MOPSO). The accident reconstruction process involved collecting data from police investigations, witness testimonies, litigant statements, and a video record. A commercial DJI Inspire 2 unmanned aerial vehicle was used to take high-resolution photographs of the accident site, and a 3D geometric model was constructed using Context Capture software. The MADYMO 50th percentile male model developed by the Netherlands Organisation (TNO) was chosen as the human model, and the Generator of Body Data (GEBOD) method was used to scale the model to match the height and weight of the accident victim. The study used characteristic injuries on the corpse to match the deformation of the vehicle and the site trace. The simulation results indicated that the predicted injury condition of the human body model was consistent with the actual accident. The optimisation results showed that NSGA-II had the smallest objective function and the best performance. The study demonstrates that optimisation algorithms can be used to accurately reconstruct vehicle-pedestrian accidents.

Tools and methods used in the study include:

- Multiobjective optimisation algorithms: NSGA-II, NCGA, and MOPSO algorithm.
- MADYMO software: Used for multi-rigid-body simulation of traffic accidents.
- DJI Inspire 2 unmanned aerial vehicle: Used to take high-resolution photographs of the accident site to create a 3D geometric model using Context Capture software.
- MADYMO 50th percentile male model: Used as the human model for the accident reconstruction.
- GEBOD method: Used to scale the human model to match the height and weight of the accident victim.
- Faro Focus 3D S120 laser scanning: Used to scan the accident vehicle and obtain point cloud data.

- Geomagic 2017 software: Used to process the point cloud data and obtain a polyhedral model of the accident vehicle.
- Hypermesh 2019 software: Used to form a finite element surface model of the vehicle and a facet model of the vehicle for import into MADYMO.
- European New Car Assessment Programme (EuroNCAP): Used to select the contact stiffness characteristics of the front part of the model vehicle based on structural stiffness test results from similar vehicles.
- One-way ANOVA: Used to evaluate the distribution differences among the results of the data of the three different algorithms for the same group.

2.4.4. Injury measurement and outcome scores

While dealing with traffic crashes and more in general with automotive safety, coding injuries is a crucial aspect to perform analysis of injury mechanisms, to classify crashes according to the injury severity and enable the study of solutions for injury reduction. Several coding scales have been developed and can be used also in databases to represent injuries. The main ones will be outlined in the following paragraphs.

Abbreviated Injury Scale (AIS)

One of the most used methods to classify injuries and their severity is the Abbreviated Injury Scale developed and maintained by the Association for the Advancement of Automotive Medicine (AAAM, 2023; JAMA, 1971).

It is a universal scoring system in the field of trauma applicable in clinical and research settings. In engineering it is commonly used as a classification system for vehicle safety. The AIS can therefore be considered as an international, interdisciplinary, and universal code of injury severity.

The AIS is an anatomically based, consensus-derived, global severity scoring system that classifies the severity of each injury on a 6-point ordinal scale (1=minor and 6=maximal, possibly fatal). The method provides standardized terminology (descriptor) to describe injuries and ranks injuries by severity. The injury descriptors are classified into nine body regions: head, face, neck, thorax, abdomen, spine, upper extremities, lower extremities, and external.

To apply the method, medical records and imaging diagnostic exams are needed and, even if the coder belongs to medical personnel, he/she should be trained by AAAM (AAAM, 2023).

Maximum Abbreviated Injury Scale (MAIS)

In multiple injured patients, the highest AIS is known as the Maximum AIS often used to describe overall severity. Worth remembering how literature indicated that MAIS was not linearly correlated with the probability of death (Stevenson M, 2001).

Injury Severity Score (ISS)

The Injury Severity Score is also an anatomically based ordinal scale, with a range from 1 to 75, used to calculate the severity of a multiple injured patient. The score is calculated as the sum of the squares of the highest AIS scores for the three most severely injured body regions among the six: head or neck, face, chest, abdominal or pelvic contents, extremities, or pelvic girdle, and external.

$$ISS = A^2 + B^2 + C^2$$

where A, B and C are the highest AIS values from three out of six different body regions.

If a lesion is graded as AIS6, the ISS is automatically calculated as 75. No more than one AIS can be taken from a single region (Carroll, 2010; Tohira, 2011). This choice puts greater emphasis on the multiplicity of trauma injury but, at the same time, it can overlook multiple injuries suffered by the same parts of the body.

New Injury Severity Score (NISS)

Another criticism of the ISS is that the score assigns the same weights across different body regions. For this reason, Osler et al. developed the New Injury Severity Score that considers the three most severe injuries regardless of body region (i.e., sum of the square of the 3 highest AIS's) (Osler, 1997; Baker,1974). The authors affirm the superiority of the NISS over the ISS to predict the outcome of the trauma patient, and this conclusion is also supported by (Lawrence W. Schneider, 2011; Mynatt, 2017).

Overcoming the ISS limitation which comes up in the case of the highest AIS scores that fall within the same body region. Indeed, NISS is more predictive of survival and performs better, statistically, than ISS (Brenneman, 1998.; Osler, 1997).

2.4.5. Injury Causation Scenarios Assessment

The Injury Causation Scenarios aims to determine the injury causation part and external injury mechanism that might have caused the injuries sustained as a result of a traffic crash.

In NHTSA's CISS programme, the AIS3+ injury causations are typically determined by documenting the AIS code, the source of energy that caused the injury, the Involved Physical Components (IPCs) contacted by the person that is considered responsible for the injury and the IPC Confidence Level, the body regions contacted by each IPC and the factors that contributed to the likelihood and/or the severity of injury (Lawrence W. Schneider, 2011;Mynatt, 2017).

DaCoTA manual suggests building injury causation around the information collected during the stages of vehicle inspection and injury coding. Some key points that might be important during the investigation are the following: in case a Vulnerable Road User (VRU) is involved; take evidence of marks and deformation on the exterior of vehicles, evidence of the trajectory of occupants during ejection; amount of vehicle intrusion; evidences about the deployment of passive safety measures such as restraint systems, air bags and child restraint systems; and finally take evidence of marks and deformations on interior parts (DACOTA manual, 2020).

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3. IN-DEPTH CRASH INVESTIGATION PROGRAMME

Benefits from the availability of in-depth crash data were presented in previous chapters. Among them is notable the possibility to develop and implement safety solutions and assess their impact on a quantitative basis.

In this chapter the key topics of an in-depth crash investigation programme will be discussed together with the main considerations to support a decision-making process for the selection of the best implementation options. The content of the chapter will be summarized in a complete proposal with a modular structure, organized in three levels, to facilitate the progressive uptake of the in-depth approach, and the removal of possible organizational and economical barriers. Accordingly, the programme is adaptable, in terms of both competencies of the personnel involved and instrumentation.

The proposal has been structured in the following three levels: basic, medium and advanced.

- The fundamental objective of the basic programme is to facilitate a comprehensive examination of road traffic accident data. For this reason, the programme prioritises the collection of data that is relatively straightforward to obtain, both in terms of the required skills and the effort required, and that provides a more comprehensive overview of road crash circumstances than the national dataset.
- The medium programme builds upon the basic level and incorporates additional variables and more sophisticated methodologies, thereby enabling a more nuanced analysis of the factors contributing to crashes. The programme requirements become more demanding in terms of the skills, effort and economic resources.
- The advanced programme offers the most comprehensive approach. It utilises advanced technologies and skills to gather an extensive array of variables, facilitating a thorough investigation of complex interactions and causal relationships in road crashes.

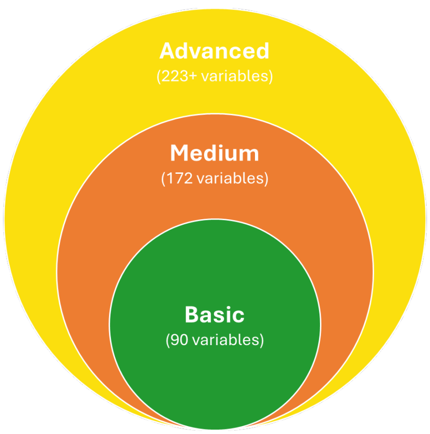

Figure 13 In-depth investigation programme options.

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3.1. SAMPLING AND WEIGHTING PROCEDURES

3.1.1. Sampling strategy

Proposed sampling strategies include the retrospective methodology, which is characterised by a lower effectiveness in terms of quality and type of data collected, but which offers an economic advantage; and the 'on-the-scene' strategy, which, although more effective, involves higher costs. A further consideration is the determination of the size of the sampling area, which is closely related to the selected strategy (Section 2.1.3; Jha et al., 2020).

In the case of the 'on-the-scene' strategy being selected, it is necessary to define a radius of action, expressed in kilometres, in order to guarantee that the investigation team can reach the potential site of the crash within approximately 30 to 40 minutes after the crash has been reported. In the case of a retrospective strategy, whereby the team's intervention occurs after the crash, the sampling distance may be greater, extending up to 40–50 km from the team headquarter.

In addition to the selection of the sampling methodology, it is imperative to establish the criteria for reporting an occurrence of a clash. Once more, the type of sampling affects the process. In the case of retrospective sampling, assuming specific filter conditions are met, it is possible to establish a communication channel with both the police and the hospital. Conversely, in the case of 'on-the-scene' sampling, it is of the utmost importance to have multiple reporting channels in place, such as the police, the first aid system and the fire brigade.

It is also of great importance, particularly in the case of the retrospective methodology, to establish a partnership with at least one of the hospitals that will receive the injured parties from the crashes that occurred in the sampling area, as well as with the first aid officers. Moreover, it is imperative to collect comprehensive data on the nature and extent of injuries sustained, as well as diagnostic information that can be used to code injuries according to the AIS system. This data is also crucial for monitoring potential long-term disabilities, at 3, 6, and 12-month intervals if the case.

3.1.2. Ethics and Confidentiality

It is essential to obtain approval of an operating protocol from an ethics committee associated with a university or hospital located in the study area. In the case that a local ethics committee is not available, it may be possible to request support from committees at other universities, even those outside the region or country. This is a crucial step to ensure the robustness of the investigation programme and the safe handling of all sensitive data with which programme participants will come into contact.

3.1.3. Weighting strategy

The representativeness of the data and the validity of the conclusions elaborated from the collected data relies on the definition and implementation of a clear weighting strategy for the analysis of road traffic accidents. As previously stated in section 2.1.4, there are numerous sophisticated techniques for weighting road crash data. One of the simplest methods is to compare the crashes investigated at the in-depth level with those collected at the national level on the basis of those variables that are highly correlated with as many other crash characteristics as possible (Hautzinger, 2005).

It is therefore of the utmost importance to gather at least a portion of the data collected at the national level for the respective survey area. This approach will facilitate the weighting of the cases collected during analysis, thereby enabling the extension to a national context of the results and conclusions derived from the in-depth database.

3.2. CRASH INVESTIGATION PROCEDURES

To guarantee homogeneity in the investigation process and a high quality of the collected data, each team should be following common investigation procedures to ensure consistency in the data collection and the reduction of human errors. They usually should cover the following aspects:

- Road traffic crash scene investigation
- Vehicle exterior investigation
- Vehicle interior investigation
- Personal Protective Equipment investigation
- Witnesses: interviewing to people involved into the road crash
- Investigation and collection of injury information

3.2.1. Road traffic crash scene investigation

According to literature, the investigation of a road traffic crash typically begins with a thorough examination of the road environment where the incident occurred. This includes assessing various factors such as the positions of vehicles post-collision, points of impact, skid marks, debris distribution, and liquid spills. Additionally, data pertaining to the road itself is collected, encompassing characteristics like road type (e.g., highway, urban, rural), traffic flow direction, road alignment (straight or curved, level or sloped), intersection type, presence of traffic lights, and road surface and weather conditions.

These details yield crucial evidence essential for both crash reconstruction and comprehensive road safety analysis. During crash reconstruction, information gathered from the road environment assists in determining vehicle trajectories leading up to the collision, identifying contributory factors, and making inferences about driver behaviour or pre-crash braking conditions.

Collecting measurements and pictures from a traffic crash scene is crucial for accurately reconstructing the dynamics of the traffic crash. It's essential to gather this data not only from the immediate surroundings of the vehicle rest position or point of impact but from a significant portion of the crash scene itself.

To properly reconstruct the traffic crash dynamics, particularly during the pre-crash phase, investigators need to collect and analyse information from a portion of the road extending between 50 meters and 100 meters before the point of impact, depending on the vehicle's traveling speed. For instance, assuming a driver reaction time of 1.5 seconds, it's necessary to examine events occurring two to three seconds before impact to determine the precipitating event and its timing (e.g. a vehicle traveling at 50 km/h -13.9 m/s- covers approximately 40 meters in 3 seconds, while at 100 km/h -27.8 m/s-, it covers twice that distance). Understanding these factors underscores the complexity and time-consuming nature of the investigation phase.

Traffic congestion is often among the initial repercussions of road traffic crashes and the subsequent restoration operations. Expedient procedures and tools are crucial for enabling investigation teams to swiftly conclude their assessments, thereby expediting the resumption of regular traffic flow (Wang et al., 2009). Given the immediate impact of traffic congestion on managing crash scenes, additional investigation procedures beyond those conducted by traffic police should not exacerbate the complexities of event management. Therefore, it's imperative that every investigative procedure prioritizes efficiency and accuracy in data collection to prevent undue delays and ensure the quality of information gathered.

In the market, a variety of measuring tools are available for crash scene investigation (refer to section 2.3 for details). Manual instruments, such as metric wheels, offer affordability and ease of use but may lack precision. On the other hand, digital tools like photogrammetry, drones, total stations, etc., though more expensive, provide higher accuracy and are adaptable across multiple stages of the investigation process. Digital instruments can efficiently capture large amounts of data with relatively high precision, making them invaluable for crash scene documentation. Close-range photogrammetry and drones emerge as a favourable compromise between data accuracy, time efficiency, and cost. Notably, they enable the generation of three-dimensional point clouds and scaled ortho-rectified images, facilitating seamless integration into crash reconstruction workflows and data entry operations. Desai et al., (2022) highlighted that just eight minutes of aerial drone footage can document over 150 meters of road (Figure 14), underscoring the efficiency and effectiveness of digital tools in crash scene documentation.

Figure 14 Scaled UAS ortho-rectified mosaic of an 8-min flight of a crash scene (Desai et al., 2022).

Certainly, in a comprehensive road traffic crash scene investigation, it's essential to acquire and preserve various types of information. Here's a detailed breakdown:

- **Vehicle point-of-rest (POR)**: the final position where the vehicle comes to a stop after a crash, providing crucial information for reconstructing the dynamics of the incident.
- **Vehicle point of impact (POI)**: the location where the initial contact occurs between a vehicle and another object, vehicle, or surface during a crash. This point is critical for understanding the sequence of events leading to the collision and the forces involved.
- **Vehicle skid marks**: the marks left on the road surface due to tire friction during hard braking or loss of traction. These marks provide valuable data on vehicle speed, direction, and driver actions leading up to the crash.
- **Vehicle scratch marks (mostly for powered two-wheeler vehicles)**: abrasions on the road surface caused by vehicle components scraping the ground during or after a crash. These marks help trace the movement and orientation of the vehicle and can be particularly significant for reconstructing crash involving two-wheelers.
- **Debris and vehicle's liquids position and scattering**: the dispersion pattern of broken vehicle parts, shattered glass, and spilled liquids (e.g., oil, coolant, fuel) around the crash site. This distribution offers insights into the collision dynamics, vehicle trajectories, and the intensity of the impact.
- **Ground human-body rest position and biological finds (if any)**: the final location where a human body comes to rest after a crash, along with any associated biological evidence (e.g., bloodstains). This information is essential for analysing the interaction between the body and the crash forces, as well as assessing injury mechanisms and severity.

A successful collection, or 'freezing,' of evidence from the crash site is crucial for the crash reconstructionist to accurately assess the dynamics of the event (Figure 15). Photographs taken at increasing distances backward from the impact point significantly enhance the quality of crash reconstruction. Even if the reconstructionist is not part of the crash investigation team, having access to all documented evidence is essential for analysis and selection. For instance, examining the first image in Figure 15 allows the exclusion of tyre marks produced by the investigated crash, as their size and trajectory are incompatible with the tyre of the powered two-wheeler (PTW) involved. Even if the tyre marks were consistent in size, their trajectory would not align with the PTW's pre-crash trajectory compared to the car's point of impact. Similarly, the scattering of glass and earthy debris in the third image indicates that the car-PTW impact occurred well before the car's point of rest, resulting in a significant advancement of the car to its point of rest.

Figure 15 Car to PTW crash investigation. Credits: InSAFE road crash database at University of Florence (IT).

Here is some advice on how to perform a complete photographic report of the crash scene:

1. Capture Vehicle's POR:
   - Take pictures of the vehicle's POR, covering it from multiple angles to provide a comprehensive view of its position relative to the crash scene.
2. Document Impact Area and Evidence:
   - Photograph the area around the most probable impact zone, ensuring all relevant evidence is captured.
   - Pay particular attention to ground skid and scratch marks, as these can offer insight into the dynamics of the crash.
3. Document Pre-Impact Paths:

- Walk backward from the impact area to document the paths followed by each road user (vehicles, pedestrians, cyclists) during their pre-impact stage.
- Take photographs approximately every 10 meters to ensure thorough coverage, capturing both the road and the vehicle at rest positions.
- Covering at least 50 meters of road before the vehicle's point of rest is a crucial step in documenting the events leading up to the crash. This ensures that the movements and positions of the vehicles and other road users are thoroughly documented, providing valuable context for the investigation and reconstruction process.

4. Maintain Consistency:
    - Maintain consistency in photographic techniques and angles throughout the report to facilitate analysis and reconstruction of the crash scene.
    - Use landmarks or reference points in the surroundings to provide spatial context for each photograph.

3.2.2. Vehicle exterior investigation

The vehicle exterior investigation begins with the understanding that during a crash, each component of the vehicles involved will leave distinctive marks on the surfaces where they come into contact. Consequently, the exterior inspection, which includes examining the undercarriage, focuses on collecting crucial evidence regarding the location and magnitude of damage. This evidence, such as impact marks and deformation pattern, provides valuable insights into the dynamics of the crash and aids in reconstructing the sequence of events leading to the collision. In particular they help to calculate the deformation energy absorbed by the vehicle (Figure 16); to fix the relative vehicles' position at the crash (Figure 17 and Figure 18) and to understand the interaction between road users (Figure 20 - Figure 21Figure 22 and Figure 23).

Vehicles, objects, and people move relative to each other during the collision; thus, the imprinted marks may be masked by damages from other subsequent contacts. It is therefore essential to take into account both the magnitude and the type of damage as they change according to the impact type and the vehicle impact speed. For example, at medium to high impact speed the vehicles' compenetration is often significant and their structures are severely deformed compared to those at low impact speed (Figure 18 - Figure 19). Hence, any evidence from the exterior must be collected properly as they may be useful in the entire data collection process: from the crash reconstruction phase to understand how road users interact with each other during the impact (Figure 20 - Figure 23) to the vehicle crashworthiness assessment.

To this end, it could be useful to implement and use the CDC (SAE, 2022) and the Truck Deformation Classification (TDC) (SAE, 2022bis) system formats both published by the Society of Automotive Engineers (SAE).

What should be investigators looking for?

- All types of damages, paying attention to discern between old (i.e., present before the crash) and new (i.e., produced by the crash under investigation).
- All evidence about the interaction between vehicles (i.e., deformation, scratches and rubber depots due to the contact with the other vehicle).
- Tyre marks on the opponent (Figure 15Figure 22Figure 21).
- All evidence about the interaction between the vehicle and the vulnerable road user (VRU) (e.g. pedestrian, cyclist, or rider) through the research of clothing fibres, hair, blood, abrasion marks, etc. traces (Figure 20 - Figure 21 and Figure 23).

How should investigators take photographs?

- Rotate around the vehicle taking photos from at least eight different angles plus an extra picture of the top/ground view (Figure 22). The number of pictures acquired has to increase if you are using them to build a vehicle point cloud via photogrammetry techniques. It is usually recommended to take photos with at least 50% overlapping. Photogrammetry is the science of obtaining accurate measurements and 3D data (point cloud) from photographs, typically used for mapping, surveying, and reconstructing objects or scenes.
- Even if photogrammetry is not used, could be fruitful to take a few pictures overlapping to the frame and a measuring rod to be able to rescale the image in scale 1:1.
- Vehicle details photos. Take photographs of any relevant area of the vehicle that is helpful during the overall investigation that may not have been adequately recorded otherwise. Focus on marks/traces of clothing fibres, hairs, blood, abrasion, scratches, etc. all around the vehicle. In case of VRU involvement, it is necessary to search them on the bumper, fender/guard, front bonnet, windshield, etc. (Figure 20Figure 21 and Figure 23).
- Detail photographs should be approached to be able to put the detail back into the bigger picture. It is necessary to be able to place the detail in a more general context, either using numbered references or an approach that takes several pictures proceeding from the general to the particular.

How should investigators measure damages?

The objective of damage measurement in a crash investigation is to assess the extent of intrusion a vehicle has experienced as a result of the collision. This assessment is crucial for understanding the severity of the crash and its impact on vehicle occupants. To achieve this objective, investigators aim to draw a detailed damage profile of the vehicle and compare it with its undeformed shape (Figure 16 and Figure 17).

Once the damage profile is established, investigators compare it with the vehicle's undeformed shape, typically using reference points and measurements obtained from manufacturer specifications or pre-crash photographs. This comparison allows investigators to quantify the extent of deformation and intrusion and assess the severity of the impact.

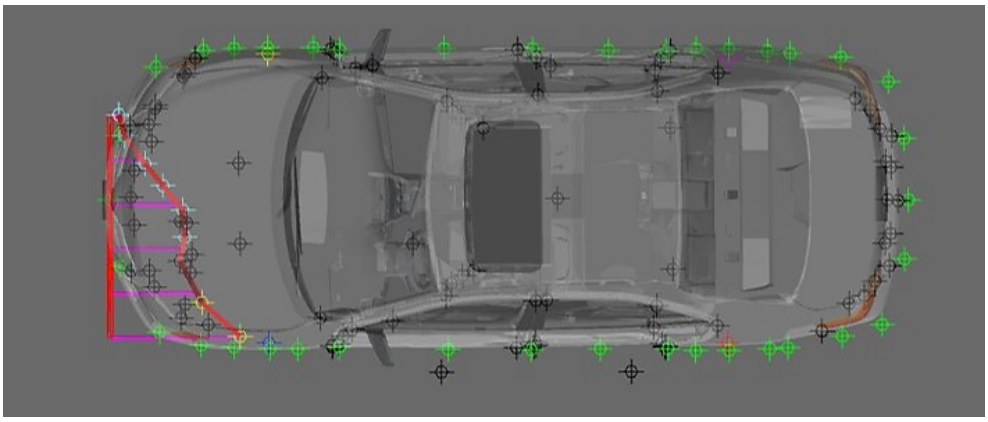

Figure 16 Example of a vehicle damage profile superimposed to the undeformed vehicle shape, and the relative Crash-3 measures (https://focusforensics.com/capabilities/accident-reconstruction/)

Damage measurement can be carried out using a lot of different measurement techniques or instruments and they should be measured horizontally and vertically, to put it in context with the area of the vehicle, and of course, it must be measured in depth. It may be useful to take incremental measurements as the height above the ground changes.

Hereafters are some examples of tools:

- meter or metric rod to manually acquire the measurements
- laser distance meter
- total station
- laser scanner
- photogrammetry

By employing a laser scanner or computer vision technique, three-dimensional models, also known as point clouds, of the deformed vehicle can be generated. These models serve as valuable resources for conducting future deformation analyses. This involves comparing the point cloud of the deformed vehicle with that of the undeformed one.

a) Direct damage measurement (Desai et al., 2021)   b) Indirect damage measurement (Recon 3d)

Figure 17 : Comparison between direct and indirect measurement system.

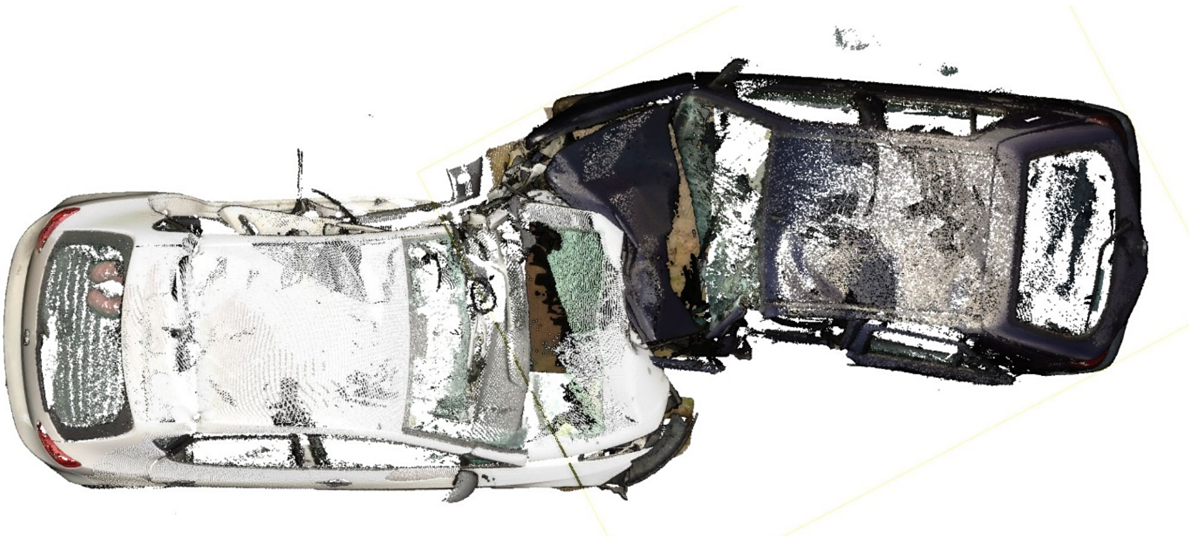

Figure 18 Example of point-cloud vehicle superimposition at crash point (Leica-Geosystems).

Primary impact　　　　Secondary impact

Figure 19 Car to Car crash investigation. Credits: InSAFE road crash database at University of Florence (IT).

Figure 20 Car to PTW crash investigation (ID 10). Credits: InSAFE road crash database at University of Florence (IT).

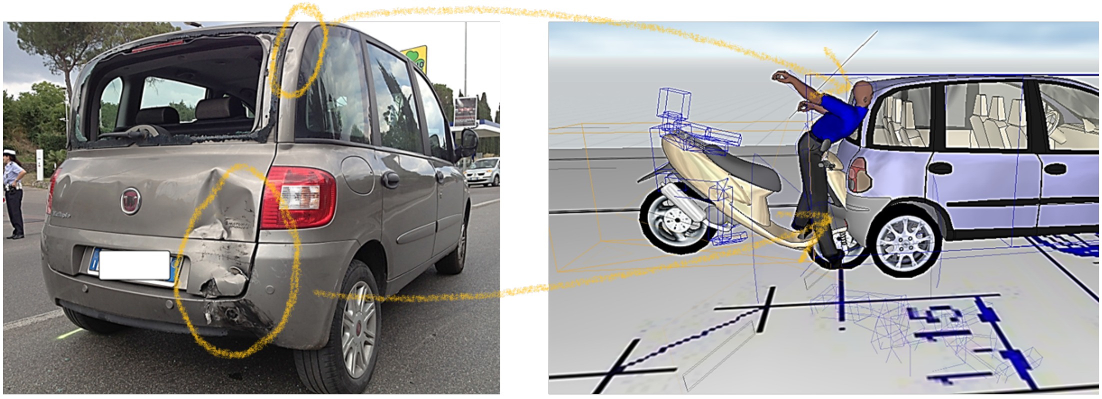

Figure 21 Car to PTW crash investigation (ID 112). Credits: InSAFE road crash database at University of Florence (IT).

Figure 22 Exterior car photo angles (left) and a set of photographs for photogrammetry (right).

Figure 23 Car to Pedestrian crash investigation (ID 51). Credits: InSAFE road crash database at University of Florence (IT).

3.2.3. Vehicle interior investigation

The vehicle interior investigation aims to gather information regarding the passenger compartment, with a focus on understanding the degree of deformation, such as intrusion, and the functionality of passive safety devices, including seatbelts, airbags, and even those installed subsequent to vehicle registration, such as child restraint systems (Figure 24 - Figure 26).

A thorough examination of these devices and the corresponding data entry into the database will serve multiple purposes, including identifying potential causes of injury and analysing the effectiveness of these safety mechanisms. Photographs should be captured from two angles in the front seat and one in the rear seat (if applicable) for both the driver and passenger sides of the vehicle. The second angle in the front seat aims to capture leg space and, where relevant, the pedalboard.

Furthermore, the investigation should prioritize the identification of traces of fibres, hairs, blood, and any potential contact points between the occupants and the passenger compartment. This approach facilitates the understanding of the impact kinematic and the injury causation as well. For example, in a car-pedestrian collision, evidence of the human body's contact with certain parts of the car is essential to reconstruct the most plausible impact kinematics, as well as the speeds of both the car and the pedestrian at the time of impact, or the relationship between the presence of biological traces and damages on the vehicle and body injuries can help to define the side from which the pedestrian was hit. Conversely, in terms of injury causation, this type of evidence could be used, for example, to distinguish between initial impacts with the vehicle and secondary impacts with the ground or other road furniture. Notably, all marks should be documented in interior observation forms, with detailed descriptions provided for each mark or damage, as outlined in the DaCoTA manual (DACOTA manual, 2020).

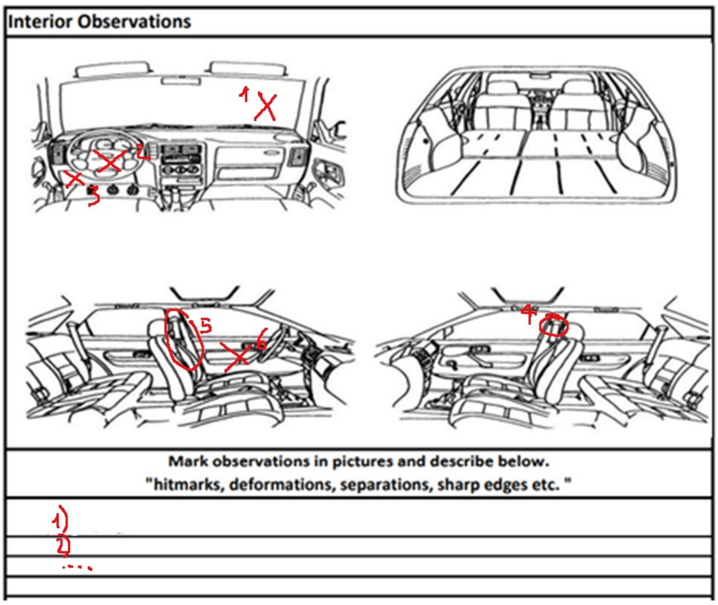

Figure 24 Interior observation forms (DaCoTA manual) (DACOTA manual, 2020).

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Figure 25 Car to VAN crash investigation. Credits: InSAFE road crash database at University of Florence (IT).

Figure 26 Car to VAN crash investigation. Credits: InSAFE road crash database at University of Florence (IT).

3.2.4. Wearable protective equipment investigation

To mitigate the risk of injury and fatalities, VRUs including cyclists and motorcyclists are encouraged to utilize Personal Protective Equipment (PPE). This equipment typically includes a helmet as a minimum requirement, along with technical clothing such as jackets, gloves, suits, and boots.

Therefore, when a crash investigator encounters a VRU involved in an accident, it is crucial to assess the type of PPE worn and its condition post-impact. This assessment serves multiple purposes, including evaluating the effectiveness of the protective gear and understanding the mechanisms of injury. Moreover, gathering this information provides valuable insights for further research and analysis aimed at improving road safety measures.

What should an investigator be looking for?

In general, crash investigations should prioritize documenting all types of marks, abrasions, and more serious damages such as fractures and cuts. Focusing on helmets, which are widely recognized as

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effective devices against head injuries, the investigation team should gather the following information, preferably in the following order to preserve evidence:

1. *Photographic Documentation*: a comprehensive photographic report should be made to preserve all evidence relating to the helmet. This will allow further analysis and retrieval of data at later stages of the investigation. Again, the photographic documentation should preferably be taken from a general to a detailed view.
2. *Retention System*: the investigation should note the type of retention system (e.g., double D-rings, quick fasten release) and assess its integrity, ensuring it meets overstrength requirements.
3. *Shell Investigation*: investigators should examine the helmet shell for damage types (e.g., abrasions, cracks, delamination) and severity and their locations.
4. *Wearing Information*: this involves recording details about the helmet's wearing status, such as whether it was not worn, properly worn, worn but not fastened, or ejected during the crash.
5. *Helmet Details*: this includes identifying the helmet type (e.g., full-face, open-face, bicycle, etc.), manufacturing date (year), size (e.g., small, medium, large, etc.), mass, and type of compliance approval (e.g., ECE, DOT, SNELL, JIS).
6. Lastly, the helmet may be acquired by the investigating team for further laboratory analysis or tests.

3.2.5. Witnesses: interviewing people involved into the road traffic crash

As stated in the DaCoTA manual (DACOTA manual, 2020), conducting interviews with road users regarding a road traffic accident is a multifaceted task. It encompasses emotional significance, legal context, and practical considerations.

Establishing a productive interview relationship requires careful attention to several key factors:

1. Building Rapport: establishing trust and rapport with the interviewee is essential. This can be achieved through empathy, active listening, and demonstrating genuine interest in their perspective.
2. Engagement: engaging the person in the interview process involves creating a comfortable and non-threatening environment. Encouraging open communication and ensuring confidentiality can help foster engagement.
3. Respect and Sensitivity: recognizing the emotional impact of the accident and respecting the interviewee's feelings and experiences is paramount. Sensitivity to their situation and emotions is crucial throughout the interview process.

When should the investigator conduct the interview?

In the context of road traffic accidents, investigators should conduct interviews as soon as possible after the crash while ensuring that the interviewee is in a suitable condition to provide information. By doing so, interviewees are more likely to provide spontaneous information, minimizing the potential for mental reconstruction or influence from discussions with others (DACOTA manual, 2020).

The timing of the interview is critical for several reasons:

1. Freshness of Memory: interviewing individuals shortly after the accident increases the likelihood of obtaining accurate and detailed information while their memories are still fresh. As time passes, memories may fade or become distorted, making it more challenging to recall specific details accurately.
2. Preservation of Evidence: conducting interviews promptly helps preserve critical evidence and information related to the accident. Details provided by witnesses, drivers, or other parties involved in the incident can contribute to a comprehensive understanding of what transpired and aid in the investigation process.
3. Legal Considerations: timely interviews allow investigators to gather relevant information while it is still timely and before potential legal proceedings unfold. This helps ensure that evidence is documented and available for use in any subsequent legal proceedings or insurance claims.
4. Emotional State of Interviewees: it's important for investigators to consider the emotional state of interviewees when scheduling interviews. While prompt interviews are ideal for preserving memory accuracy, interviewees may need some time to recover emotionally from the trauma of the accident before being interviewed.

The procedure should be segmented into two stages:

- Initial Interview: it is a relatively brief on-site interview conducted at the scene of the crash. However, in the event that a person is injured, the interview can be conducted in the hospital as soon as possible.
- Follow-up Interview: this entails a complementary data collection interview within 48 hours of the crash. During this stage, the interview should build upon the initial findings gathered during the initial interview, along with an examination of the initial data collected by the interdisciplinary team.

How should the investigator prepare for the interview?

The interviewer should avoid preconceptions to prevent biasing the interview with subjectively directed questions. It's essential to be prepared by understanding the overall course of the crash, including the number of vehicles involved, crash configuration, and other pertinent details. To achieve this, a pre-interview team investigation debriefing can be valuable for sharing evidence and determining appropriate questions.

The interview should flow like a normal conversation, so having a guide can be helpful, but it shouldn't be followed too rigidly. Hereafter a rearranged and extended version of the interview prompt shown in the Dacota Manual (DACOTA manual, 2020):

Introduction of the crash investigation programme

“Good [morning/afternoon], my name is [Investigator's Name], and I’m with [Investigation Team/Organization]. We are here as part of the [Programme Name Acronym] Road Crash Investigation Programme, which aims to understand crashes to improve road safety and prevent future incidents. The information you provide will help us identify what happened and why. Participation is voluntary, and all data will be anonymized. If you are ready, I will start with a few questions about the crash where you have been involved.”

Description of Events (to guide the conversation, use these key phrases)

“Thank you for speaking with us. I would like to understand what happened in as much detail as you can provide. Please take your time and describe the events as you remember them, starting from before the crash occurred. Once you have shared your experience, I may ask for more details about specific moments.”

Driving Context: "*Can you describe the driving conditions before the crash? What was the environment like (e.g., road type, weather, traffic)? What were you doing at the time?*"

Driving Situation: "*What was happening just before the situation began to change? What did you notice about your surroundings and other road users?*"

Rupture: "*Can you explain the moment when you realized something was wrong? What happened, and what did you perceive in that moment?*"

Emergency: "*What actions did you take to avoid the crash, if any? What were your immediate reactions?*"

Crash: "*Can you describe the crash itself? How did it unfold from your perspective?*"

Additional - Facts and Movements: "*What were the movements or manoeuvres of your vehicle and others involved? Can you describe how the vehicles interacted?*"

Additional - Perception of Events: "*What did you see, hear, or feel during these moments?*”

Additional – Reactions: "*What actions did you take, and when? Did you notice how others responded?*"

Possible section closure: "*Your detailed account is extremely valuable for us to reconstruct the sequence of events accurately. Please let me know if you recall anything else as we proceed.*"

Context of the route (to guide the conversation, use these key phrases)

"*Now, I would like to ask some questions about the moments leading up to the crash to better understand the context in the vehicle and your overall state. Please share as much as you feel comfortable.*"

Mood and Ambiance in the Vehicle: "How would you describe the mood in the vehicle before the crash? Was it calm, tense, or something else? Were there conversations or activities happening?"

Temporal Constraints: "*Were you on a schedule or feeling rushed at the time? Was there any time pressure influencing your driving?*"

Knowledge of the Route: "*How familiar were you with the route? Were you relying on automatic habits, or were you navigating or searching for directions?*"

Secondary Tasks: "*Were you engaged in any other activities, like talking to passengers, adjusting controls, or thinking about something unrelated to driving?*"

Level of Alertness: "*How alert were you feeling at the time? Were you experiencing any fatigue, stress, or drowsiness?*"

Attention Focus: "*Where was your attention directed just before the crash? Were you focused on a specific vehicle, part of the road, or something else?* "

Possible section closure: "*These details help us better understand how the situation developed and the factors that may have influenced the events. Please let me know if there's anything else you'd like to add.*"

Difficulties met (to guide the conversation, use these key phrases)

"Now, I would like to ask some questions about the moments leading up to the crash to better understand the context in the vehicle and your overall state. Please share as much as you feel comfortable."

Mood and Ambiance in the Vehicle: "*How would you describe the mood in the vehicle before the crash? Was it calm, tense, or something else? Were there conversations or activities happening?*"

Temporal Constraints: "*Were you on a schedule or feeling rushed at the time? Was there any time pressure influencing your driving?*"

Knowledge of the Route: "*How familiar were you with the route? Were you relying on automatic habits, or were you navigating or searching for directions?*"

Secondary Tasks: "*Were you engaged in any other activities, like talking to passengers, adjusting controls, or thinking about something unrelated to driving?*"

Level of Vigilance: "*How alert were you feeling at the time? Were you experiencing any fatigue, stress, or drowsiness?*"

Attention Focus: "*Where was your attention directed just before the crash? Were you focused on a specific vehicle, part of the road, or something else?*",

Possible section closure: "These details help us better understand how the situation developed and the factors that may have influenced the events. Please let me know if there's anything else you'd like to add."

Additionally, the interview should be conducted either in a forward or backward manner. A forward interview allows the interviewee to freely express themselves about the subject, while a backward

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interview encourages clarification of any discrepancies, ensuring reliability and accuracy of their claims.

Before starting the interview, the investigator should explain the significance and purpose of the interview for the project they are working on. It's advisable to take the necessary time to introduce oneself, briefly outline the project and its goals, reassure the interviewee about the ethical guarantees of discretion and non-disclosure of the interview contents, and explain the interview protocol (DACOTA manual, 2020).

3.2.6. Investigation and collection of injury information

The classification of road traffic injury severity can vary depending on the source and purpose of classification. However, there are some common differences observed in road traffic injury severity classification, particularly between medical and police reports.

Medical Reports:

- Medical reports typically classify road traffic injuries based on medical severity and clinical assessment such as the International Classification of Diseases, 11th revision (ICD-11). The ICD-11 is a widely used system for coding and classifying diseases, injuries, and health conditions. It provides a standardized framework for healthcare professionals to document and classify injuries, facilitating communication, research, and analysis in the healthcare field.
- Severity classification often considers factors such as the extent of physical trauma, the severity of injuries, and the prognosis for recovery.
- Medical severity classification focuses on the medical treatment required, potential long-term disabilities, and impact on quality of life.
- However, as reported in section 2.4.4, in the automotive safety field, traumatic injuries are commonly classified using the AIS.

Police Reports:

- Police reports classify road traffic injuries based on the circumstances of the crash and the level of involvement in the collision.
- Severity classification in police reports often considers factors such as the degree of vehicle damage, the number of vehicles involved, and the presence of fatalities or serious injuries.
- Police classifications may include categories such as property damage only, minor injury, serious injury, or fatal injury based on the observed impact of the crash.
- In certain instances, police classification systems may utilize the MAIS score to differentiate between minor and serious injuries, usually setting a cut-off point at MAIS 3. However, employing the AIS score necessitates significant training, which can be challenging to find within police departments.

An in-depth investigation team should collect injury information from road traffic accidents with accurate attention to detail and thoroughness.

Here are some best practices:

- Coordination with Medical Professionals: Establish communication channels with medical professionals, emergency responders, and healthcare facilities involved in treating accident victims. Obtain medical records, injury assessments, treatments, and imaging studies to comprehensively identify and document all injuries, including internal trauma and soft tissue injuries, in order to understand the nature and severity of injuries sustained.
- On-Scene Assessment: Conduct on-scene assessments to document injuries immediately following the accident. Gather information about the number of injured individuals, their locations, and the types of injuries observed. Capture photographs and videos to document the conditions of injured victims and the accident scene thoroughly. Take detailed notes to accurately document injuries and their locations.
- Injury Classification Systems: Utilize the AIS to categorize and quantify the severity of injuries. Assign appropriate injury severity scores based on the anatomical location and extent of injuries.
- Physical Examinations and Forensic Analysis: Conduct forensic analysis of injuries to determine causation factors, including blunt force trauma, penetrating injuries, and secondary impacts. Document injury patterns, bruising, lacerations, fractures, and other physical evidence of trauma.
- Collaboration with Experts: Collaborate with medical experts, forensic specialists, and accident reconstructionist to analyse injury patterns and mechanisms, as well as to assess the impact of vehicle dynamics and crash dynamics on injury outcomes. Seek expert opinions on injury causation, impact dynamics, and potential long-term consequences. Incorporate medical expertise into the investigation process to ensure the accuracy and reliability of injury information.
- Documentation and Record-Keeping: Maintain detailed records of all injury-related information, including medical reports, diagnostic images, and injury severity scores. Organize documentation systematically to facilitate analysis and interpretation by the investigation team.
- Legal and Ethical Considerations: Compliance with legal and ethical guidelines is essential when collecting and using injury-related information. It is crucial to safeguard the privacy and confidentiality of crash victims while maintaining transparency and accountability throughout the investigative process, as outlined in paragraph 2.1.2. The collection of medical information must adhere to strict confidentiality standards and require prior ethics approval. If team health personnel are responsible for collecting this data, they must first obtain informed consent from the individuals involved. Conversely, when medical data are acquired from a hospital setting, the exchange must comply with approved ethical protocols and strictly follow national data protection regulations.

3.3. CRASH INVESTIGATION AND ANALYSIS TOOLS

Table 6 provides an overview of tools needed for an in-depth study of road traffic crashes. These tools have been declined according to the three levels of the programme, where each level introduces increasingly sophisticated instruments that facilitate greater accuracy and detail. The "Crash Scene & Vehicle Investigation" category comprises tools for gathering measurements and spatial data, encompassing both basic measuring instruments and advanced devices such as drones and laser scanners for detailed scene analysis. The "Crash Reconstruction" category includes software and computational resources for simulating and analysing the crash.

The proposed multilevel structure aims to establish a scalable framework that balances accuracy and efficiency, aligning the depth of each investigation with the complexity of the required data. This approach seeks to strike a balance between operational effectiveness and the practical constraints of limited resources and funding.

Table 6 Tool list for an in-depth road crash investigation program based on time of use and budget.

Phase	Tools options		
	Basic	Medium	Advanced
Crash Scene & Vehicle investigation	Mechanical measuring instruments: measuring tape, measuring wheel Notepad with web connection (1/team) GPS Surveying Equipment Station Digital single-lens reflex (SLR) camera (even a smartphone) Computer Aided Drawing (CAD) Software	Mechanical measuring instruments: measuring tape, measuring wheel Notepad with web connection (1/team) GPS Surveying Equipment Station Digital single-lens reflex (SLR) camera Computer Aided Drawing (CAD) Software Unmanned aerial systems (UAS): Drone Digital images and 3D point cloud editing software	Mechanical measuring instruments: measuring tape, measuring wheel Notepad with web connection (1/team) GPS Surveying Equipment Station Digital single-lens reflex (SLR) camera Computer Aided Drawing (CAD) Software Unmanned aerial systems (UAS): Drone Digital images and 3D point cloud editing software Laser Scanner Event Data Recorder (EDR) reader device with vehicle's connections
Crash Reconstruction		Crash reconstruction software (2 licenses) Workstation (2)	Crash reconstruction software (4+ licenses) Workstation (4+)

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3.4. CRASH INVESTIGATION TEAM PROFILES

As previously stated, the composition of the crash investigation team must be multidisciplinary, given the nature of the work. The objective is to arrange the team in accordance with the number of personnel and their respective areas of expertise, including traffic crashes, injury management, and other factors such as the environment, societal impact, and numerous others. As previously indicated in section 2.1.5, the investigation team must possess an understanding of the intricate interconnectivity between environmental, vehicular, and human factors. Consequently, the profiles of the aforementioned team should encompass expertise from a multitude of scientific disciplines, including but not limited to technical, biological, and social sciences. This conclusion is derived from an analysis of the processes involved in crash investigation, data acquisition and analysis, and reporting (Sandin, 2005).

It is recommended that the team be composed of individuals with the following expertise, each of whom should be assigned certain specific tasks (see Section 3.5 “Team operational options” and Table 7 for the team composition based on the program level):

- Road engineering.
- Vehicle engineering and biomechanics.
- Physical trauma management.
- Emotional trauma management.

A Road Engineering expert is a civil engineer or similar professional with specialized expertise in road design, road safety audits, and traffic management, particularly with a focus on reducing crash risks and enhancing roadway safety. This expert plays a critical role in the design, assessment, and improvement of roadway infrastructure, requiring a deep understanding of road geometry, traffic flow patterns, and the environmental and human factors that contribute to crash occurrences. They evaluate key safety factors such as sight distance, road surface conditions, signage, and traffic barriers to mitigate collision risks. In crash investigations, they have strong skills in terms of assessment and audit of factors such as sight distance, road surface conditions, signage, and traffic barriers, and therefore, it is an essential member of the investigative team.

A Vehicle Engineering and Biomechanics expert is an individual with specialized expertise at the intersection of mechanical engineering and human biomechanics, dedicated to the study, design, and optimization of vehicular systems to ensure occupant safety and reduce injury risks. This role requires advanced knowledge of vehicle dynamics, including stability, control, and structural crashworthiness, integrated with biomechanical principles that examine the response of the human body under various forces encountered during vehicular incidents. Through empirical research, computational modelling, and experimental validation, such an expert assesses and predicts injury mechanisms, informs the development of regulatory safety standards, and contributes to the creation of advanced protection systems. Their work is pivotal in advancing vehicular safety innovations and refining safety standards to enhance public health outcomes (Probst, 2014).

A Physical Trauma Management specialist in a crash investigation team must possess a blend of clinical and analytical skills essential for both immediate response to injuries and systematic injury assessment. This expert's role requires proficiency in emergency first aid and advanced trauma care, enabling them to stabilize crash victims and provide critical initial treatment at the scene, if needed. They must be adept at conducting rapid, accurate assessments of injuries under pressure conditions, prioritizing life-saving interventions while minimizing further harm. In addition to their emergency medical skills, a Trauma Management specialist must be trained in injury documentation and coding, particularly using AIS. This requires an understanding of anatomical injury classifications and severity scoring, enabling them to systematically record and categorize injuries according to standardized scales used in crash investigations. This dual expertise allows the Trauma Management specialist to support the investigative team by providing accurate data on injury types and severities, which is crucial for analysing crash dynamics, determining the effectiveness of safety systems, and informing improvements in road safety. Mo et al., (2019) found out that collaboration, communication, and decisiveness as the most preferred attributes of a trauma team leader. For a trauma management specialist in a crash investigation team, possessing these key leadership traits, alongside strong organizational and protocol adherence skills, is essential - not only for providing immediate care but also for effective coordination within a rapidly assembled team, ensuring accurate injury assessment, documentation, and data collection, crucial for understanding trauma outcomes and advancing road safety.

An Emotional Trauma Management could be a traffic psychologist that brings a unique and essential perspective to a crash investigation team, enhancing both the epistemological and preventive aims of the investigation. Their role goes beyond identifying physical or mechanical causes; it includes understanding the human factors that contribute to crash incidents. Traffic psychologists' study behavioural, cognitive, and emotional elements influencing drivers, passengers, and pedestrians, providing insight into the human decisions and psychological states that may have played a role in a crash. By analysing patterns in driver behaviour, such as risk perception, attention lapses, stress, and decision-making under pressure, they help uncover subtle, often overlooked factors that could contribute to an accident. This specialist also contributes to the moral and existential dimensions of accident investigation. By examining the psychological roots of human error or risky behaviour, they help frame the crash not merely as a technical failure but as an event shaped by complex, interwoven psychological and situational influences. This perspective aligns with societal expectations that crash investigations make human suffering "accountable to reason" by connecting the accident's cause to factors open to correction and prevention. In doing so, traffic psychologists move the investigation beyond simple attribution of fault to single acts or individuals, advocating for broader, systemic understandings that support long-term preventive measures. Their input can transform findings into targeted interventions for improving traffic safety through education, policy changes, and behaviour-modifying strategies, ultimately contributing to a safer and more accountable transportation environment. A traffic psychologist should have skills to conduct interviews, investigate drivers', pedestrians', cyclists' behaviour, and decision-making processes in a particular situation (Dekker, 2015).

3.5. TEAM OPERATIONAL OPTIONS

The proposed Operational Team for traffic safety research in Africa addresses the need for a structured, adaptable approach to enhance the collection and analysis of road safety data. The operational team is structured to operate at three progressive levels: *Basic*, *Medium*, and *Advanced*.

The rationale behind the proposed multilevel structure is to provide a scalable framework that is balanced in terms of accuracy and efficiency, matching the scope of each investigation to the complexity of the data required. This framework is designed to achieve a compromise between operational effectiveness and the realities of limited resources and funding.

The initial, *Basic* level is consistent with the foundational requirements proposed by the ARSO in their proposal to define a common set of indicators to be collected for the purpose of analysing and monitoring traffic safety at the country level (Segui-Gomez, 2021). As the operational team progresses to the *Medium* and *Advanced* levels, the investigation will expand to include a greater variety of data (variables) collected at greater frequency and depth. This will increase the robustness of the safety analyses.

The progressive increment in the complexity of data collection methods and variable coverage at each level will facilitate a more detailed and comprehensive understanding of the dynamics of road crashes and the associated risk factors. Concomitantly with these developments, the financial resources required to maintain the team will increase in line with the growth in operational capacity, enabling the acquisition of additional personnel, technology and infrastructure necessary for each level of expanded operations. Thus, this progressive structure ensures that, despite the constraints on resources, the operational team is able to adapt to differing levels of funding and logistical support.

The team's multi-level framework offers a scalable model for strengthening road safety efforts, providing an adaptable solution that aligns with both academic and stakeholder goals to improve traffic safety across Africa. Moreover, the operational flexibility of this framework is designed to adapt to the growing needs of road safety research, allowing investigations to go beyond standard procedures as they scale up to deal with more complex case. This enables the investigation programme to deliver high-quality, data-driven evidence to support advances in crash prevention and road safety.

Each level is characterised by distinct operational capabilities and investigative depth. However, it should be noted that the following figures are not to be taken as definitive data, but rather as a basic point of reference.

- **Basic Option** – represents the foundational level of investigation, suitable for routine crash cases where data demands are minimal, and complexity is low. A small team size is designated, focusing on collecting essential data points necessary for a preliminary understanding of the crash dynamics. This configuration allows for a limited daily sampling rate, enabling the investigation team to handle cases efficiently while maintaining fundamental data integrity. The Basic Option is designed to deliver a cost-effective investigative approach without sacrificing essential data quality, making it an ideal choice for cases where detailed, multifactorial analysis is not critical. It prioritizes essential resource allocation, with minimal overhead, ensuring operational viability for a range of straightforward cases.

- **Medium Option** – expands on the Basic configuration by increasing team size, data complexity, and daily sampling capabilities. It is designed to address cases of moderate complexity, where more detailed insights into crash factors are necessary. The medium-tier team is equipped to handle a broader scope of data collection, capturing additional variables such as environmental conditions, vehicle dynamics, and extended human factors that may have influenced the crash outcome. This option balances efficiency with enhanced analytical depth, allowing for a more nuanced understanding of moderate-level incidents while maintaining reasonable cost parameters. By incorporating an intermediate level of detail and sampling frequency, the Medium Option provides a comprehensive, yet resource-conscious solution for a range of more involved investigations.
- **Advanced Option** – represents the entry-level of the highest tier of investigation. This configuration involves the largest team size and highest sampling rate, enabling exhaustive data collection that includes a wide array of factors such as biomechanical assessments, advanced vehicle dynamics, and detailed reconstructions of pre- and post-crash conditions. The Full Option's resource-intensive nature is balanced by its ability to deliver the most comprehensive level of analysis, making it ideally suited for high-stakes cases where precise insights are critical for understanding intricate crash dynamics and informing preventive measures. While the Full Option incurs the highest operational costs, it ensures maximum data accuracy and depth, providing an invaluable resource for cases that demand extensive investigatory rigor.

Table 7 shows the composition of the operational team divided into two main categories: Investigation Team(s) and Back Office Team, reflecting the increase in operational complexity and depth of investigative capabilities.

Table 7 Tool list for an in-depth road crash investigation program based on time of use and program budget.

Category		Team Operational Options (# of team members / time commitment)		
		Basic	Medium	Full
Investigation Team(s)	Crash Specialist	2 full-time	4 full-time	6 full-time
	Trauma Management Specialist (Medical doctor or Healthcare assistant)	-	1 part-time (50%)	3 full-time
	Psychologist	-	1 part-time (50%)	2 full-time
	Crash Reconstruction Specialist	-	2 full-time	4+ full-time
Backoffice Team	Data Entry Specialist	Performed by crash investigators and/or the database management specialist	1 full-time	2 full-time
	Database Management Specialist	1 part-time (25%)	1 part-time (75%)	1 full-time
	Administration & Fundraising Specialist	1 part-time (25%)	1 part-time (75%)	1 full-time
Total number of members (summation over all teams)		*4*	*11*	*19+*

3.6. GUIDELINES FOR THE EXPERT REVIEW BOARD SKILLS

The expert review board is a multidisciplinary team established to ensure a comprehensive, accurate, and impartial evaluation and validation of road crash cases, playing a critical role in uncovering the causes of incidents, validating evidence, and providing insights that contribute to improved road safety and injury prevention.

The review board tasked with validating road crash cases must possess a diverse range of skills tailored to their specific assessment responsibilities. A strong foundation in the principles of physics is essential, enabling members to understand crash kinematics and dynamics, including the interactions between vehicles and the forces involved during collisions. Familiarity with crash reconstruction techniques and software will further enhance their ability to accurately simulate crash scenarios and analyse the sequence of events.

Members should have a solid understanding of human anatomy and injury patterns to effectively link injuries to their causes. This requires skills in forensic analysis, allowing the board to scrutinize medical reports and correlate findings with crash data, ensuring a comprehensive evaluation of causation. Attention to detail is critical, as identifying discrepancies between the evidence and reported injuries can significantly impact case validity.

A deep understanding of biomechanics is also necessary. Board members are asked to validate what found by the investigation team and the crash reconstructionist personnel. This expertise will enable them to recognize and interpret injury mechanisms, working alongside medical professionals to understand the implications of different injury patterns. Experience with biomechanical modelling and simulations is valuable, providing insights into potential injury outcomes based on crash dynamics.

In addition to these skills, the board must also consider the influence of roadway conditions on crash outcomes. A background in traffic engineering will help members evaluate how factors such as roadway design, traffic control measures, and environmental conditions contribute to crash severity. Proficiency in conducting field investigations to assess road conditions and signage related to the crash scene is equally important.

By combining technical proficiency, analytical abilities, and effective communication skills, the review board will be well-equipped to produce thorough and reliable assessments of road crash cases. Their interdisciplinary collaboration with engineers, medical experts, and traffic professionals will further enrich the review process, leading to informed conclusions and recommendations for future safety improvements.

3.7. IN-DEPTH CRASH INVESTIGATION PROGRAMME OPTIONS

The Programme Options (Basic, Medium, Full) reflect a strategic scaling in resources, personnel, and database capacities, with each level designed to support more detailed, resource-intensive crash investigation efforts (Table 8). Core elements, such as ethical standards and an expert review board, are consistently prioritized across all levels. As the program advances, it incorporates more comprehensive database options, tool packs, and sampling methods, including on-scene sampling in the full option for immediate data collection. The investigation team structure also intensifies, with increased team availability and expanded roles for crash reconstruction and database management at higher levels. Additionally, financial oversight becomes more robust, with a full-time funding expert in the full option to support the program's enhanced complexity.

- Ethics: Ethics compliance is mandatory across all options, ensuring all programme levels meet ethical standards.
- Sampling Strategy:
  - *Basic*: Uses a retrospective approach with a sampling radius of up to 30 km from the team location. This suggests data collection occurs after road crashes have already been reported.
  - *Medium* and *Advanced*: Both have an on-the-scene strategy, with a wider radius of 40–50 km. This proactive approach likely involves immediate data collection at crash sites, offering more timely and potentially detailed data.
- Database: The data storage and management system vary in complexity, with the Basic option providing a basic database, Medium with a medium level, and Advanced using a comprehensive database. This reflects an increasing capability to store, analyse, and manage data as you move up the levels.
- Weighting Strategy: All options use a weighting strategy based on national variables, which may standardize data across regional or national scales for consistency.
- Expert Review Board: This is not available in the Basic option as no crash reconstruction and injury-to-cause linkage is performed but is mandatory in both the Medium and Advanced options, suggesting a higher level of oversight and validation for the more advanced programmes.
- Tool Pack: Tools provided increase in complexity from basic in the Basic option to full in the Advanced option. This likely affects the depth and type of data analysis that can be performed.

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- Investigation Teams:
  - *Basic*: One team available per day, operating five days a week.
  - *Medium*: Two teams per day, operating five days a week. Moreover, in order to guarantee comprehensive coverage of the three daily time slots (6-14, 14-22, 22-6), each team will perform a weekly time rotation (shift).
  - *Advanced*: Three teams available daily, covering seven days a week, providing the most extensive investigation coverage. Moreover, in order to guarantee comprehensive coverage of the three daily time slots (6-14, 14-22, 22-6), each team will perform a weekly time rotation (shift).

Table 8 Options for a crash data collection system based on three budget levels.

Category	**Programme options**		
	Basic	**Medium**	**Advanced**
Ethics	mandatory	mandatory	mandatory
Sampling strategy	retrospective up to 30 km from the team location	on-the-scene up to 40-50 km from the team location	on-the-scene up to 40-50 km from the team location
Database	basic	medium	full
Weighting strategy	based on national variables	based on national variables	based on national variables
Expert Review Board	-	mandatory	mandatory
Tool Pack	basic	medium	full
Investigation Team(s)	1 team/day 5-days a week	2 team/day 5-days a week	3 team/day 7-days a week

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4. IN-DEPTH CRASH DATASET AND DATABASE DEFINITION

4.1. DEFINITION AND USE

An in-depth crash database is a collection of detailed and comprehensive information about road features, injuries and vehicle crashed data both in terms of vehicle features and deformations that kineto-dynamic parameters coming from EDR and crash reconstruction. It is usually compiled by a team of medical and technical experts and police specialists who gather the necessary information soon after the crash. As illustrated above, there are three principal distinctions between an in-depth crash database and a national one:

- Number and type of crashes collected: an in-depth database typically includes a smaller, more selective set of crashes compared to a national database. Cases are selected based on specific research objectives, focusing on details that align with the aims of the research programme.
- Geographical scope: data collection for an in-depth database is generally limited to a specific, often smaller, geographical area, typically within a radius of 40 km from the location of the operational team.
- Detail and quantity of data: the number of variables collected in an in-depth database may range from a few hundred to several thousand, depending on the level of detail required for the research.

This database is an essential resource for investigating the causes of the crash and determining injury patterns. It contains a combination of data on injury severity, vehicle damage, and other contributing factors that are crucial for identifying safety measures to prevent future crashes. The in-depth crash database plays a vital role in promoting road safety by providing valuable information that can be used to develop evidence-based policies and interventions to reduce the frequency and severity of crashes (Thomas, P., et al., n.d.).

The importance of in-depth crash data is widely recognized, and efforts are being made to improve its collection and dissemination. Many countries have established national crash data systems (CADaS, MMUCC, ARSO mini CADas, etc.), which collect and analyse data from police reports, hospital records, and other sources (ITF, 2016). Nonetheless, the in-depth crash data collection programs are crucial for understanding the causes and consequences of road crashes and for developing effective safety strategies. Such data provides insights into the circumstances, factors, and harm suffered in crashes, leading to the development of safety systems, evaluation of road infrastructure, and identification of areas for improvement. In-depth crash data is also valuable in understanding driver behaviour, developing targeted education and awareness campaigns to improve driver safety, and for informing road safety policies and initiatives (Lenard, J. A., 2017).

4.2. RATIONALE FOR DATABASE DEFINITION

As already discussed with regard to the structuring of the investigation programme, the composition of the operational team and the choice of the tools required for data collection, the same database was proposed in the three options: Basic, Medium and Advanced.

This subdivision was designed to allow for progressiveness in the acquisition of information, which would lead to an increase in the size of the operational team and the tools required for the collection or analysis of each case. Progressiveness has been structured on several levels, taking into account, among other, the number of cases to be collected, the level of detail required and the availability of economic resources. This allows the definition of a highly scalable programme that can be adapted to specific needs and economic budgets.

The allocation of variables to the database was made according to the difficulty of finding information, both in terms of the skills and tools required and the agreements and collaborations to be activated (e.g., with hospitals). In addition, the selection of variables was influenced by two relevant factors. The first is the possibility of contextualising the data in the national context, so that the analyses carried out at an in-depth level can be extended to a national dimension. This is ensured by the inclusion of all variables in the ARSO protocol. The second factor concerns the possibility of linking the proposed database to others at international level, with the double advantage of simplifying the comparability of specific analyses thanks to the adoption of clearly defined variables.

4.3. DATA STRUCTURE

Rationale

In this section, recommendations and guidelines for a minimum set of data collection procedures and standard definitions that could be applied to the African context are outlined. For that purpose, relative manuals from African, European, and international projects were exploited by giving emphasis on the data structure, definitions, and formats for the most important and common variables in an in-depth crash database. The establishment of international rules for crash data variables, values, structure and definitions has been recommended by several international research projects and some efforts for harmonizing accident data at the international level have already taken place (e.g., CARE system).

The selection of data elements and variables is based on the integrated analysis of reputable sources, including the WHO (2010) Report on Data Systems, CADaS, MMUCC, and ARSO-recommended crash-related data sets. The data structure, definitions, and formats for the most common variables are adapted mainly based on the CADaS database. Additionally, selected variables from the MMUCC database are adapted to enhance the completeness and efficiency of the database while considering their practicality and potential for meaningful insights.

The definitions of variables in various databases are primarily based on the guidelines provided by the WHO. While it is important to adapt the definitions to local conditions, such as excluding weather conditions like snow or ice in hot climates, preserving the provided definitions is crucial to ensure data consistency and comparability on both national and global levels, allowing for meaningful insights, and accurate assessments in the field of road safety (WHO, 2010).

The database adopts existing standardized international definitions of variables and values which are accompanied by a concise description, highlighting their importance and usefulness in crash analysis. Most of the variables included in the database are carefully selected to constitute the minimum data sets that must be recorded to ensure sufficient information about the crash is available. These variables are deemed obligatory, meaning they must be collected to provide a comprehensive understanding of the crash event. By adhering to these obligations and including these essential variables in the data collection process, the database can capture crucial information necessary for in-depth analysis and evaluation of road safety.

Accordingly, the data structure is organized into seven categories, hereafter indicated as tables, which are related one each other as shown in Figure 27.

- Crash-related variables
- Road-related variables
- Participant-related variables
- Person-related variables
- Safety-System-related variables
- Injury-related variables
- Reconstruction-related variables

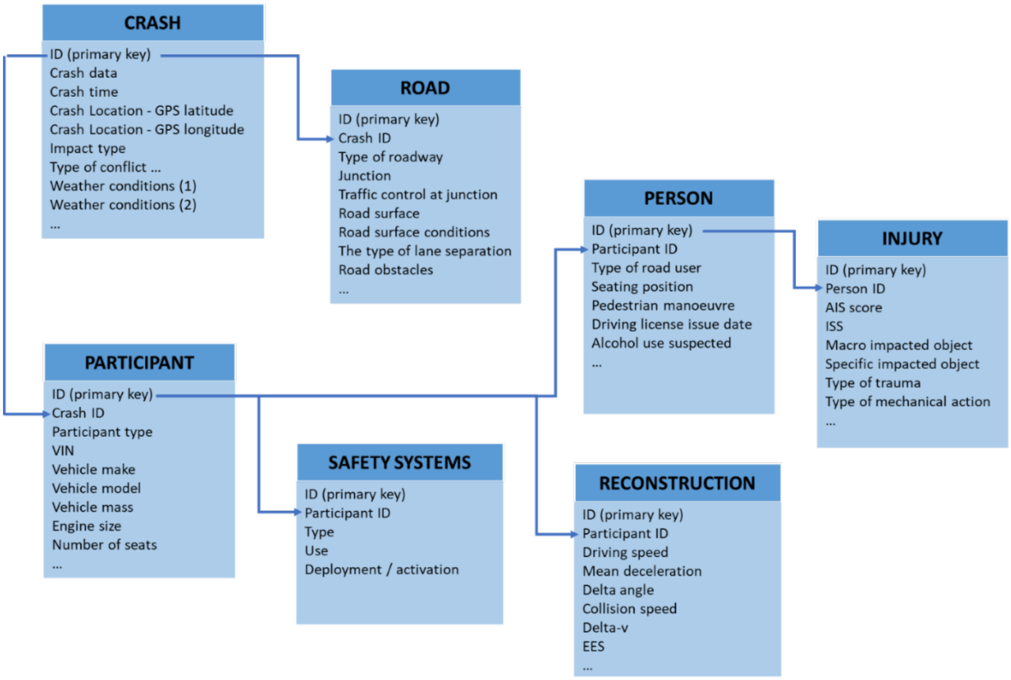

Figure 27 TransSafe Database structure.

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In particular, the table Participants collects the characteristics of all categories of road users who are involved in the road crash event in question. These include, but are not limited to, car occupants, bus users, motorcycle and bicycle riders, and so forth. While the table entitled "Person" collects all the information relative to each person involved in the event.

Table 9 outlines the number of indicators included in different "Dataset Options" across various category indicators related to crash investigations. The Basic option provides a limited dataset with essential indicators (90 indicators), while the medium option (172 indicators) adds more detail, especially in participant and road-related categories. The Full option (223 indicators) includes all categories and maximizes the number of indicators, particularly in person-, injury-, and reconstruction-related areas, allowing for the most in-depth investigation. This progression reflects a trade-off between data complexity and resource requirements, with the Full option being the most thorough but also the most resource-intensive.

Table 9 Number of variables grouped for category indicators and dataset options.

Category Indicators	Dataset Options		
	Basic	Medium	Advanced
Crash-related	20	22	22
Road-related	18	22	26
Participant-related	15	38	55
Person-related	37	57	76
Safety System-related	-	6	6
Injury-related	-	-	11
Reconstruction-related	-	27	27
Total	**90**	**172**	**223**

For each of the variables included in the dataset, the following information are presented:

Sources: This is the name of the dataset from which the variable is derived.

Table: The name of the database table where the variable is stored.

Variable name: The designation of the variable employed within the database for the purpose of storing the pertinent piece of information.

Variable Label: The label of the proposed variable.

Variable definition and scope: A brief description of the variable is provided, followed by the importance and usefulness of the variable, explaining the rationale behind its selection.

List of values/modalities: The attribute values to each variable are listed.

Data Type: The way in which each variable has to be provided, such as numeric, text, etc.

Programme option: The programme options are basic, medium and full. All the variables listed for each type of programme are to be considered mandatory. With regard to the full option, the number of variables is the minimum that should be used to ensure a comprehensive road crash database.

Referring to Annex 1 to outline the specific definition of the TransSafe dataset and the coding of all variables.

Notes

This section provides general guidelines for the correct interpretation of the dataset, with a particular focus on the explanation of specific variables.

In particular, we refer to the type of collision, which is represented by four distinct variables: the variables designated as COLLTYPE1, COLLTYPE2, COLLTYPE31, and COLLTYPE32 are used to categorise the type of collision. The inclusion of these variables is based on two main reasons. On one hand, the presence of this variable in the national ARSO dataset allows for weighting the collected data against the national context; on the other hand, the same variable is present in the international IGLAD dataset, which enhances data compatibility. COLLTYPE31 and COLLTYPE32, in contrast, originate from the U.S. dataset MUMUCC and provide more detailed information on the impacted objects.

The following is an illustrative example:

- COLLTYPE1: Fixed obstacle (ID3)
- COLLTYPE31: Traffic Barriers and Parts (ID3)
- COLLTYPE32: Guardrail End (ID4)
- COLLTYPE2: Leaving the carriageway to the right (ID8)

Similar considerations apply to the ROADLOC1-5 and ROADJUNCTION variables. ROADLOC1-5 variables come from the MUMUCC dataset, which adopts a more detailed classification, while ROADJUNCTION is included in the national ARSO dataset, also contributing to the data weighting process.

Likewise, the PARTTYPE1 and PARTTYPE2 variables, originating from the ARSO and IGLAD datasets, respectively, offer different levels of distinction among vehicle types. Although partially overlapping, these variables enhance comparability with other databases.

Furthermore, it should be noted that the base and medium versions of the dataset include a variable for the presence of the vehicle's ABS system, as this characteristic is easily identifiable and not deactivatable if specified in the vehicle's technical sheet.

Lastly, it is specified that the variables derived from the MUMUCC and IGLAD datasets correspond exactly to those officially listed in the respective codebooks.

4.4. DATABASE STRUCTURE

To effectively store and manage road crash cases, a well-structured database is essential. A database is a structured collection of data, organized for easy access, management, and update. In this case, it would contain all relevant data about each crash case, such as date, location, vehicle types, injuries, and environmental conditions, allowing for systematic storage, retrieval, and analysis.

To manage this data efficiently, a database management system (DBMS) could be used. A DBMS provides the tools necessary for creating, modifying, and querying databases. It ensures data integrity, security, and multi-user access. Common examples of DBMSs include Microsoft Access, MySQL, and MongoDB. For structured, relational data like crash cases, a Relational Database Management System (RDBMS) is often ideal.

An RDBMS stores data in structured tables that relate to each other through keys, making it highly organized and accessible. This structure is particularly advantageous for crash data, where relationships exist between various entities, such as people, vehicles, and crash locations. RDBMSs support SQL (Structured Query Language), enabling efficient data retrieval and complex queries, which is critical for analysing crash data. Key advantages of an RDBMS include data consistency, ease of access, and support for complex data relationships.

To enhance access and usability, a 3-Tier Web Architecture is commonly employed, dividing the system into three layers: presentation, logic, and data.

- Presentation Layer: this layer is the user interface, where users interact with the database, typically through a web or desktop application. For example, investigators could use a web interface to enter crash data or retrieve reports. The presentation layer communicates with the logic layer to retrieve and display information in an accessible format.
- Logic Layer: this layer processes user inputs, applies business rules, and handles the communication between the presentation and data layers. In a crash data system, the logic layer could include processing functions to validate data entries or apply algorithms for categorizing crashes. This layer ensures that data operations follow the rules set for accuracy and consistency.
- Data Layer: also called the database layer, stores the data itself. It consists of the physical database and handles data storage, retrieval, and updates. For instance, in a road crash database, this layer would contain tables for crashes, vehicles, and drivers, structured and connected through the RDBMS.

To support this 3-tier architecture, a Local Area Network (LAN) is usually required to ensure a smooth flow of data between the layers, especially in environments where multiple users may be inputting or querying data simultaneously. Finally, it is mandatory to implement robust security measures to protect data access. This may involve user authentication, encryption, and access controls to prevent unauthorized access, ensuring the sensitive information in crash cases remains secure.

4.5. AVAILABILITY OF DATA AND POSSIBLE SOURCES

The availability of individual data variables is a significant challenge when it comes to road safety data in African countries. It is widely recognized that there is a lack of comprehensive and reliable road safety data in these regions. Even when data are available, there is often limited information about the data collection systems, data definitions, and other crucial aspects (Tomas P. et al., 2019). Although data for most of the selected data sets in the data structure are likely to be available, ensuring easy access to all the required information will be challenging unless substantial efforts are dedicated to establishing a system that makes this information easily available and usable. The selected variables are crucial for comprehensive analysis and effective management of road crashes. Therefore, it is necessary to exploit multiple sources, such as police reports, hospital records, vehicle and driver insurance reports, National IDs, driver licenses, death certificates, and road inventory information, to collect the data and bridge any existing gaps in data availability for the different variables (WHO, 2010).

However, it is essential to prioritize the sources to ensure consistency and a higher level of accuracy in the collected data. Establishing clear guidelines on the preferred sources and their respective roles in data collection is crucial. Moreover, creating a comprehensive road safety data system requires substantial dedication and collaboration among relevant stakeholders, including government agencies, law enforcement, healthcare institutions, and other key entities (Segui-Gomez, 2021). Above mentioned report established forty-seven variables and their associated values were eventually chosen as the recommended minimum crash-related data points for voluntary collection in the national crash data systems of African countries. Although all variables were marked as "mandatory," countries were allowed to use responses like "N/A" when specific information was not available (Segui-Gomez, 2021).

5. CONCLUSION

The TRANS-SAFE project represents a transformative contribution to the global effort to mitigate road traffic accidents, with a particular focus on Africa. Through this deliverable, the project addresses a critical gap in road safety by proposing a structured, scalable framework for in-depth crash investigation. This framework integrates the latest advancements in data collection, analysis, and interpretation while adapting to the unique challenges and resource constraints of various regions. The deliverable embodies a commitment to creating safer road systems and enhancing the effectiveness of crash investigation practices worldwide.

The comprehensive review of global best practices highlighted the variability in crash investigation standards and methodologies, from national-level databases to in-depth crash studies. By synthesizing this information, the project emphasizes the importance of harmonizing data collection practices. It aligns with international standards such as the CADaS and the MMUCC, ensuring compatibility with existing frameworks. This alignment facilitates international collaboration, enabling cross-border sharing of insights and strategies to improve road safety outcomes.

The core of the TRANS-SAFE framework is the multidisciplinary approach. The proposed crash investigation teams are designed to include experts from diverse fields such as road engineering, vehicle safety, biomechanics, and trauma management. This ensures a holistic understanding of crash dynamics, from environmental factors to human behaviour and vehicle performance. The deliverable also provides flexibility by outlining multiple operational options (basic, medium, and advanced), allowing adaptation to various levels of complexity, resource availability, and data collection needs.

Scalability is a key strength of the framework. The tiered approach enables research groups with differing economic capacities to implement tailored investigation programmes, ranging from minimal resource setups to advanced, fully equipped operations. This adaptability ensures that even research group with limited infrastructure can begin building effective crash investigation capabilities.

The project recognizes the transformative potential of technology in improving the accuracy and efficiency of crash investigations. By incorporating advanced tools such as LiDAR, UAVs, and photogrammetry, the framework enables the collection of precise, high-quality data. These technologies facilitate detailed crash reconstruction, enhancing the ability to identify causal factors and injury mechanisms. Furthermore, the emphasis on data integrity, including robust sampling strategies, weighting procedures, and ethical guidelines, ensures that collected data is both reliable and responsibly managed.

The deliverable also introduces a standardized minimum data structure that balances comprehensiveness with practicality. This structure supports meaningful analyses while maintaining compatibility with international datasets. It includes essential variables covering crash details, road conditions, vehicle dynamics, and occupant characteristics, enabling an in-depth understanding of road crash events.

The framework is built on a strong ethical foundation, recognizing the sensitivity of crash data, particularly when it involves personal and medical information. The deliverable outlines strict guidelines for data confidentiality, informed consent, and responsible sharing, ensuring compliance with national and international privacy regulations. By fostering trust among stakeholders – including investigators, policymakers, and the public – the project creates a supportive environment for long-term collaboration.

The TRANS-SAFE framework lays a solid foundation for further advancements in road safety research and practice. Future iterations of the programme could integrate emerging technologies such as artificial intelligence and machine learning to automate data analysis and improve predictive capabilities. Expanding collaboration with local and international stakeholders will also enhance the programme's scalability and impact, ensuring its relevance in a rapidly evolving landscape.

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7. ANNEXES

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7.1 ANNEX 1 – TRANS-SAFE DATABASE PROPOSAL

(Programme levels: B – Basic; M – Medium; A – Advanced)

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
arso/iglad	CRASH	CASENR	Crash identification number (ID)	-	The unique identifier (e.g., a 10-digit number) within a given year that identifies a particular crash.	Num.	x	x	x
arso/iglad	CRASH	DATA	Crash data	-	The date (day, month, and year), on which the crash occurred.	Num.	x	x	x
arso/iglad	CRASH	TIME	Crash time	-	The time at which the crash occurred, using the 24-hour clock format (00.00-23:59).	Num.	x	x	x
arso/iglad	CRASH	GPSLAT	Crash Location - GPS latitude	-	GPS latitude about the exact location at which the crash occurred.	Num.	x	x	x
arso/iglad	CRASH	GPSLONG	Crash Location - GPS longitude	-	GPS longitude about the exact location at which the crash occurred.	Num.	x	x	x
iglad	CRASH	ACCDESC	Crash description	-	Here is a comprehensive description of the accident made by the Case Administrator. Besides a general description follow items should be indicated: addition of all relevant technical and medical characteristics to accident genesis and consequences of accidents. Based on the de-scription, the circumstances of the accident must be understandable even for an outsider.	Text	x	x	x
arso	CRASH	COLLTYPE1	Crash type 1	1 Pedestrian 2 Parked vehicle 3 Fixed obstacle 4 Non-fixed obstacle	The crash type is characterized by the first injury or damage-producing event of the crash.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				5 Animal 6 Single vehicle crash/non-collision 7 Crash with two or more vehicles 88888 Other crashes					
iglad	CRASH	COLLTYPE2	Crash type 2	1 Collision with another vehicle which starts, stops or is stationary 2 Collision with another vehicle moving ahead or waiting 3 Collision with another vehicle moving laterally in the same direction 4 Collision with another oncoming vehicle 5 Collision with another vehicle which turns into or crosses a road 6 Collision between vehicle and pedestrian 7 Collision with an obstacle in the carriageway 8 Leaving the carriageway to the right 9 Leaving the carriageway to the left 88888 collision of another type 99999 unknown	Moving direction of the involved vehicles at the point of the first collision on the roadway or the first mechanical impact on a vehicle of there was no collision between the opponents	Num.	x	x	x
mmucc	CRASH	COLLTYPE31	In case of a collision with a	1: Bridge Parts 2: Structures	In a case of a Collision With Fixed Object	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
			fixed obstacle, select the object impacted	3: Traffic Barriers and Parts 4: Posts, Poles, and Supports 5: Other Trafficway Components 6: Other Specific Fixed Objects 7: Parked vehicles 88888 Other 99999 Unknown					
mmucc	CRASH	COLLTYPE32	And select the specific object impacted	1.1 Bridge Overhead Structure 1.2 Bridge Pier or Support 1.3 Bridge Rail (includes parapet) 2.1 Building 2.1 Wall 3.1 Cable Barrier 3.2 Concrete Traffic Barrier 3.3 Guardrail Face 3.4 Guardrail End 3.5 Impact Attenuator or Crash Cushion 3.6 Other Traffic Barrier 4.1 Traffic Sign or Support 4.2 Traffic Signal or Support 4.3 Utility Pole or Light Support 4.4 Other Post, Pole, or Other Supports 5.1 Culvert 5.2 Curb	In a case of a Collision With Fixed Object	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				5.3 Ditch 5.4 Embankment 6.1 Boulder 6.2 Ground 6.3 Tree (standing only) 6.4 Shrubbery 6.5 Snowbank 6.6 Fence 6.7 Mailbox 6.8 Fire Hydrant					
arso	CRASH	IMPTYPE	Impact type	0 No impact between motor vehicles 1 Single vehicle 2 Rear-end impact (front-to-rear or rear-to-front) 3 Head-on impact (front to front) 4 Angle impact, same direction 5 Angle impact, opposite direction 6 Angle impact, right angle 7 Angle impact, direction not specified 8 Side-by-side impact, same direction (sideswipe) 9 Side-by-side impact , opposite direction (sideswipe) 10 Rear to side impact 11 Rear to rear impact	Indicates the manner in which the road motor vehicles involved initially collided with each other (first harmful event). The variable refers to the first impact of the crash, if that impact was between two road motor vehicles. See Figure 5. Manner of collision and associated crash diagrams, in the MMUCC codebook, NHTSA DOT HS 813 525 January 2024.	Num.	x	x	x
iglad	CRASH	ACCTYPE	Type of situation or the conflict	See IGLAD Codebook	The type of accident describes the situation or the conflict that led to	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
			that led to the crash		the accident. It is coded according to the catalogue of the HUK from 1977 or alternatively the modified version for left hand traffic. [REF. IGLAD Codebook Phase 4: 2021]				
iglad	CRASH	ACCTYPEA	Select or insert the participant A (PARTNR) referring crash type (ACCTYPEA)	-	The participant (PARTNR) of Participant A referring to the accident type (see ACCTYPE) is given. [REF. IGLAD Codebook Phase 4: 2021]	Num.	x	x	x
iglad	CRASH	ACCTYPEB	Select or insert the participant B (PARTNR) referring crash type (ACCTYPEB)	-	The participant (PARTNR) of Participant B referring to the accident type (see ACCTYPE) is given. [REF. IGLAD Codebook Phase 4: 2021]	Num.	x	x	x
arso/iglad	CRASH	WEATHER1	Weather conditions (1)	Clear, bright; Cloudy; Rain; Snow, hail; Fog, mist or smoke; Sleet, hail; Severe winds; Other weather condition; Unknown weather condition	No hindrance from weather, neither condensation nor intense movement of air. Clear and cloudy sky included.	Num.	x	x	x
arso/iglad	CRASH	WEATHER2	Weather conditions (2)	Clear, bright; Cloudy; Rain; Snow, hail; Fog, mist or smoke; Sleet, hail; Severe winds; Other weather condition; Unknown weather condition	Rain - Heavy or light.	Num.	x	x	x
arso/iglad	CRASH	LIGHTCON	Light conditions	1 Daylight 2 Twilight 3 Darkness 4 Dark with streetlights	The level of natural and artificial light at the crash location, at the time of the crash.	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				unlit 5 Dark with streetlights lit 6 Sudden change 9 Unknown					
iglad	CRASH	MAINFACT	Main contributing factor	Basic Version 1 none 2 alcohol 3 use of wrong lane or illegal road usage 4 violation against lane discipline (e.g. driving on outside lane) 5 overtaking on the wrong side (undertaking) 6 overtaking into oncoming traffic 7 overtaking into unclear traffic situation 8 overtaking without adequate visibility 9 overtaking without consideration and adequate warning to following traffic 10 mistake in returning to initial lane 11 other overtaking mistakes 12 mistake when being overtaken, e.g. swerving, accelerating 13 disregarding the oncoming traffic's right of way when passing	The contributing factor that has the main (most critically) influence in triggering the accident. ‘Alcohol’ is not necessarily a main contributing factor for the accident because it only fosters wrong behavior but drinking does not always lead to an accident. Thus, the main contributing factor must be another one. The main contributing factor "MAINFACT" has to be coded again in one of the contributing factors "FACTOR1"/"FACTOR2"/"FACTOR3" of the main causer of the accident!	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				stationary vehicle or obstacle 14 disregarding the following traffic's right of way when passing stationary vehicle or obstacle 15 failure during driving in congested traffic or lane merging 16 disregarding the traffic regulation "priority to the right" 17 disregarding the traffic regulation signs (give way) 18 disregarding the priority traffic when joining a motorway or dual carriageway 19 disregarding the right of way by vehicles joining from a track way 20 disregarding the direction of traffic regulation by traffic lights or police officers 21 disregarding the priority of oncoming traffic when shown by sign 208 22 disregarding the priority of railway traffic 23 mistake during turning 24 mistake during u-turn or					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				reversing 25 failure during joining the flowing traffic 26 wrong behaviour towards pedestrians at pedestrian crossings 27 wrong behaviour towards pedestrians at traffic calming for pedestrians 28 wrong behaviour towards pedestrians when turning 29 wrong behaviour towards pedestrians at public transport stops 30 wrong behaviour towards pedestrians at other places 31 forbidden stopping or parking 32 failure of adequate warning for stopped/broken down vehicles, accident scenes, or stopped school busses 33 traffic rule violation during vehicle loading or unloading 34 disregarding the lighting regulations 35 overloading 36 not adequately secured					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				cargo 37 other mistakes of the driver 38 defective lighting 39 defective tires 40 defective brakes 41 defective towing device 42 other technical deficiencies 43 wrong behaviour of the pedestrian in traffic situations regulated by traffic lights or police officers 44 wrong behaviour of the pedestrian at crossings without regulation by traffic lights or police officers 45 wrong behaviour of the pedestrian near crossings or junctions, traffic lights or pedestrian crossings during dense traffic in other places 46 wrong behaviour of the pedestrian due to sudden emergence from view restricted areas 47 wrong behaviour of the pedestrian (ignoring the road traffic) 48 other wrong behaviour of the pedestrian					

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				49 wrong behaviour of the pedestrian due to no usage of pedestrian path 50 wrong behaviour of the pedestrian due to usage of wrong road side 51 wrong behaviour of the pedestrian due to playing on or besides the road 52 wrong behaviour of the pedestrian due to other mistakes 53 road soiling due to oil leakage 54 other road soiling by road users 55 snow, ice 56 rain 57 other influences (leaves, clay etc.) 58 lane grooves in combination with rain, snow, ice 59 other state of the road 60 inappropriate road sign condition 61 inadequate street lighting 62 inadequate securing of railway crossings 63 influence of weather / view obstruction due to fog 64 influence of weather /					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				view obstruction due to rain, hail, snow 65 influence of weather / view obstruction due to sun glare 66 influence of weather / view obstruction due to cross wind 67 influence of weather / view obstruction due to storm 68 inappropriate or not secured construction site on the road 69 game animals on road 70 other animal on road 71 other obstacles on the road 72 darkness 73 another vehicle which is gone 74 other causes 75 unknown Medium/Full Version (add the following modalities) 1 other stimulation substances, e.g. drugs, medication 2 drowsiness 3 other physical or psychical deficiencies 4 speeding (exceeding					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				speed limit) 5 excessive speed for conditions (no exceeding of speed limit) 6 lack of safety distance 7 heavy braking without obvious reason 8 defective steering					
iglad	CRASH	EMARRIV	Emergency arrival	HHMM	The time when the first EMS reached the accident site (HHMM)	Time		x	x
arso/iglad	CRASH	ACCSEV	Crash severity	Fatal; Serious/severe injury; Slight/minor injury; no injuries; unknown	Describes the severity of the road crash, based on the most severe injury of any person involved.	Num.	x	x	x
iglad	CRASH	STATUS	Case status	0 not yet defined 1 incomplete 2 completely coded, not yet checked 3 completely coded, not plausible 4 completely coded, plausible 9 denied and replaced / not to be used for analyses	Status for the fulfillment of all current plausibility checks.	Num.	x	x	x
insafe	CRASH	ACCTRAFDEN	Traffic density at time of crash	1 no other traffic 2 light traffic 3 moderate traffic 4 heavy traffic, traffic moving 5 heavy traffic, congested roadway 8-other (*describe, 80	Traffic density at the time of the crash (from people involved in the crash and witness interviews)	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				characters) 99999 unknown					
transsafe	ROAD	ROADNR	Road Identification number (ID)	-	The unique identifier (e.g. a 10-digit number) within a given year that identifies a particular road.	Num.	x	x	x
transSafe	ROAD	CASENR	Crash identification number (ID)	-	The case number ensures the unequivocal allocation of a data Table within the database and is always the first variable to be indicated	Num.	x	x	x
arso	ROAD	ROADTYPE	Type of roadway	1 Motorway/freeway 2 Express road 3 Urban road, two-way 4 Urban road, one-way 5 Road outside a built-up area 6 Restricted road 88888 Other 99999 unknown	Describes the type of road, whether the road has two directions of travel, and whether the carriageway is physically divided. For crashes occurring at junctions, where the crash cannot be clearly allocated in one road, the road where the vehicle with priority was moving is indicated	Num.	x	x	x
arso	ROAD	ROADFUNCLASS	Road functional class	Principal arterial; Secondary arterial; Collector; Local	Describes the character of service or function of the road where the first harmful event took place. For crashes occurring at junctions, where the crash cannot be clearly allocated to one road, the road where the vehicle with priority was moving is indicated.	Num.	x	x	x
mmucc	ROAD	ROADLOC1	The location of the first harmful event within or outside the roadway	1 On Roadway 2 Continuous Left-Turn Lane 3 On Shoulder 4 On Roadside 5 On Median 6 Pedestrian Refuge Island	The location of the first harmful event it relates to its position within or outside the trafficway. See figure 3 "Diagram of a trafficway" and figure 4 "Diagram of a trafficway with parking lanes" in the MMUCC codebook,	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				or Traffic Island 7 In Parking Lane or Zone 8 Separator 9 Gore 10 Off-Roadway, Location Unknown 11 Non-Trafficway Area 99999 unknown	NHTSA DOT HS 813 525 January 2024.				
mmucc	ROAD	ROADLOC2	The location of the first harmful event with respect to presence in a junction	1 Non-Junction 2 Acceleration or Deceleration Lane 3 Crossover-Related 4 Driveway Access or Related 5 Entrance or Exit Ramp or Related 6 Intersection or Related 7 Railway Grade Crossing 8 Shared-Use Path or Trail 9 Through Roadway 10 Other Location Within an Interchange Area (median, shoulder, and roadside) 99999 unknown	The location of the first harmful event with respect to presence in a junction or proximity to components typically in junction or interchange areas.	Num.	x	x	x
mmucc	ROAD	ROADLOC3	Type of Intersection	1 Not an Intersection 2 T-Intersection 3 Y-Intersection 4 L-Intersection 5 Four-Leg Intersection 6 Five or More Legs and Not Circular 7 Circular Intersection (e.g.,	Allows separation of various intersection types when the location of the first harmful event is in an intersection or related to the use of an intersection.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				Roundabout, Traffic Circle) 8 Other Intersection Type 99999 unknown					
mmucc	ROAD	ROADLOC4	Work zone	1 Work Zone Type 2 Location of the Crash 3 Work Zone Description 4 Workers Present (select one) 5 Law Enforcement Present (select one)	A crash that occurs in or related to a construction, maintenance, or utility work zone, whether workers were present at the time of the crash or not.	Num.	x	x	x
mmucc	ROAD	ROADLOC5	Work zone, specify	1.1 None 1.2 Construction 1.3 Maintenance 1.4 Utility 1.5 Work Zone, Type Unknown 2.1 Before the First Work Zone Warning Sign 2.2 Advance Warning Area 2.3 Transition Area 2.4 Activity Area 2.5 Termination Area 2.6 Not Applicable (Not Within or Related to a Work Zone) 3.1 Lane Closure 3.2 Lane Shift 3.3 Crossover 3.4 Work on Shoulder or Median 3.5 Intermittent or Moving Work 3.6 Other Type of Work	A crash that occurs in or related to a construction, maintenance, or utility work zone, whether workers were present at the time of the crash or not.	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				Zone 3.7 Not Applicable (Not Within or Related to a Work Zone) 4.1 No 4.2 Yes 4.3 Not Applicable (Not Within or Related to a Work Zone) 4.4 Unknown 5.1 No 5.2 Yes 5.3 Not Applicable (Not Within or Related to a Work Zone) 5.4 Unknown					
arso	ROAD	ROADJUNCTION	Junction	1. At-grade, crossroad – Road intersection with four arms. 2. At-grade, roundabout – Circular road. 3. At-grade, T, or staggered junction – Road intersection with three arms. Includes T-intersections and intersections with an acute angle. 4. At-grade, multiple junction – A junction with more than four arms (excluding roundabouts). 5. At-grade, other – Other	Indicates whether the crash occurred at a junction (two or more roads intersecting) and defines the type of junction. In at-grade junctions, all roads intersect at the same level. In not-at-grade junctions, roads do not intersect at the same level.	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				at-grade junction type not described above. 6. Not at grade – The junction includes roads that do not intersect at the same level. 7. Not at junction – The crash has occurred at a distance greater than 20 meters from a junction. 9. Unknown – The crash location relative to a junction is unknown.					
arso	ROAD	ROADTRAFFIC	Traffic control at junction	1. Authorized person – Police officer or traffic warden at intersection controls the traffic. Applicable even if traffic signals or other junction control systems are present. 2. Stop sign – Priority is determined by stop sign(s). 3. Give-way sign or markings – Give-way sign or markings determine priority. 4. Other traffic signs – Priority is determined by traffic sign(s) other than 'stop', 'give way', or markings.	Type of traffic control at the junction where crash occurred. Applies only to crashes that occur at a junction.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				5. Automatic traffic signal (working) – Priority is determined by a traffic signal that was working at the time of the crash. 6. Automatic traffic signal (out of order) – A traffic signal is present but out of order at time of crash. 7. Uncontrolled – The junction is not controlled by an authorized person, traffic signs, markings, automatic traffic signals, or other means. 8. Other – The junction is controlled by means other than an authorized person, signs, markings, or automatic traffic signals.					
iglad	ROAD	ROADSURF	Road surface	1 asphalt 2 concrete 3 paving/cobble stones 4 sand/gravel 5 alternating pavement 88888 other 99999 unknown	The type of road surface is coded here for the considered crash	Num.	x	x	x
arso	ROAD	ROADCOND	Road surface conditions	1. Dry – Dry and clean road surface. 2. Snow, frost, ice – Snow, frost, or ice on the road. 3. Slippery – Slippery road	The condition of the road surface at the time and place of the crash.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				surface due to existence of sand, gravel, mud, leaves, oil on the road. Does not include snow, frost, ice, or wet road surface. 4. Wet, damp – Wet road surface. Does not include flooding. 5. Flood – Still or moving water on the road. 6. Other – Other road surface conditions not mentioned above. 9. Unknown – The road surface conditions were unknown.					
iglad	ROAD	LANESEPAR	The type of lane separation	1 no separation / junction 10 physical separation, not further specified 11 guard rail: steel 12 guard rail: concrete 13 guard rail: wire ropes 14 Temporary separation (e.g. construction site) 15 other (e.g. wood) 20 Dimensional separation (Grass, central strip, traffic island) 30 road marking, not further specified 31 dashed line	The type of lane separation is coded here for the considered accident. In case of multiple matches it should be prioritised from top to bottom.	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				32 solid line 33 solid/dashed line 34 double solid line 35 keep-out area 77777 not applicable (e.g. one-way) 88888other (e.g. alternating) 99999 unknown					
arso	ROAD	ROADOBST	Road obstacles	yes; no: unknown	The presence of any person or object that obstructed the movement of the vehicles on the road. Includes any animal standing or moving (either hit or not), and any object not meant to be on the road. Does not include vehicles (parked or moving vehicles, pedestrians) or obstacles on the side of the carriageway (for example, poles, trees)	Num.	x	x	x
arso	ROAD	ROADCURVE	Road curve	1. Tight curve – The crash occurred inside a road curve that was tight (based on the judgment of the police officer). 2. Open curve – The crash occurred inside a road curve that was open (based on the judgment of the police officer). 3. No curve – The crash did not occur inside a road curve. 9. Unknown – It is not	Indicates whether the crash occurred inside a curve, and what type of curve.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				defined whether the crash occurred inside a road curve.					
arso	ROAD	ROADSEGGRADE1	Road segment grade 1)	1. Yes – The crash occurred at a road segment with a high grade. 2. No – The crash did not occur at a road segment with a high grade. 9. Unknown – It is not defined whether the crash occurred at a road segment with a high grade.	Indicates whether the crash occurred on a road segment with a steep gradient.	Num.	x	x	x
mmucc	ROAD	ROADSEGGRADE2	Road segment grade 2)	1 Level 2 Uphill 3 Hillcrest 4 Downhill 5 Sag (bottom) 6 Non-Trafficway or Driveway Access 99999 unknown	The inclination characteristics of the roadway in the direction of travel for this vehicle, just prior to this vehicle's involvement in the crash. See figure 28 " Roadway grade" in the MMUCC codebook, NHTSA DOT HS 813 525 January 2024.	Num.		x	x
arso	ROAD	ROADVLIM	Speed limits	-	The legal speed limit at the location of the crash.	Num.	x	x	x
mmucc	ROAD	ROADTFLOW	Trafficway Flow	1 One-Way 2 Two-Way 3 Two-Way With a Continuous Left-Turn Lane 4 Non-Trafficway or Driveway Access 99999 unknown	Identifies whether the trafficway associated with this vehicle serves one-way or two-way traffic, just prior to this vehicle's involvement in the crash.	Num.	x	x	x
mmucc	ROAD	ROADMEDBAR	Median Barrier Presence	1 Median Without a Traffic Barrier (e.g., grass,	Identifies whether the trafficway associated with this vehicle included	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				vegetation, flush or painted > 4', curb) 2 Median With Traffic Barrier (e.g., guardrail, cable barrier, concrete barrier) 77777 not applicable (no median, e.g., centerline, two-way left-turn lane) 99999 unknown	a median barrier, just prior to this vehicle's involvement in the crash.				
mmucc	ROAD	ROADNUMLANE	Road number of Open Lanes	-	Total number of open lanes in this motor vehicle's environment, just prior to this vehicle's involvement in the crash, including through lanes, turn lanes, acceleration or deceleration lanes, or any other lanes (From scene photographs, scene diagram).	Num.		x	x
mmucc/insafe	ROAD	ROADALL	Roadway Alignment	1 Straight 2 Curve Left 3 Curve Right 4 Non-Trafficway or Driveway Access 99999 unknown	The geometric or layout characteristics of the roadway in the direction of travel for this vehicle, just prior to this vehicle's involvement in the crash.	Num.		x	x
insafe	ROAD	ROADLANETR	Lane travelled	-	Number of lane travelled by the vehicle [1 to 9]	Num.			x
insafe	ROAD	ROADLANWID	Lane width	-	Lane width in meters	Num.			x
insafe	ROAD	ROADKKLANWID	Kerb to kerb roadway width	-	Kerb to kerb roadway width (in meters)	Num.			x
insafe	ROAD	ROADCONTAM	Road contaminated by	0 none 1 water 2 oil, petroleum derivatives 3 sand, soil, dirt	Road contaminated by … (From scene photographs, Accident scene investigation)	Num.			x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				4 gravel 5 loads dropped from another vehicle 6 temporary sign board 99999 unknown					
transsafe	PARTICIPANT	PARTNR	Participant Identification number (ID)	-	The unique identifier (e.g. a 10-digit number) within a given year that identifies a particular Participant.	Num.	x	x	x
transSafe	PARTICIPANT	CASENR	Crash identification number (ID)	-	Unique number assigned to identify the crash	Num.	x	x	x
arso	PARTICIPANT	PARTTYPE1	Participant type (1)	1 Bicycle 2 Other non-motor vehicle 3 Two/three-wheel motor vehicle 4 Passenger car 5 Bus/coach/trolley 6 Light goods vehicle (<3.5 t) 7 Heavy goods vehicle (>3.5 t) 8 Pedestrian 9 Animal-propelled vehicles 10 Other motor vehicle	The type of participant involved in the crash	Num.	x	x	x
iglad	PARTICIPANT	PARTTYPE2	Participant type (2)	1 pedestrian 2 bicycle 3 motorized two-wheeler 4 motorized three-wheeler 5 passenger car 6 SUV 7 light truck 8 VAN	The type of participant involved in the crash	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				9 bus 10 truck 11 truck with trailer 12 tractor (without trailer) 13 tractor with trailer (also with semitrailer only) 14 trackbound vehicle (train, tram et al.) 15 agricultural tractor 16 animal driven carriages 17 electric bicycle or tricycle 88888 - other 99999 - unknown					
insafe	PARTICIPANT	PTWSTYLE	Vehicle style motorised two-wheelers	1 Conventional street L1 or L3 vehicle (tank between knees) 2 Conventional street L1 or L3 vehicle (tank between knees) 3 Dual purpose, on-road off-road motorcycle 4 Sport, race replica 5 Cruiser 6 Chopper, modified chopper 7 Touring 8 Scooter 9 Step-through 10 Sport touring 11 Motorcycle plus side car, left 12 Motorcycle plus side	Vehicle style motorised two-wheelers	Num.			x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				car, right 13 Off-road motorcycle, motocross, enduro, trials 88888 - other 99999 - unknown					
arso	PARTICIPANT	PARTVIN	Vehicle identification number (VIN)	-	Unique vehicle number attached to the engine compartment of the vehicle by the manufacturer to identify each vehicle involved in the crash.	Num.		x	x
arso	PARTICIPANT	PARTREGNR	Vehicle registration number	-	Unique vehicle registration number appearing on the number plate and registration documents.	Text	x	x	x
arso	PARTICIPANT	PARTCOREG	Country of vehicle registration	-	Whether the vehicle is registered in a country different than where it crashes.	Num.	x	x	x
arso/iglad	PARTICIPANT	VEHMAKE	Vehicle make	-	Indicate the make (distinctive name) assigned by motor vehicle manufacturer. Mandatory if the vehicle is a motorized vehicle. Not applicable to bicycles, tricycles, rickshaws, and animal-powered vehicles.	Num.	x	x	x
arso/iglad	PARTICIPANT	MODEL	Vehicle model	-	The code assigned by the manufacturer to denote a family of motor vehicles (within a make) that have a degree of similarity in construction.	Text	x	x	x
arso/iglad	PARTICIPANT	REGYEAR	Vehicle year of manufacture	-	The year assigned to a motor vehicle by the manufacturer.	Num.	x	x	x
iglad	PARTICIPANT	VEHMASS	Vehicle mass	-	Vehicle mass is the curb weight (coded in kilogram). The curb weight	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					of passenger vehicles and motorized two-wheelers include the content of the fuel tank. In case of trucks the curb weight includes 75kg for the driver. A trailer, if attached to the vehicle, is not taken into account in the curb weight. The mass should be coded only for vehicles. The mass of a pedestrian has to be coded in OCCUPANT table and here as code 77777-not applicable.				
arso/iglad	PARTICIPANT	ENGINE	Engine size	-	The size of the vehicle's engine is recorded in cubic centimeters.	Num.		x	x
arso/iglad	PARTICIPANT	POWER	Vehicle special function	No special function; Taxi; Vehicle used as bus; Police/military; Emergency vehicle; Other; Unknown	The type of special function being served by this vehicle, regardless of whether the function is marked on the vehicle.	Num.	x	x	x
iglad	PARTICIPANT	SEATS	Number of seats	-	If participant is a vehicle, this is the total number of seats in the vehicle (also not occupied seats). Otherwise, 'not applicable' is coded. For trams and trains the total number is necessary.	Num.		x	x
iglad	PARTICIPANT	TRAILER	Existence and damage of trailer	1 trailer / semi-trailer attached, n.f.s. 2 no trailer / semi-trailer 3 trailer / semi-trailer attached, not damaged 4 trailer / semi-trailer attached, damaged 77777 not applicable (pedestrian, bicycle, or	This variable indicates whether a trailer was attached to the vehicle during the accident. This includes usual trailers as well as semi-trailers. In addition to the information about the existence of a trailer, its damage status is also coded.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				electric micro vehicle) 99999 unknown					
iglad	PARTICIPANT	SCENARIOTYPE	Pre-Crash Scenario	10 - D - Other driving accident 11 - D1 - Driving accident in nearside bend 12 - D2 - Driving accident in farside bend 13 - D3 - Driving accident on straight road 20 - L - Other longitudinal accident 21 - L1 - Running up 22 - L2 - Object cutting in from nearside and running up 23 - L3 - Object cutting in from farside and running up 24 - L4 - Running-up from behind 25 - L5 - Lane changing nearside and object from behind 26 - L6 - Lane changing farside and object from behind 27 - L7 - Evasion to the right 28 - L8 - Evasion to the left 30 - On - Other oncoming accident 31 - On1 - Oncoming on	Accident scenario according to participation ACCTYPEA or ACCTYPEB. Each accident can be referred to using two scenarios depending on the perspectives of the participants AC-CTYPEA and ACCTYPEB. All other participants will not be assigned to a scenario. For single-vehicle accidents, only ACCTYPEA will be assigned to a scenario. This variable can be recoded from the variables ACCTYPE, ACCTYPEA, and ACCTYPEB.	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				same lane 32 - On2 - Lane changing to offside and oncoming 40 - T - Other turning accident 41 - T1 - Turning nearside and object from behind 42 - T2 - Turning nearside and object oncoming 43 - T3 - Turning farside and object oncoming 44 - T4 - Turning farside and object from farside 45 - T5 - Turning farside and object from behind 46 - T9 - Turning farside and object from nearside 47 - T10 - Turning nearside and object from farside 48 - T14 - Turning nearside and object from nearside 50 - C - Other crossing accident 51 - C1 - Crossing from nearside 52 - C2 - Crossing from farside 60 - O - Other accident 61 - O1 - Inability 62 - O2 - Obstacle 63 - O3 - Technical defect 64 - O4 - Animal 70 - B - Other backing up					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				accident 71 - B1 - Backing up and object oncoming 72 - B2 - Backing up and object from nearside 81 - P1 - Parking accident 82 - P2 - Parked vehicle 91 - S1 - Dooring nearside 92 - S2 - Dooring farside 93 - S3 - Opening door nearside 94 - S4 - Opening door farside 99998 - n/e - Neither ACCTYPEA nor ACCTYPEB 99999 - n/c - No scenario applicable / unknown					
arso	PARTICIPANT	MANEUVER	Vehicle maneuver	Reversing; Parked; Entering or leaving a parking position; Slowing or stopping; Moving off; Waiting to turn; Turning (unknown); Turning left; Turning right; Changing lane; Avoidance maneuver; Overtaking vehicle; Straightforward/normal driving; Other; Unknown	The controlled maneuver for this motor vehicle prior to the crash.	Num.	x	x	x
iglad	PARTICIPANT	ADLEVEL	Maximum level for autonomous driving functions	Level 0; Level 1; Level 2; Level 3; Level 4; Level 5; 77777 - not applicable (PTW, pedestrian, bicycle,	The variable gives the highest possible level of automation the vehicle can be driven in on the basis of systems the vehicle is equipped with. The definition of levels is	Num.			x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				or electric micro vehicle); 99999 - unknown	according to standard SAE J3016. For PTWs, pedestrians, bicycles or electric micro vehicle “77777 - not applicable (PTW, pedestrian, bicycle, or electric micro vehicle)" has to be coded.				
iglad	PARTICIPANT	OPPON1	Primary collision - opponent	1 - Participant 1 2 - Participant 2 3 - Participant 3 4 - Participant 4 5 - Participant 5 6 - Participant 6 7 - Participant 7 8 - Participant 8 9 - Participant 9 10 - Participant 10 100 - animal 101 - object on road 102 - road surface 103 - sidewalk/bicycle lane 104 - other paved road 105 - roadside 106 - ejected occupant 107 - guardrail 108 - traffic sign 109 - traffic light 110 - pole 111 - tree 112 - rails 113 - wall 114 - water 77777 - not applicable	The opponent of the primary collision. If the opponent is a vehicle or pedestrian, the corresponding participant number of the opponent is coded. Otherwise, if opponent is an object or animal, one of the codes 100 and above are used (see the format section). For simplification, only the primary and secondary collisions are coded. If there are more than two collisions, the two most severe collisions are coded. Parked trailers without Truck or Tractor has to be coded as an object.	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				88888 - other 99999 - unknown					
iglad	PARTICIPANT	NROPPON1	Primary collision - opponent collision	1 - primary collision 2 - secondary collision 77777 - not applicable 99999 - unknown	This is the number of the collision of the opponent (primary or secondary) and can be used to match collisions between two collided participants. The opponent itself is coded in the previous variable “Primary collision – opponent”. If the collision of the opponent is neither his primary nor secondary collision “unknown” is coded.	Num.		x	x
iglad	PARTICIPANT	CDC1DIRE	Primary collision - CDC / TDC Force Direction	-	The principal direction of force is coded that caused the damage on the vehicle according to CDC 1 & 2. This direction is equal to the direction of the change of momentum of the impact analysis. The coding is conducted according the o’clock direction in 30 deg steps whereas the 12 o’clock direction represents a force direction front to rear parallel to the longitudinal axis of the vehicle. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. CDC1DIRE and CDC1AREA should also be coded for pedestrians, two-wheelers and electric micro vehicles, all further CDC values should be coded than as "not applicable". The entry of “00” indicates that the	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					impact is not horizontal, as in a rollover or undercarriage type impact.				
iglad	PARTICIPANT	CDC1AREA	Primary collision - CDC / TDC Area of Deformation	F - Front R - Right Side B - Back (rear or rear of trailer or straight truck) L - Left Side D - Back (rear of tractor) (TDC only) C - Rear of cab (TDC only) V - Front of Cargo Area (TDC only) T - Top U - Undercarriage 7 - not applicable 9 - unknown	The CDC1AREA codes the main deformed vehicle area according to CDC 3. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. CDC1DIRE and CDC1AREA should also be coded for pedestrians, two-wheelers and electric micro vehicles, all further CDC values should be coded than as "not applicable".	Num.		x	x
iglad	PARTICIPANT	CDC1LONG	Primary collision - CDC / TDC Specific longitudinal or lateral area	CDC: D0 - Distributed – side or end L0 - Left – front or rear - w/o beam L1 - Left – front or rear - w/ beam C0 - Centre – front or rear - betw. long. beams R0 - Right – front or rear - w/o beam R1 - Right – front or rear - w/ beam F0 - Side Front – left or right P0 - Side Centre Section – left or right	The CDC1LONG codes the specific horizontal location of the damage. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. It must not be coded for pedestrians and 2wheeler.	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				P1 - Side Centre Section – left or right - betw. A-B pillar P2 - Side Centre Section – left or right - betw. B-C pillar B0 - Side Rear – left or right Y0 - Side or End – F+P or L+C Y1 - Side or End – F+P or L+C - first 2/3 Z0 - Side or End – B+P or R+C Z1 - Side or End – B+P or R+C - first 2/3 77 - not applicable 99 - unknown TDC: L - Left C - Center R - Right F - Front (Left or right, Top or Bottom) P - Cab W - Rear of cab in front of semitrailer K - Tractor (P + W) S - Tractor (F + P + W) B - Rear of cab to rear of trailer or cargo area T - Trailer Y - F + P or L + C					

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				Z - B + P or R + C D - Distributed (F+P+B or L+C+R) 77 - not applicable 99 - unknown					
iglad	PARTICIPANT	CDC1VERT	Primary collision - CDC / TDC Specific vertical area	Vertical location A - All H - Top of Frame to top of Vehicle E - Everything below Belt Line G - Belt Line and Above M - Middle—top of frame to belt line L - Bottom/top of frame (incl. undercarriage) W - Below undercarriage level (wheels and tyres only) Lateral location D - Distributed L - Left C - Center R - Right Y - L and C Z - R and C TDC only T - Everything above cab (TDC only) B - Belt line and above (cargo areas and trailers) (TDC only) F - Belt line and below (incl.	The CDC1VERT codes the specific Vertical or Lateral Location of Deformation and Classification Code. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. It must not be coded for pedestrians and 2wheeler.	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				undercarriage) (cargo areas and trailers) (TDC only) 7 - not applicable 9 - unknown					
iglad	PARTICIPANT	CDC1TYPE	Primary collision - CDC / TDC Type of damage distribution	W - Wide impact Area N - Narrow Impact Area S - Sideswipe O - Rollover (includes rolling onto side)A - Overhanging structures (inverted step) E - Corner (extends from corner to = 16 in [410mm]) K - Conversion in impact type (requires multiple CDC) U - No residual Deformation R - Override (TDC only) 7 - not applicable 9 - unknown	The CDC1TYPE defines the type of impact. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. It must not be coded for pedestrian and 2wheeler.	Num.		x	x
iglad	PARTICIPANT	CDC1EXTT	Primary collision - CDC / TDC Maximum extent of penetration	-	The degree of deformation is determined for different vehicle types with the use of the following figures. The degree of deformation is the differential between the zone in which the main intrusion ends and the zone in which it starts (max. value = 9). Always 1 is added to the result. Example: Damage starts in zone 1 and ends in zone 8. The difference is 7 and the degree of deformation is 8. For trucks the TDC (SAE J1301)	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					should be used instead, but also coded within the CDC variables. It must not be coded for pedestrians and 2wheeler.				
iglad	PARTICIPANT	CDC1PERC	Primary collision - CDC / TDC Maximum extent of penetration in percent	7777 - not applicable 9999 - unknown	The deformation percentage is Coded in relation to the vehicle length, width or height, depending on the direction of collision. In this connection it should be noted that the total width or height of the vehicle is always 100%, whereas the total vehicle length equals 200%. The 100% base for intrusions from the front or rear is thus half the vehicle length. Where deformations exceed 99% a 99 is coded. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. It must not be coded for pedestrians and 2wheeler.	Num.		x	x
iglad	PARTICIPANT	OPPON2	Secondary collision - opponent	1 - Participant 1 2 - Participant 2 3 - Participant 3 4 - Participant 4 5 - Participant 5 6 - Participant 6 7 - Participant 7 8 - Participant 8 9 - Participant 9 10 - Participant 10 100 - animal 101 - object on road	The opponent of the primary collision. If the opponent is a vehicle or pedestrian, the corresponding participant number of the opponent is coded. Otherwise, if opponent is an object or animal, one of the codes 100 and above are used (see the format section). For simplification, only the primary and secondary collisions are coded. If there are more than two collisions, the two most severe collisions are coded. Parked	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				102 - road surface 103 - sidewalk/bicycle lane 104 - other paved road 105 - roadside 106 - ejected occupant 107 - guardrail 108 - traffic sign 109 - traffic light 110 - pole 111 - tree 112 - rails 113 - wall 114 - water 77777 - not applicable 88888 - other 99999 - unknown	trailers without Truck or Tractor has to be coded as an object. Note: A "parked" car is a standing car without any people inside and will be coded as an object. A standing car with people inside will not be coded as "parked" but as a participant "standing/waiting". A rolling car without a driver will be coded as a participant.				
iglad	PARTICIPANT	NROPPON2	Secondary collision - opponent collision	1 - primary collision 2 - secondary collision 7777 - not applicable 9999 - unknown	This is the number of the collision of the opponent (primary or secondary) and can be used to match collisions between two collided participants. The opponent itself is coded in the previous variable “Primary collision – opponent”. If the collision of the opponent is neither his primary nor secondary collision “unknown” is coded.	Num.		x	x
iglad	PARTICIPANT	CDC2DIRE	Secondary collision - CDC / TDC Force Direction	00 - impact is not horizontal 01 - 01 (+30°) 02 - 02 (+60°) 03 - 03 (+90°) 04 - 04 (+120°) 05 - 05 (+150°)	The principal direction of force is coded that caused the damage on the vehicle according to CDC 1 & 2. This direction is equal to the direction of the change of momentum of the impact analysis. The coding is conducted according the o’clock	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				06 - 06 (+180°) 07 - 07 (-150°) 08 - 08 (-120°) 09 - 09 (-90°) 10 - 10 (-60°) 11 - 11 (-30°) 12 - 12 (0°) 13 - Intra-unit force (only TDC) 77 - not applicable 99 - unknown	direction in 30 deg steps whereas the 12 o'clock direction represents a force direction front to rear parallel to the longitudinal axis of the vehicle. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. CDC2DIRE and CDC2AREA should also be coded for pedestrians, two-wheelers and electric micro vehicles, all further CDC values should be coded than as "not applicable". The entry of "00" indicates that the impact is not horizontal, as in a rollover or undercarriage type impact.				
iglad	PARTICIPANT	CDC2AREA	Secondary collision - CDC / TDC Area of Deformation	F - Front R - Right Side B - Back (rear or rear of trailer or straight truck) L - Left Side D - Back (rear of tractor) (only TDC) C - Rear of cab (only TDC) V - Front of Cargo Area (only TDC) T - Top U - Undercarriage 7 - not applicable 9 - unknown	The CDC2AREA codes the main deformed vehicle area according to CDC 3. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. CDC2DIRE and CDC2AREA should also be coded for pedestrians, two-wheelers and electric micro vehicles, all further CDC values should be coded than as "not applicable".	Num.		x	x
iglad	PARTICIPANT	CDC2LONG	Secondary collision - CDC / TDC Specific	CDC: D0 - Distributed – side or end L0 - Left – front or rear -	The CDC2LONG codes the specific horizontal location of the damage. For trucks the TDC (SAE J1301) should be used instead, but also	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
			longitudinal or lateral area	w/o beam L1 - Left – front or rear - w/ beam C0 - Centre – front or rear - betw. long. beams R0 - Right – front or rear - w/o beam R1 - Right – front or rear - w/ beam F0 - Side Front – left or right P0 - Side Centre Section – left or right P1 - Side Centre Section – left or right - betw. A-B pillar P2 - Side Centre Section – left or right - betw. B-C pillar B0 - Side Rear – left or right Y0 - Side or End – F+P or L+C Y1 - Side or End – F+P or L+C - first 2/3 Z0 - Side or End – B+P or R+C Z1 - Side or End – B+P or R+C - first 2/3 77 - not applicable 99 - unknown TDC: L - Left C - Center	coded within the CDC variables. It must not be coded for pedestrians and 2wheeler.				

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				R - Right F - Front (Left or right, Top or Bottom) P - Cab W - Rear of cab in front of semitrailer K - Tractor (P + W) S - Tractor (F + P + W) B - Rear of cab to rear of trailer or cargo area T - Trailer Y - F + P or L + C Z - B + P or R + C D - Distributed (F+P+B or L+C+R) 77 - not applicable 99 - unknown					
iglad	PARTICIPANT	CDC2VERT	Secondary collision - CDC / TDC Specific vertical area	Vertical location A - All H - Top of Frame to top of Vehicle E - Everything below Belt LineG - Belt Line and Above M - Middle—top of frame to belt line L - Bottom/top of frame (incl. undercarriage) W - Below undercarriage level (wheels and tyres only) Lateral location D - Distributed	The CDC2VERT codes the specific Vertical or Lateral Location of Deformation and Classification Code. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. It must not be coded for pedestrians and 2wheeler.	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				L - Left C - Center R - Right Y - L and C Z - R and C TDC only T - Everything above cab (TDC only) B - Belt line and above (cargo areas and trailers) (TDC only) F - Belt line and below (incl. undercarriage) (cargo areas and trailers) (TDC only) 7 - not applicable 9 - unknown					
iglad	PARTICIPANT	CDC2TYPE	Secondary collision - CDC / TDC Type of damage distribution	W - Wide impact Area N - Narrow Impact Area S - Sideswipe O - Rollover (includes rolling onto side)A - Overhanging structures (inverted step) E - Corner (extends from corner to = 16 in [410mm]) K - Conversion in impact type (requires multiple CDC) U - No residual Deformation R - Override (TDC only) 7 - not applicable 9 - unknown	The CDC2TYPE defines the type of impact. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. It must not be coded for pedestrian and 2wheeler.	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
iglad	PARTICIPANT	CDC2EXTT	Secondary collision - CDC / TDC Maximum extent of penetration in percent	7777 - not applicable 9999 - unknown	The deformation percentage is coded in relation to the vehicle length, width or height, depending on the direction of collision. In this connection it should be noted that the total width or height of the vehicle is always 100%, whereas the total vehicle length equals 200%. The 100% base for intrusions from the front or rear is thus half the vehicle length. Where deformations exceed 99% a 99 is coded. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables. It must not be coded for pedestrians and 2wheeler.	Num.		x	x
iglad	PARTICIPANT	CDC2PERC	Secondary collision - CDC / TDC Maximum extent of penetration in percent	7777 - not applicable 9999 - unknown	The deformation percentage is Coded in relation to the vehicle length, width or height, depending on the direction of collision. In this connection it should be noted that the total width or height of the vehicle is always 100%, whereas the total vehicle length equals 200%. The 100% base for intrusions from the front or rear is thus half the vehicle length. Where deformations exceed 99% a 99 is coded. For trucks the TDC (SAE J1301) should be used instead, but also coded within the CDC variables.	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					It must not be coded for pedestrians and 2wheeler.				
iglad	PARTICIPANT	FACTOR1	Contributing factor 1 - without ranking	Basic Version 1 none 2 alcohol 3 use of wrong lane or illegal road usage 4 violation against lane discipline (e.g. driving on outside lane) 5 overtaking on the wrong side (undertaking) 6 overtaking into oncoming traffic 7 overtaking into unclear traffic situation 8 overtaking without adequate visibility 9 overtaking without consideration and adequate warning to following traffic 10 mistake in returning to initial lane 11 other overtaking mistakes 12 mistake when being overtaken, e.g. swerving, accelerating 13 disregarding the oncoming traffic's right of way when passing stationary vehicle or obstacle	Contributing factor from the view of the participant. In most cases there are several contributing factors associated with one participant from which at most three can be coded in the variables “Contributing factor 1 – 3”.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				14 disregarding the following traffic's right of way when passing stationary vehicle or obstacle 15 failure during driving in congested traffic or lane merging 16 disregarding the traffic regulation "priority to the right" 17 disregarding the traffic regulation signs (give way) 18 disregarding the priority traffic when joining a motorway or dual carriageway 19 disregarding the right of way by vehicles joining from a track way 20 disregarding the direction of traffic regulation by traffic lights or police officers 21 disregarding the priority of oncoming traffic when shown by sign 208 22 disregarding the priority of railway traffic 23 mistake during turning 24 mistake during u-turn or reversing 25 failure during joining the					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				flowing traffic 26 wrong behaviour towards pedestrians at pedestrian crossings 27 wrong behaviour towards pedestrians at traffic calming for pedestrians 28 wrong behaviour towards pedestrians when turning 29 wrong behaviour towards pedestrians at public transport stops 30 wrong behaviour towards pedestrians at other places 31 forbidden stopping or parking 32 failure of adequate warning for stopped/broken down vehicles, accident scenes, or stopped school busses 33 traffic rule violation during vehicle loading or unloading 34 disregarding the lighting regulations 35 overloading 36 not adequately secured cargo 37 other mistakes of the					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				driver 38 defective lighting 39 defective tires 40 defective brakes 41 defective towing device 42 other technical deficiencies 43 wrong behaviour of the pedestrian in traffic situations regulated by traffic lights or police officers 44 wrong behaviour of the pedestrian at crossings without regulation by traffic lights or police officers 45 wrong behaviour of the pedestrian near crossings or junctions, traffic lights or pedestrian crossings during dense traffic in other places 46 wrong behaviour of the pedestrian due to sudden emergence from view restricted areas 47 wrong behaviour of the pedestrian (ignoring the road traffic) 48 other wrong behaviour of the pedestrian 49 wrong behaviour of the pedestrian due to no usage					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				of pedestrian path 50 wrong behaviour of the pedestrian due to usage of wrong road side 51 wrong behaviour of the pedestrian due to playing on or besides the road 52 wrong behaviour of the pedestrian due to other mistakes 53 road soiling due to oil leakage 54 other road soiling by road users 55 snow, ice 56 rain 57 other influences (leaves, clay etc.) 58 lane grooves in combination with rain, snow, ice 59 other state of the road 60 inappropriate road sign condition 61 inadequate street lighting 62 inadequate securing of railway crossings 63 influence of weather / view obstruction due to fog 64 influence of weather / view obstruction due to rain, hail, snow					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				65 influence of weather / view obstruction due to sun glare 66 influence of weather / view obstruction due to cross wind 67 influence of weather / view obstruction due to storm 68 inappropriate or not secured construction site on the road 69 game animals on road 70 other animal on road 71 other obstacles on the road 72 darkness 73 another vehicle which is gone 74 other causes 75 unknown Medium/Full Version (add the following modalities) 1 other stimulation substances, e.g. drugs, medication 2 drowsiness 3 other physical or psychical deficiencies 4 speeding (exceeding speed limit) 5 excessive speed for					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				conditions (no exceeding of speed limit) 6 lack of safety distance 7 heavy braking without obvious reason 8 defective steering					
iglad	PARTICIPANT	FACTOR2	Contributing factor 2 - without ranking	Basic Version 1 none 2 alcohol 3 use of wrong lane or illegal road usage 4 violation against lane discipline (e.g. driving on outside lane) 5 overtaking on the wrong side (undertaking) 6 overtaking into oncoming traffic 7 overtaking into unclear traffic situation 8 overtaking without adequate visibility 9 overtaking without consideration and adequate warning to following traffic 10 mistake in returning to initial lane 11 other overtaking mistakes 12 mistake when being overtaken, e.g. swerving, accelerating 13 disregarding the	Contributing factor from the view of the participant. In most cases there are several contributing factors associated with one participant from which at most three can be coded in the variables "Contributing factor 1 – 3".	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				oncoming traffic's right of way when passing stationary vehicle or obstacle 14 disregarding the following traffic's right of way when passing stationary vehicle or obstacle 15 failure during driving in congested traffic or lane merging 16 disregarding the traffic regulation "priority to the right" 17 disregarding the traffic regulation signs (give way) 18 disregarding the priority traffic when joining a motorway or dual carriageway 19 disregarding the right of way by vehicles joining from a track way 20 disregarding the direction of traffic regulation by traffic lights or police officers 21 disregarding the priority of oncoming traffic when shown by sign 208 22 disregarding the priority of railway traffic					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				23 mistake during turning 24 mistake during u-turn or reversing 25 failure during joining the flowing traffic 26 wrong behaviour towards pedestrians at pedestrian crossings 27 wrong behaviour towards pedestrians at traffic calming for pedestrians 28 wrong behaviour towards pedestrians when turning 29 wrong behaviour towards pedestrians at public transport stops 30 wrong behaviour towards pedestrians at other places 31 forbidden stopping or parking 32 failure of adequate warning for stopped/broken down vehicles, accident scenes, or stopped school busses 33 traffic rule violation during vehicle loading or unloading 34 disregarding the lighting regulations					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				35 overloading 36 not adequately secured cargo 37 other mistakes of the driver 38 defective lighting 39 defective tires 40 defective brakes 41 defective towing device 42 other technical deficiencies 43 wrong behaviour of the pedestrian in traffic situations regulated by traffic lights or police officers 44 wrong behaviour of the pedestrian at crossings without regulation by traffic lights or police officers 45 wrong behaviour of the pedestrian near crossings or junctions, traffic lights or pedestrian crossings during dense traffic in other places 46 wrong behaviour of the pedestrian due to sudden emergence from view restricted areas 47 wrong behaviour of the pedestrian (ignoring the road traffic)					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				48 other wrong behaviour of the pedestrian 49 wrong behaviour of the pedestrian due to no usage of pedestrian path 50 wrong behaviour of the pedestrian due to usage of wrong road side 51 wrong behaviour of the pedestrian due to playing on or besides the road 52 wrong behaviour of the pedestrian due to other mistakes 53 road soiling due to oil leakage 54 other road soiling by road users 55 snow, ice 56 rain 57 other influences (leaves, clay etc.) 58 lane grooves in combination with rain, snow, ice 59 other state of the road 60 inappropriate road sign condition 61 inadequate street lighting 62 inadequate securing of railway crossings 63 influence of weather /					

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				view obstruction due to fog 64 influence of weather / view obstruction due to rain, hail, snow 65 influence of weather / view obstruction due to sun glare 66 influence of weather / view obstruction due to cross wind 67 influence of weather / view obstruction due to storm 68 inappropriate or not secured construction site on the road 69 game animals on road 70 other animal on road 71 other obstacles on the road 72 darkness 73 another vehicle which is gone 74 other causes 75 unknown Medium/Full Version (add the following modalities) 1 other stimulation substances, e.g. drugs, medication 2 drowsiness 3 other physical or					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				psychical deficiencies 4 speeding (exceeding speed limit) 5 excessive speed for conditions (no exceeding of speed limit) 6 lack of safety distance 7 heavy braking without obvious reason 8 defective steering					
iglad	PARTICIPANT	FACTOR3	Contributing factor 3 - without ranking	Basic Version 1 none 2 alcohol 3 use of wrong lane or illegal road usage 4 violation against lane discipline (e.g. driving on outside lane) 5 overtaking on the wrong side (undertaking) 6 overtaking into oncoming traffic 7 overtaking into unclear traffic situation 8 overtaking without adequate visibility 9 overtaking without consideration and adequate warning to following traffic 10 mistake in returning to initial lane 11 other overtaking mistakes	Contributing factor from the view of the participant. In most cases there are several contributing factors associated with one participant from which at most three can be coded in the variables “Contributing factor 1 – 3”.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				12 mistake when being overtaken, e.g. swerving, accelerating 13 disregarding the oncoming traffic's right of way when passing stationary vehicle or obstacle 14 disregarding the following traffic's right of way when passing stationary vehicle or obstacle 15 failure during driving in congested traffic or lane merging 16 disregarding the traffic regulation "priority to the right" 17 disregarding the traffic regulation signs (give way) 18 disregarding the priority traffic when joining a motorway or dual carriageway 19 disregarding the right of way by vehicles joining from a track way 20 disregarding the direction of traffic regulation by traffic lights or police officers 21 disregarding the priority					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				of oncoming traffic when shown by sign 208 22 disregarding the priority of railway traffic 23 mistake during turning 24 mistake during u-turn or reversing 25 failure during joining the flowing traffic 26 wrong behaviour towards pedestrians at pedestrian crossings 27 wrong behaviour towards pedestrians at traffic calming for pedestrians 28 wrong behaviour towards pedestrians when turning 29 wrong behaviour towards pedestrians at public transport stops 30 wrong behaviour towards pedestrians at other places 31 forbidden stopping or parking 32 failure of adequate warning for stopped/broken down vehicles, accident scenes, or stopped school busses 33 traffic rule violation					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				during vehicle loading or unloading 34 disregarding the lighting regulations 35 overloading 36 not adequately secured cargo 37 other mistakes of the driver 38 defective lighting 39 defective tires 40 defective brakes 41 defective towing device 42 other technical deficiencies 43 wrong behaviour of the pedestrian in traffic situations regulated by traffic lights or police officers 44 wrong behaviour of the pedestrian at crossings without regulation by traffic lights or police officers 45 wrong behaviour of the pedestrian near crossings or junctions, traffic lights or pedestrian crossings during dense traffic in other places 46 wrong behaviour of the pedestrian due to sudden emergence from view					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				restricted areas 47 wrong behaviour of the pedestrian (ignoring the road traffic) 48 other wrong behaviour of the pedestrian 49 wrong behaviour of the pedestrian due to no usage of pedestrian path 50 wrong behaviour of the pedestrian due to usage of wrong road side 51 wrong behaviour of the pedestrian due to playing on or besides the road 52 wrong behaviour of the pedestrian due to other mistakes 53 road soiling due to oil leakage 54 other road soiling by road users 55 snow, ice 56 rain 57 other influences (leaves, clay etc.) 58 lane grooves in combination with rain, snow, ice 59 other state of the road 60 inappropriate road sign condition 61 inadequate street					

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				lighting 62 inadequate securing of railway crossings 63 influence of weather / view obstruction due to fog 64 influence of weather / view obstruction due to rain, hail, snow 65 influence of weather / view obstruction due to sun glare 66 influence of weather / view obstruction due to cross wind 67 influence of weather / view obstruction due to storm 68 inappropriate or not secured construction site on the road 69 game animals on road 70 other animal on road 71 other obstacles on the road 72 darkness 73 another vehicle which is gone 74 other causes 75 unknown Medium/Full Version (add the following modalities) 1 other stimulation					

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				substances, e.g. drugs, medication 2 drowsiness 3 other physical or psychical deficiencies 4 speeding (exceeding speed limit) 5 excessive speed for conditions (no exceeding of speed limit) 6 lack of safety distance 7 heavy braking without obvious reason 8 defective steering					
insafe	PARTICIPANT	TYRESIZEF	Tyre size front	-	Tyre size e.g. 205/65R15 91V (From vehicle inspection, vehicle photographs)	Num.			x
insafe	PARTICIPANT	TYRESIZER	Tyre size rear	-	Tyre size e.g. 205/65R15 91V (From vehicle inspection, vehicle photographs)	Num.			x
insafe	PARTICIPANT	TYRETREDEPFL	Measured tread depth - Front left tyre	-	Measured tread depth (From vehicle inspection)	Num.			x
insafe	PARTICIPANT	TYRETREDEPFR	Measured tread depth - Front right tyre	-	Measured tread depth (From vehicle inspection)	Num.			x
insafe	PARTICIPANT	TYRETREDEPRL	Measured tread depth - Rear left tyre	-	Measured tread depth (From vehicle inspection)	Num.			x
insafe	PARTICIPANT	TYRETREDEPRR	Measured tread depth - Rear right tyre	-	Measured tread depth (From vehicle inspection)	Num.			x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
insafe	PARTICIPANT	TYREPRESFL	Tyre inflation pressure - Front left tyre	-	Measured tread depth - Tyre inflation pressure (From vehicle inspection)	Num.			x
insafe	PARTICIPANT	TYREPRESFR	Tyre inflation pressure - Front right tyre	-	Measured tread depth - Tyre inflation pressure (From vehicle inspection)	Num.			x
insafe	PARTICIPANT	TYREPRESRL	Tyre inflation pressure - Rear left tyre	-	Measured tread depth - Tyre inflation pressure (From vehicle inspection)	Num.			x
insafe	PARTICIPANT	TYREPRESRR	Tyre inflation pressure - Rear right tyre	-	Measured tread depth - Tyre inflation pressure (From vehicle inspection)	Num.			x
insafe	PARTICIPANT	TYREBRAEVIDFL	Tyre braking evidence - Front left tyre	0 none 1 evidence of moderate braking 2 evidence of heavy braking without wheel lock up 3 evidence of heavy locked wheel braking, one skid patch 4 evidence of heavy locked wheel braking, multiple skid patches 88888 - other 99999 - unknown	Tyre braking evidence (From vehicle inspection, vehicle photographs)	Num.			x
insafe	PARTICIPANT	TYREBRAEVIDFR	Tyre braking evidence - Front right tyre	0 none 1 evidence of moderate braking 2 evidence of heavy braking without wheel lock up	Tyre braking evidence (From vehicle inspection, vehicle photographs)	Num.			x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				3 evidence of heavy locked wheel braking, one skid patch 4 evidence of heavy locked wheel braking, multiple skid patches 88888 - other 99999 - unknown					
insafe	PARTICIPANT	TYREBRAEVIDRL	Tyre braking evidence - Rear left tyre	0 none 1 evidence of moderate braking 2 evidence of heavy braking without wheel lock up 3 evidence of heavy locked wheel braking, one skid patch 4 evidence of heavy locked wheel braking, multiple skid patches 88888 - other 99999 - unknown	Tyre braking evidence (From vehicle inspection, vehicle photographs)	Num.			x
insafe	PARTICIPANT	TYREBRAEVIDRR	Tyre braking evidence - Rear left tyre	0 none 1 evidence of moderate braking 2 evidence of heavy braking without wheel lock up 3 evidence of heavy locked wheel braking, one skid patch 4 evidence of heavy locked wheel braking, multiple skid	Tyre braking evidence (From vehicle inspection, vehicle photographs)	Num.			x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				patches 88888 - other 99999 - unknown					
insafe	PARTICIPANT	VEHINSP	Vehicle inspection	0 no 1 yes 77777 - not applicable 99999 - unknown	Vehicle inspection	Num.			x
transsafe	SAFETYSYSTEM	SAFESYNR	Safet System Identification number (ID)	-	The unique identifier (e.g. a 10-digit number) within a given year that identifies a particular Safet System.	Num.	x	x	x
iglad	SAFETYSYSTEM	PARTNR	Participant ID	-	Unique number assigned to identify each vehicle involved in the crash	Num.		x	x
iglad	SAFETYSYSTEM	SYSNR	System number ID	-	Unique number assigned to identify each safety system used/present	Num.		x	x
iglad	SAFETYSYSTEM	SYSTYPE	Type	Basic/Medium versions 1 antilock brake system (ABS) Full Version 2 traction control system 3 electronic stability control (ESC) 4 cruise control 5 adaptive cruise control (ACC) 6 brake assist (BA) 7 automatic emergency brake (AEB) 8 lane departure warning (LDW) 9 lane keeping assistant (LKA) 10 blind spot monitoring	Type of safety active system which is built into the vehicle.	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				(BSM) 11 seat belt reminder 12 xenon lights 13 bending light 14 adaptive light distribution 15 automatic headlights 16 active pedestrian protection 17 intelligent brake lights 18 speed limiter 19 head up display 20 low friction detection 21 daytime running light 22 collision warning 23 preventive occupant protection system 24 alcohol lock system 25 turn off assistant 26 backup warning aid 27 night vision 28 eCall 29 drowsy driver detection system					
iglad	SAFETYSYSTEM	SYSUSE	Use	1 yes 2 no 3 misuse 77777 not applicable 99999 unknown	Safety system was in a usable mode, which means turned on (for active safety systems) or used (e.g. buckled up for belts) during the accident. For some systems, a misuse mode exists (e.g. belts), which should be explicitly coded as "misuse".	Num.		x	x
iglad	SAFETYSYSTEM	DEPLACT	Deployment / activation	1 yes 2 no	Depending on the type of safety system and accident severity, an	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				3 misuse 77777 not applicable 99999 unknown	activation or deployment of the system is needed in the course of the accident for to take full advantage of its benefit. For example air bags are deployed or belt pretensioners are activated when becoming effective. If the system is deployed or activated, 'yes' should be coded. Activation in the sense switched on/off should be coded in the variable 'Use'. For some systems there is only one value possible, e.g. activation for a belt w/o pretensioner is always 'not applicable'.				
transsafe	PARTRECON	CASENR	Participant reconstruction Identification number (ID)	-	The unique identifier (e.g. a 10-digit number) within a given year that identifies the Participant reconstruction activity	Num.			
arso/iglad	PARTRECON	PARTNR	Participant ID	-	Unique number assigned to identify each vehicle involved in the crash	Num.		x	x
iglad	PARTRECON	INISPEED1	Primary collision - driving speed	99999 - unknown	The driving speed is defined as the speed in km/h before a critical situation was recognised. In case of the primary collision it is identical with the so-called initial braking speed or the speed at which reaction occurred; in subsequent collisions it is identical with the coasting speed of the preceding collision. Variables from reconstruction are based on calculations. The accuracy	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					of each variable should be the best estimation.				
iglad	PARTRECON	DECEL1	Primary collision - mean deceleration	77777 - not applicable (only for pedestrians) 99999 - unknown	The mean braking deceleration DECEL1 is coded in m/s2 * 10 before the crash. If the vehicle was accelerated before the collision, DECEL1 is negative. Example: The entry for a deceleration of 8.3 m/s2 is 83 and the entry for an acceleration of 1.0 m/s2 is -10 Mainly the start point should be the speed at the point of the critical situation. If vehicle is decelerating before braking and if no braking the same like the collision speed. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.	Num.		x	x
iglad	PARTRECON	DECDIST1	Primary collision - deceleration distance	77777 - not applicable (only for pedestrians)99999 - unknown	The deceleration distance used for reconstruction is coded from the initial braking position to the collision point. The deceleration distance is shown in m * 10. Example: The entry for a deceleration distance of 8.3 m is 83. Response time and steering time are not considered. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
iglad	PARTRECON	DEFANG1	Primary collision - delta angle	-	Delta angle is the change of the angle (deflection angle) during the collision, or the difference in degrees between the vehicle collision run-in and run-out angles. Anti-clockwise changes in angle are coded as positive (+) values, those in the clockwise direction as negative (-) values.	Num.		x	x
iglad	PARTRECON	COLSPEED1	Primary collision - collision speed	77777 - not applicable (only for participants w/o collision) 99999 - unknown	Speed of the vehicle in km/h at the time of collision. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.	Num.		x	x
iglad	PARTRECON	DELTAV1	Primary collision - delta-v	99999 - unknown	The Delta-v is the vector difference between immediate post-crash and pre-crash velocity. It is coded in km/h. When a rider ejects from a motorcycle, delta-v is coded for the motorcycle only. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.	Num.		x	x
iglad	PARTRECON	EES1	Primary collision - EES	77777 - not applicable 99999 - unknown	The energy equivalent speed (EES) is calculated from the energy balance and is coded in km/h. When a rider ejects from a motorcycle, EES is coded for the motorcycle only. For pedestrians or bicycles '77777 - not applicable' must be coded.	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.				
iglad	PARTRECON	INISPEED2	Secondary collision - driving speed	77777 - not applicable 99999 - unknown	The driving speed is defined as the speed in km/h before a critical situation was recognised. In case of the primary collision it is identical with the so-called initial braking speed or the speed at which reaction occurred; in subsequent collisions it is identical with the coasting speed of the preceding collision. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.	Num.		x	x
iglad	PARTRECON	DECEL2	Secondary collision - mean deceleration	77777 - not applicable 99999 - unknown	The mean braking deceleration DECEL2 is coded in m/s2 * 10 before the crash. If the vehicle was accelerated before the collision, DECEL2 is negative. Example: The entry for a deceleration of 8.3 m/s2 is 83 and the entry for an acceleration of 1.0 m/s2 is -10. Mainly the start point should be the speed at the point of the critical situation. If vehicle is decelerating before braking and if no braking the same like the collision speed. Variables from reconstruction are based on calculations. The accuracy	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					of each variable should be the best estimation.				
iglad	PARTRECON	DECDIST2	Secondary collision - deceleration distance	77777 - not applicable 99999 - unknown	The deceleration distance used for reconstruction is coded from the initial braking position to the collision point. The deceleration distance is shown in m * 10. Example: The entry for a deceleration distance of 8.3 m is 83. Response time and steering time are not considered. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.	Num.		x	x
iglad	PARTRECON	DEFANG2	Secondary collision - delta angle	-	Delta angle is the change of the angle (deflection angle) during the collision, or the difference in degrees between the vehicle collision run-in and run-out angles. Anti-clockwise changes in angle are coded as positive (+) values, those in the clockwise direction as negative (-) values.	Num.		x	x
iglad	PARTRECON	COLSPEED2	Secondary collision - collision speed	77777 - not applicable (only for participants w/o collision) 99999 - unknown	Speed of the vehicle in km/h at the time of collision. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation	Num.		x	x
iglad	PARTRECON	DELTAV2	Secondary collision - delta-v	77777 - not applicable 99999 - unknown	The Delta-v is the vector difference between immediate post-crash and pre-crash velocity. It is coded in	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					km/h. When a rider ejects from a motorcycle, delta-v is coded for the motorcycle only. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.				
iglad	PARTRECON	EES2	Secondary collision - EES	77777 - not applicable 99999 - unknown	The energy equivalent speed (EES) is calculated from the energy balance and is coded in km/h. When a rider ejects from a motorcycle, EES is coded for the motorcycle only. For pedestrians or bicycles '77777 - not applicable' must be coded. Variables from reconstruction are based on calculations. The accuracy of each variable should be the best estimation.	Num.		x	x
iglad	PARTRECON	CHECK_RECO1	Check of reconstruction data 1	0 - not plausible 1 - plausible 66666 - not defined	Reconstruction data check 1: Conservation of Momentum For details see: Dario Vangi, Carlo Cialdai, Michelangelo-Santo Gulino, Kjell Gunnar Robbersmyr. 2018. Vehicle Accident Databases: Correctness Checks for Accident Kinematic Data. designs. 2018.	Num.		x	x
iglad	PARTRECON	CHECK_RECO2	Check of reconstruction data 2	0 - not plausible 1 - plausible 66666 - not defined	Reconstruction data check 2: Velocity Triangles For details see: Dario Vangi, Carlo Cialdai, Michelangelo-Santo Gulino,	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					Kjell Gunnar Robbersmyr. 2018. Ve-hicle Accident Databases: Correctness Checks for Accident Kinematic Data. designs. 2018.				
iglad	PARTRECON	CHECK_RECO3	Check of reconstruction data 3	0 - not plausible 1 - plausible 66666 - not defined	Reconstruction data check 3: Energy Loss For details see: Dario Vangi, Carlo Cialdai, Michelangelo-Santo Gulino, Kjell Gunnar Robbersmyr. 2018. Ve-hicle Accident Databases: Correctness Checks for Accident Kinematic Data. designs. 2018.	Num.		x	x
insafe	PARTRECON	PARTROLL	Vehicle Roll Angle at first impact	-	Vehicle roll angle at first impact [deg]	Num.		x	x
insafe	PARTRECON	PARTYAW	Vehicle Yaw Angle at first impact	-	Vehicle Yaw Angle at first impact [deg]	Num.		x	x
insafe	PARTRECON	PARTPITCH	Vehicle Pitch Angle at first impact	-	Vehicle Pitch Angle at first impact [deg]	Num.		x	x
insafe	PARTRECON	PARTSLIP	Vehicle Slip Angle at first impact	-	Angle of vehicle slip just before first impact measured in relation to the longitudinal axis of the vehicle [deg]	Num.		x	x
insafe	PARTRECON	PARTCOLANG	Collision Angle	-	collision angle between vehicles [deg]	Num.		x	x
insafe	PARTRECON	PARTPREANGSPE	Pre-crash angular speed [rad/s]	-	Pre-crash angular speed [rad/s]	Num.		x	x
insafe	PARTRECON	PARTPOSTANGSPE	Post-crash angular speed [rad/s]	-	Post-crash angular speed [rad/s]	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
insafe	PARTRECON	PARTCPDOF	Calculated PDOF	-	Calculated Principla Direction of Force (PDOF)	Num.		x	x
transSafe	PERSON	PERSID	Person number	-	Unique number assigned to identify the person	Num.	x	x	x
arso/iglad	PERSON	PARTNR	Participant ID	-	Unique number assigned to identify each vehicle involved in the crash	Num.	x	x	x
arso/iglad	PERSON	OCCNR	Occupant number	-	Unique number assigned to identify the person	Num.	x	x	x
arso/iglad	PERSON	OCCTYPE	Type of road user	1. Driver – Driver or operator of motorized or nonmotorized vehicle. Includes cyclists, persons pulling a rickshaw, or riding an animal. 2. Passenger – Person riding on or in a vehicle, who is not the driver. Includes person in the act of boarding, alighting from a vehicle, or sitting/standing. 3. Pedestrian – Person on foot, pushing, or holding a bicycle, pram, or a pushchair, leading or herding an animal, riding a toy cycle, on roller skates, skateboard or skis. Excludes persons in the act of boarding or alighting from a vehicle. 4. Cyclist – Person on	This variable indicates the role of each person at the time of the crash.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				bicycle. 8. Other – Person involved in the crash who is not of any type listed above. 9. Unknown – It is not known what role the person played in the crash.					
arso	PERSON	OCCNAT	Driver nationality	-	The behavior of a driver of a vehicle who is involved in a collision with another vehicle, property, or human being, who knowingly fails to stop to give his/her name, license number, and other information as required by statute to the injured party, a witness, or law enforcement officers.	Num.	x	x	x
arso	PERSON	OCCSEATPOS	Seating position	Subfield: Row Data values: 1. Front 2. Rear 3. Not applicable (for example, riding on motor vehicle exterior) 8. Other 9. Unknown Subfield: Seat Data values: 1. Left 2. Middle 3. Right 4. Not applicable (for	The location of the person in the vehicle at the time of the crash.	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				example, riding on motor vehicle exterior) 8. Other 9. Unknown					
arso	PERSON	PEDLINKVHN	Pedestrian's linked vehicle number	-	The unique number assigned for this crash to the motor vehicle that collided with this person. The vehicle number assigned under to the motor vehicle that collided with this person.	Num.	x	x	x
arso	PERSON	PEDMANEU	Pedestrian maneuver	1. Crossing – The pedestrian was crossing the road. 2 .Walking on the carriageway – The pedestrian was walking across the carriageway, facing or not facing traffic.3. Standing on the carriageway – The pedestrian was on the carriageway and was stationary (standing, sitting, lying, and so on). 4. Not on the carriageway – The pedestrian was standing or moving on the sidewalk or any point beside the carriageway. 8. Other – The vehicle or the pedestrian was performing a maneuver not	The action of the pedestrian immediately prior to the crash.	Num.	x	x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				included in the list of the previous values. 9. Unknown – The maneuver performed by the vehicle or pedestrian was not recorded or it was unknown.					
arso	PERSON	OCCLICENSEDATE	Driving license issue date	Value (MMYYYY) 1. Never issued a driving license 9. Date of issue of first license unknown	Indicates the date (month and year) of issue of the person's first driving license, provisional or full, pertaining to the vehicle they were driving.	Num.	x	x	x
arso	PERSON	OCCLICENSETYPE	Driver license type fitting vehicle	1 No 2 Yes	Whether the driving license allowed the driver to operate the vehicle s/he was operating.	Num.	x	x	x
arso	PERSON	OCCUALCO	Alcohol use suspected	1. No 2. Yes 3. Not applicable (for example, if person is not driver of motorized vehicle) 9. Unknown	Law enforcement officer suspects that person involved in the crash has used alcohol	Num.	x	x	x
insafe	PERSON	OCCUALCOIMP	Alcohol impairment	0 yes 1 no 2 not significantly impaired 3 significantly impaired 77777 not applicable 99999 unknown	Interview-based assessment of alcohol impairment	Num.		x	x
arso	PERSON	OCCUALCOTEST	Alcohol test	1 Test not given 2 Test refused 3 Test given	Describes alcohol test status, type, and result.	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				77777 not applicable 99999 unknown					
arso	PERSON	OCCUALCOTEST	Alcohol test, Test type	1 Blood 2 Breath 3 Urine 8 Other 77777 not applicable 99999 unknown	Describes alcohol test status, type, and result.	Num.		x	x
arso	PERSON	OCCUALCOTEST	Alcohol test, Test result	1 Pending 77777 not applicable 99999 unknown	Describes alcohol test status, type, and result.	Num.		x	x
insafe	PERSON	OCCUALCOBAC	Blood alcohol concentration (BAC)	-	Blood alcohol concentration (BAC) - mg/100ml	Num.			x
arso	PERSON	OCCUDRUG	Drug use	1 No suspicion or evidence of drug use 2 Suspicion of drug use 3 Evidence of drug use (further subfields can specify test type and values) 4 Not applicable (for example, if person is not driver of motorized vehicle) 9 Unknown	Indication of suspicion or evidence that person involved in the crash has used illicit drugs.	Num.		x	x
insafe	PERSON	OCCUDRUGIMP	Drug impairment	0 yes 1 no 3 not significantly impaired 4 significantly impaired 77777 not applicable 99999 unknown	Interview-based assessment of drug impairment	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
insafe	PERSON	OCCUDRUGTYPE	Type of drugs	0 stimulant 1 depressant 77777 not applicable 99999 unknown	Type of drugs	Num.			x
arso	PERSON	OCCUBIRTH	Date of birth	-	Indicates the date of birth of the person involved in the crash.	Num.	x	x	x
arso	PERSON	DRIVERHITRUN	Hit and run	1 No 2 Yes	The behaviour of a driver of a vehicle who is involved in a collision with another vehicle, property, or human being, who knowingly fails to stop to give his/her name, license number, and other information as required by statute to the injured party, a witness, or law enforcement officers.	Num.	x	x	x
arso/iglad	PERSON	AGE	Age	-	The age in years of the person involved in the crash.	Num.	x	x	x
arso/iglad	PERSON	GENDER	Sex	1. Male – Based on identification documents/personal ID number or determined by the police. 2. Female – Based on identification documents /personal ID number or determined by the police. 9. Unknown – Sex could not be determined (police unable to trace person, not specified).	Indicates the sex of the person involved in the crash.	Num.	x	x	x
iglad	PERSON	WEIGHT	Weight	-	Weight of the person in kilograms.	Num.		x	x
iglad	PERSON	HEIGHT	Height	-	Height of the person in cm	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
arso/iglad	PERSON	INJSEVE	Injury severity	1. Fatal injury – Person was killed immediately or died within 30 days, as a result of the crash. 2. Serious/severe injury – Person was hospitalized for at least 24 hours because of injuries sustained in the crash. 3. Slight/minor injury – Person was injured and hospitalized for less than 24 hours or not hospitalized. 4. No injury – Person was not injured. 9. Unknown – Injury severity was not recorded or is unknown.	The injury severity level for a person involved in the crash.	Num.	x	x	x
iglad	PERSON	MAIS	Maximum AIS per person	1 2 3 4 5 6	Maximum AIS suffered by the person	Num.	x	x	x
iglad	PERSON	AISREGIO1	MAIS region 1 head	-	Here the maximum injury level for brain and scull (w/o face) is coded. The localization covers AIS body region 1. (AIS05 update 2008) If hospital doesn’t provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					(TWG 04/17). Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.				
iglad	PERSON	AISREGIO2	MAIS region 2 face	-	Here the maximum injury level for the face (w/o face) is coded. The localization covers AIS body region 2. (AIS05 update 2008) If hospital doesn't provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding (TWG 04/17). Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.	Num.		x	x
iglad	PERSON	AISREGIO3	MAIS region 3 neck w/o spine	-	Here the maximum injury level for the neck (w/o cervical spine) is coded. The localization covers AIS body region 3. (AIS05 update 2008) If hospital doesn't provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding (TWG 04/17). Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.	Num.		x	x
iglad	PERSON	AISREGIO4	MAIS region 4 thorax w/o shoulder	-	Here the maximum injury level for the thorax (w/o shoulders) is coded. The localization covers AIS body region 4. (AIS05 update 2008)	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					If hospital doesn’t provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding (TWG 04/17). Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.				
iglad	PERSON	AISREGIO5	MAIS region 5 abdomen	-	Here the maximum injury level for the abdomen is coded. The localization covers AIS body region 5. (AIS05 update 2008) If hospital doesn’t provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding (TWG 04/17). Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.	Num.		x	x
iglad	PERSON	AISREGIO6	MAIS region 6 spine	-	Here the maximum injury level for the spine is coded. The localization covers AIS body region 6. (AIS05 update 2008) If hospital doesn’t provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding (TWG 04/17). Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.	Num.		x	x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
iglad	PERSON	AISREGIO7	MAIS region 7 upper extremities	-	Here the maximum injury level for the upper extremities is coded. The localization covers AIS body region 7. (AIS05 update 2008) If hospital doesn't provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding (TWG 04/17). Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.	Num.		x	x
iglad	PERSON	AISREGIO8	MAIS region 8 lower extremities	-	Here the maximum injury level for the lower extremities is coded. The localization covers AIS body region 8. (AIS05 update 2008) If hospital doesn't provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding (TWG 04/17). Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.	Num.		x	x
iglad	PERSON	AISREGIO9	MAIS region 9 not specified injuries	-	Here the maximum injury level for not specified injuries is coded. The localization covers AIS body region 9. (AIS05 update 2008) If hospital doesn't provide injury data but occupant reports about his injuries, then self-report of the occupant should be used for coding (TWG 04/17).	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					Note: Until member year 2018 the AIS90 update AIS98 was used. There was no recode of previous data.				
arso/iglad	PERSON	BELT	Seat belt	0 not present 1 present (not specified) 2 present w/o pret. & lim. 3 present w/ pretensioner 4 present w/ limiter 5 present w/ pret. & lim. 77777 not applicable 99999 unknown	Describes the use of occupant restraint system	Num.	x	x	x
arso/iglad	PERSON	BELT_USE	Seat belt use	0 not used 1 used (not specified) 2 used - activated 3 used - not activated 4 misuse 77777 not applicable 99999 - unknown	Statement whether the Seat belt was used (occupant was buckled up) during the accident. A misuse mode should be explicitly coded as “misuse”.	Num.	x	x	x
iglad	PERSON	AIRBF	Airbag front	0 not present 1 present 77777 not applicable 99999 unknown	Airbag front presence at the occupants seat. The Airbag front characteristics relate exclusively to vehicle occupants. Code '77777 - not applicable' for other persons. Appendix A contains examples for coding airbags.	Num.	x	x	x
iglad	PERSON	AIRBF_DEPL	Airbag front deployment	0 not deployed 1 deployed 2 deactivated 77777 not applicable 99999 unknown	Statement whether the Airbag front was deployed. Appendix A contains examples for coding airbags.	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
iglad	PERSON	AIRBTC	Airbag tubular/curtain	0 - not present 1 - present (not specified) 2 - present - front + rear 3 - present - front 77777 - not applicable 99999 - unknown	Airbag tubular/curtain presence at the occupants seat. The Airbag tubular/curtain characteristics relate exclusively to vehicle occupants. Code '77777 - not applicable' for other persons. Appendix A contains examples for coding airbags.	Num.	x	x	x
iglad	PERSON	AIRBTC_DEPL	Airbag tubular/curtain deployment	0 - not deployed 1 - deployed 77777 - not applicable 99999 - unknown	Statement whether the Airbag tubular/curtain was deployed. Appendix A contains examples for coding airbags.	Num.	x	x	x
iglad	PERSON	SIDEB	Sidebag	0 - not present 1 - present (not further specified) 2 - present - head 3 - present - thorax 4 - present - pelvis5 - present - head & thorax 6 - present - head & pelvis 7 - present - thorax & pelvis 8 - present - head & thorax & pelvis 77777 - not applicable 99999 - unknown	Sidebag presence at the occupants seat. The Sidebag characteristics relate exclusively to vehicle occupants	Num.	x	x	x
iglad	PERSON	SIDEB_DEPL	Sidebag deployment	0 - not deployed 1 - deployed 77777 - not applicable99999 - unknown	Statement whether the Sidebag was deployed.	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
iglad	PERSON	KNEEB	Kneebag	0 - not present 1 - present 77777 - not applicable 99999 - unknown	Kneebag presence at the occupants seat. The Kneebag characteristics relate exclusively to vehicle occupants	Num.	x	x	x
iglad	PERSON	KNEEB_DEPL	Kneebag deployment	0 - not deployed 1 - deployed 77777 - not applicable 99999 - unknown	Statement whether the Kneebag was deployed.	Num.	x	x	x
iglad	PERSON	AIRBSR	Seat ramp airbag	0 - not present 1 - present 77777 - not applicable 99999 - unknown	Seat ramp airbag presence at the occupants seat. The Seat ramp airbag characteristics relate exclusively to vehicle occupants. Code '77777 - not applicable' for other persons.	Num.	x	x	x
iglad	PERSON	AIRBSR_DEPL	Seat ramp airbag deployment	0 - not deployed 1 - deployed 77777 - not applicable 99999 - unknown	Statement whether the Seat ramp airbag was deployed.	Num.	x	x	x
iglad	PERSON	AIRBR	Rear airbag	0 - not present 1 - present 77777 - not applicable 99999 - unknown	Rear airbag presence at the occupants seat. The Rear airbag characteristics relate exclusively to vehicle occupants and considers only rear passengers.	Num.	x	x	x
iglad	PERSON	AIRBR_DEPL	Rear airbag deployment	0 - not deployed 1 - deployed 77777 - not applicable 99999 - unknown	Statement whether the Rear airbag was deployed.	Num.	x	x	x
iglad	PERSON	AIRBFC	Front center airbag	0 - not present 1 - present 77777 - not applicable 99999 - unknown	Front center airbag presence at the occupants seat. The Front center airbag characteristics relate exclusively to vehicle occupants.	Num.	x	x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
iglad	PERSON	AIRBFC_DEPL	Front center airbag deployment	0 - not deployed 1 - deployed 77777 - not applicable 99999 - unknown	Statement whether the Front center airbag was deployed.	Num.	x	x	x
iglad	PERSON	HEADREST	Headrest protection system	0 - not present 1 - present 77777 - not applicable 99999 - unknown	Headrest protection system presence at the occupants seat. The Headrest protection system characteristics relate exclusively to vehicle occupants.	Num.	x	x	x
iglad	PERSON	HEADREST_DEPL	Headrest protection system deployment	0 - not deployed 1 - deployed 77777 - not applicable 99999 - unknown	Statement whether the Headrest protection system was deployed.	Num.	x	x	x
arso/iglad	PERSON	CHILDSEAT	Child seat	0 - not present 1 - used (not further specified) 2 - used - forward facing 3 - used - rearward facing 4 - misuse 77777 - not applicable 99999 - unknown	Child seat presence.	Num.	x	x	x
iglad	PERSON	BOLCHILD	Bolster table for children	0 - not present 1 - used 2 - misuse 77777 - not applicable 99999 - unknown	Bolster table for children presence.	Num.	x	x	x
iglad	PERSON	PROTCLO	Protective clothes	0 - not present 1 - used 2 - misuse 77777 - not applicable 99999 - unknown	Protective clothes presence	Num.		x	x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
arso/iglad	PERSON	HELM	Helmet	0 not present 1 used 2 misuse 77777 not applicable 99999 unknown	Describes the use of occupant helmet from interview and scene evidences	Num.	x	x	x
insafe	PERSON	HELMTYPE	Helmet type	1 full face 2 full face with flipped chine 3 open face 4 half helmet 5 not motorcycle helmet 6 bicycle 7 not bicycle helmet 77777 not applicable 99999 unknown	Helmet type from helmet inspection and photographs	Num.		x	x
insafe	PERSON	HELMMAKE	Helmet Manufacturer	-	Helmet manufacturer from helmet inspection and photographs	Num.			x
insafe	PERSON	HELMMODEL	Helmet model	-	Helmet model from helmet inspection and photographs	Num.			x
insafe	PERSON	HELMDATE	Helmet date of manufacture [yyyy]	-	date of manufacture [yyyy]	Num.			x
insafe	PERSON	HELMSIZE	Helmet label size	0 extra small (XS) 1 small (S) 2 medium (M) 3 large (L) 4 extra large (XL) 4 extra extra large (XXL) 77777 not applicable 99999 unknown	Helmet label size from helmet inspection and photographs	Num.			x
insafe	PERSON	HELMMASS	Helmet mass	-	Helmet mass [kg] from helmet inspection and photographs	Num.			x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
insafe	PERSON	HELMCONF	Helmet is approved according to	0 no standards labelled 1 ECE-22-05 2 ECE-22-06 3 SNELL 085 25-NZS 4 FMVSS 218; … 99999 unknown 77777 not applicable	Indication of whether the helmet has been approved in accordance with the following standards … from helmet inspection and photographs	Num.			x
insafe	PERSON	HELMCOVER	Type of cover	1 partial 2 full coverage 3 full facial, integral chin bar but no face shield 4 full facial, removable chin bar 5 full facial, retractable chin bar 6 full facial coverage, integral chin bar and face shield 77777 not applicable 99999 unknown	Type of cover from helmet inspection and photographs	Num.			x
insafe	PERSON	HELMRET	Helmet retention system type	0 double d-ring 1 slide bar 2 quick fasten 77777 not applicable 99999 unknown	Helmet retention system type from helmet inspection and photographs	Num.			x
insafe	PERSON	HELMRETFAIL	Helmet retention system failure	0 yes 1 no 77777 not applicable 99999 unknown	Helmet retention system failure from helmet inspection and photographs	Num.			x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
insafe	PERSON	HELMRETFAILTY	Helmet retention system failure type	1 chin strap pulled through D-rings, slid bar, or clamp latch 2 quick release let go 3 hanger fitting failed 4 shell rivets failed 5 webbing tensile failure 6 stitching failure in webbing 7 webbing laceration 77777 not applicable 99999 unknown	Helmet retention system failure type from helmet inspection and photographs	Num.			x
insafe	PERSON	HELMSTAY	Did the helmet stay on head during the crash?	0 yes, helmet retained in place to completion of accident events 1 yes, helmet moved on head but was retained 2 no, helmet ejected from head during pre-crash time period 3 no, helmet ejected from head during crash 4 no, helmet ejected from head after collision 77777 not applicable 99999 unknown	Assess whether the helmet remained on the head during the crash, using medical records, helmet inspection and photographs.	Num.			x
insafe	PERSON	HELMFITTED	Was the helmet correctly fitted to the head?	0 yes 1 yes, the helmet moved, but it was still worn 2 no, the helmet was ejected during the crash 3 no, the helmet was	Assess if the helmet was correctly fitted to the head	Num.			x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				ejected after the crash 99999 unknown					
insafe	PERSON	HELMFIT	Helmet fits the head	0 acceptable fit 1 too large, too loose 2 too small, too tight 99999 unknown	Status on how the helmet fits the head, from rider/passenger interview and helmet inspection and photographs	Num.			x
insafe	PERSON	HELMRETSEC	Was the helmet securely fastened?	0 yes 1 yes, the helmet moved, but it was still worn 2 no, the helmet was ejected during the crash 3 no, the helmet was ejected after the crash 99999 unknown	Assess if the helmet was securely fastened to the head	Num.			x
insafe	PERSON	HELMCOND	Condition prior to crash	0-not applicable 1 no significant prior damage 2 minor damage, possibly from handling and use, but not prior structural damage (From Helmet inspection worksheet, rider/passenger interview) 3 moderate damage to exterior finish and comfort pads, possibly from handling and use, but no prior structural damage 4 significant prior damage to shell and liner, but not in area of accident impact 5 significant prior damage	Helmet condition prior to crash from helmet inspection and photographs	Num.			x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				to shell and liner located in area of most severe accident impact 6 significant prior damage to shell and liner located in area of second most severe accident impact 77777 not applicable 99999 unknown					
insafe	PERSON	HELMDAMGE	Sheel damage type	01 no significant damage 02 freckles, small indentations, pockmarks 03 abrasion 04 fracture through 05 crack, split, not through fracture 06 delamination, gross 07 micro delamination 08 puncture 09 rubber transfer 10 paint transfer 77777 not applicable 99999 unknown	Damage type from helmet inspection and photographs	Num.			x
insafe	PERSON	HELMDAMGELOC	Sheel damage type, location	1 2 .. , 28	Damage location according to helmet image and relative grid (from helmet inspection and photographs)	Num.			x
insafe	INJURY	INJURYNR	Injury number	-	Unique number assigned to identify the crash	Num.			x
insafe	INJURY	OCCNR	Person ID	-	Unique number assigned to identify the person	Num.			x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
insafe	INJURY	AISINJURY	Injury according to AIS score	-	Use the AIS score to code each injury sustained by the person.	Num.			x
insafe	INJURY	ISS	ISS - Injury Severity Score	-	Injury Severity Score	Num.			x
insafe	INJURY	IMPLINK1	Macro impacted/hit object	1 car interior 2 car exterior 3 environment 4 ptw 5 bicycle 77777 not applicable 99999 unknown	State the impacted/hit object	Num.			x
insafe	INJURY	IMPLINK2	Specific impacted/hit object	1.1 Bonnet (hood) 1.2 Bumper - Front 1 .3 Bumper - Rear 1.4 Cant rail - Left 1.5 Cant rail - Right 1.6 Crushed by vehicle 1. 7 Door anterior - Right 1.8 Door anterior- Left 1.9 Door posterior - Left 1.10 Door posterior - Right 1.11 etc. 2.1 Airbag (NFS) 2.2 Airbag - Front 2.3Airbag - Knee 2.4 Airbag - Other location 2.5 Airbag - Side 2.6 Airbag- Cant rail (side roof rail) 2.7 Cant rail - Left 2.8 Cant rail - Right 2.9 Centre console / tunnel	State the specific impacted/hit object	Num.			x

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Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
				(NFS) 2.10 Child restraint (NFS) 2.11 Dash panel (NFS) 2.12 etc. 3.1 Barrier/wall 3.2 Building, structure 3.3 Curb 3.4 Ground 3.5 Guard rail 3.6 Pole/post 3.7 Sidewalk 3.7 Tree 3.9 Unpaved shoulder 3.10 etc. 4.1 etc.					
insafe/dacota	INJURY	INJMECH1	The type of trauma	1 'A' Blunt 2 'B' Penetrating, superficial 3 'C' Penetrating, deep 4 'D' Perforating 5 'E' Thermal 6 'F' Chemical 7 'G' Electrical 8 'H' High pressure (explosion) 7 'H' Combination 77777 not applicable 99999 unknown	The type of trauma describes the type of mechanical, thermal or chemical action, which causes the injury. The values 'A' to 'D' in the following list represent different types of mechanical action, caused by a contact between the body and a physical structure, which are the most common types in road traffic accidents. The types 'E' to 'G' represent non-mechanical actions. Blunt trauma means that a penetration into the human body is not present. Penetrating trauma is divided into superficial (limited to the surface area) and deep (not limited to the surface area). Perforating trauma	Num.			x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					is a specific type of deep penetrating trauma through a greater part of the body, where there is an entrance and an exit wound.				
insafe/dacota	INJURY	INJMECH2	The proximity of action	1 Local/direct (located at the contact surface) 2 Distant/indirect (not located at the contact surface) 3 Combination of local/direct and distant/indirect 77777 not applicable 99999 unknown	The proximity of action describes if the injury is located at or very close to the contact surface, or at a distance from the surface.	Num.			x
insafe/dacota	INJURY	INJMECH3	The character (origin) of action	1 Non-inertia effect 2 Inertia effect 3 Combination of non-inertia and inertia effects 77777 not applicable 99999 unknown	The character (origin) of action specifies if the injury occurred due to forces, transmitted from the impact area to the body parts where the injury is located by inertia effects or not. Non-inertia action is mediated by forces transmitted through structures, between the impact area and the site of injury, without a significant inertia effect (most often due to a movement of rigid or semi-rigid structures - like bones - between the impact point and the site of injury). Inertia action is mediated by a forces acting on a specific part of the body, which cause a change of velocity (acceleration) of another part of the body at a distance from the	Num.			x

Sources	Table	Variable	Label	Modalities	Definition	Data Type	B	M	A
					impact area, without a significant rigid mechanical coupling.				
insafe/dacota	INJURY	INJMECH4	The joint injury descriptor	1 Hyperextension 2 Hyperflexion 3 Hypertranslation 4 Hypertorsion (including supination & pronation as sub-classifications) 5 Hyperadduction 6 Hyperabduction 7 Combinations of 1-6 8 Joint injury without non-physiological movement 77777 not applicable 99999 unknown	The joint injury descriptor is used for joint injuries only. It defines the mode, by which an exaggerated or non-physiological movement of a joint causes injuries. This part of the code could preferably be used for joints in the extremities, like shoulder, elbow, finger, hip, knee, and ankle. It is not supposed to be used for joints in the vertebral column, even if this would be possible in some cases.	Num.			x
insafe/dacota	INJURY	INJMECH5	The type of mechanical action	1 A- Compression 2 B - Tension 3 C -Shear 4 D - Bending 5 E - Twisting 6 F - Shock wave effect 7 G - Vacuum effect (contre coup) 8 H - Combination of mechanical actions 77777 not applicable 99999 unknown	The type of mechanical action preferably describes the mode, by which a force acts at the tissue ("microscopic") level. Probably, this part of the code can be used only for specific injuries. In many cases, several modes are active, and if so, the most relevant type of mode should be coded. As this part of the code requires a detailed understanding of the injury process, it might be coded only for some injuries.	Num.			x
TOTAL VARIABLES							**92**	**172**	**223**