Road Accident Investigation

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Abstract

As the world witnessed, the motor vehicle, a mode of transport, is one of the most significant inventions for humans. At the same time, rapid urbanization, steady increase in the number of vehicles, speeding, and negligence on the road increase accident risk. According to the "Global Status Report on Road Safety" published by the World Health Organization (WHO), road/vehicle accident is the eighth leading cause of death for people, that is approximately 1.35 million every year in the world. Accident cases are rapidly increasing. This chapter explains the key elements of the systematic and scientific methods for road accident investigation. Determination of vehicle direction, the velocity at pre-crash, during a crash, post-crash, and change in the velocity are the primary queries for the investigating officer to the way of accident reconstruction. Despite significant usage of conventional scientific methods such as theory, empirical formula, and performing a crash test, there are few limitations for reconstructing the accident scene. The

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results based on conventional methods require knowledge and expertise; therefore, small errors may cause damage in all the perspectives for reconstruction. However, advancements in reconstruction techniques, i.e., accident database, computer simulation software, and event data recorder (EDR), provide great accuracy and significant results.

Keywords

Accident · Forensic investigation · Road accident · Air crashes · Accident investigation

16.1 Introduction

The word accident is typically derived from the Latin verb *accidere,* which means the unfortunate occurrence, happening, falls upon, or by reasonable chance. "Accident" can be defined as a tragic event or action that may not return the result as originally intended but routinely experiences an unfavorable impact on the overall affair (Vincoli 1994). "Road accident" is a term that describes the accident with people and property by the involvement of at least one vehicle on the road. Meanwhile, road accidents, traffic accidents, vehicle accidents, and vehicle collisions are used as synonyms in this chapter.

Contrary to the commonly encountered misshape as arson, beating, stabbing, murder, theft, etc., motorized vehicle accidents or road accidents are proportionately new that are subject to forensic investigation. Vehicular accidents veered to new mayhem instruments as the motorized vehicle was introduced to humans.

Firstly, the concept of an automobile, based on the steam engine, began in Europe. In 1769 Nicolas Cugnot, inventor of the first vehicle, tested the first tractor energized by a steam engine. Cugnot was the first person reported to get into a motor vehicle accident (Nyamwange and Nyamwange 2014). At almost the closing of the nineteenth century, the first gasoline-based motor vehicles were introduced. In 1891, the first automobile accident undoubtedly occurred in American history was in Ohio City. James William Lambert, a successful American automobile inventor, was the first reasonable person undoubtedly involved in the gasoline-powered, single-cylinder automobile accident (Fig. 16.1). His vehicle received careens out of control after hitting the tree root and then smashed into a hitching post (Bailey 1960). During the first and mid-twentieth century, except the years during World War II, motor vehicle industries went through rapid growth and made vehicles globally. The commercialization of vehicles adapted by people is same as other technologies that compress time and distance and promote personal independence (James and Nordby 2009).

There were no vehicular mishaps before the innovation of self-propelled vehicles. From the early year of the invention of motor vehicles, death in vehicular accidents and property loss is relatively low. For example, in Great Britain during the year 1896, two people were killed in a vehicle accident, while in 1899 in the USA, it was only a case registered. Nevertheless, during the mid of the twentieth century, the production of vehicles increases promptly that equally elevates people's death and

Fig. 16.1 John W. Lambert (Bailey 1960)

injury due to vehicle accidents. For instance, by the end of 1965, only in the USA, 49,000 and 3,500,000 people were killed and injured in vehicle accidents. In the very next year, in 1966, more than 12,000 and 14,000 people in France and the Federal Republic of Germany lost their lives in vehicle accidents (Nogayeva et al. 2020). However, the statistics of death and injuries in a vehicle accident are sobering and recorded by different national and international organizations worldwide.

Organizations like National Crime Record Bureau (NCRB, India), National Highway Traffic Safety Administration (NHTSA, USA), and World Health Organization (WHO) produce data on road accidents and losses every year. For example, WHO statistics say vehicles collision is responsible for the leading cause of death of 1.35 million lives every year, which is the eighth leading cause of death globally in 2016. The severity of vehicle accident injury that leads to death in the world can be seen in Table 16.1.

It is evident from the day the self-propelled vehicle was invented that it had sufficient mass and velocity to cause severe injury and property loss. Apparently, in the earlier history of motorized vehicles, forensic investigation of the vehicular accident was not intricate. However, the development and commercialization of vehicles propel the frequency of vehicle accidents. The frequent collisions of cars, trucks, bicycles, and motorcycles make vehicle accident is most prone and indulges nearly 20–50 million people in getting injured globally make to be forensically examined. The significant factors for road accidents are improper driving, excessive speed, intoxication (alcohol and drugs), right of way, failure of vehicular yield, evident failure to stop at the signal, disregard of signals, bad road conditions, improper turn and maneuver, improper passing, inexperienced driver, too close following, distracted driving, overloading of vehicles, and poor vision (e.g., Dazzling sun) (Rolison 2020; Mahata et al. 2019; Naurois et al. 2017).

Table 16.1 WHO's estimates of death related to vehicle accident (per 1M population) in 2013 and 2016

Country	2013	2016	Country	2013	2016	Country	2013	2016	Country	2013	2016
Afghanistan	15.5	15.1	Denmark	3.5	4	Lesotho	28.2	28.9	Saint Vincent and the Grenadines	8.2	
Albania	15.1	13.6	Djibouti	24.7		Liberia	33.7	35.9	Samoa	15.8	11.3
Algeria	23.8		Dominica	15.3	10.9	Libya	23.8	26.1	San Marino	3.2	0
Andorra	7.6		Dominican Republic	29.3	34.6	Lithuania	10.6	8	Sao Tome and Principe	31.1	27.5
Angola	26.9	23.6	Ecuador	20.1	21.3	Luxembourg	8.7	6.3	Saudi Arabia	27.4	28.8
Antigua and Barbuda	6.7	7.9	Egypt	12.8	9.7	Madagascar	28.4	28.6	Senegal	27.2	23.4
Argentina	13.6	14	El Salvador	21.1	22.2	Malawi	35	31	Serbia	7.7	7.4
Armenia	18.3	17.1	Equatorial Guinea	22.9	24.6	Malaysia	24	23.6	Seychelles	8.6	15.9
Australia	5.4	5.6	Eritrea	24.1	25.3	Maldives	3.5	0.9	Sierra Leone	27.3	
Austria	5.4	5.2	Estonia	7	6.1	Mali	25.6	23.1	Singapore	3.6	2.8
Azerbaijan	10	8.7	Eswatini	24.2	26.9	Malta	5.1	6.1	Slovakia	6.6	6.1
Bahamas	13.8		Ethiopia	25.3	26.7	Marshall Islands	5.7		Slovenia	6.4	6.4
Bahrain	8		Fiji	5.8	9.6	Mauritania	24.5	24.7	Solomon Islands	19.2	17.4
Bangladesh	13.6	15.3	Finland	4.8	4.7	Mauritius	12.2	13.7	Somalia	25.4	27.1
Barbados	6.7	5.6	France	5.1	5.5	Mexico	12.3	13.1	South Africa	25.1	25.9
Belarus	13.7	8.9	Gabon	22.9	23.2	Micronesia	1.9	1.9	South Sudan	27.9	29.9
Belgium	6.7	5.8	Gambia	29.4	29.7	Monaco	0		Spain	3.7	4.1
Belize	24.4	28.3	Georgia	11.8	15.3	Mongolia	21	16.5	Sri Lanka	17.4	14.9
Benin	27.7	27.5	Germany	4.3	4.1	Montenegro	11.9	10.7	Sudan	24.3	25.7
Bhutan	15.1	17.4	Ghana	26.2	24.9	Morocco	20.8	19.6	Suriname	19.1	14.5
Bolivia	23.2	15.5	Greece	9.1	9.2	Mozambique	31.6	30.1	Sweden	2.8	2.8
Bosnia and Herzegovina	17.7	15.7	Grenada	5.7	9.3	Myanmar	20.3	19.9	Switzerland	3.3	2.7

Botswana	23.6	23.8	Guatemala	19	16.6	Namibia	23.9	30.4	Syrian Arab Republic	20	26.5
Brazil	23.4	19.7	Guinea	27.3	28.2	Nepal	17	15.9	Tajikistan	18.8	18.1
Brunei Darussalam	8		Guinea-Bissau	27.5	31.1	Netherlands	3.4	3.8	Thailand	36.2	32.7
Bulgaria	8.3	10.2	Guyana	17.3	24.6	New Zealand	6	7.8	Timor-Leste	16.6	12.7
Burkina Faso	30	30.5	Haiti	15.1		Nicaragua	15.3		Togo	31.1	29.2
Burundi	31.3	34.7	Honduras	17.4	16.7	Niger	26.4	26.2	Tonga	7.6	16.8
Cabo Verde	26.1	25	Hungary	7.7	7.8	Nigeria	20.5	21.4	Trinidad and Tobago	14.1	12.1
Cambodia	17.4	17.8	Iceland	4.6	6.6	Norway	3.8	2.7	Tunisia	24.4	22.8
Cameroon	27.6	30.1	India	16.6	22.6	Oman	25.4	16.1	Turkey	8.9	12.3
Canada	6	5.8	Indonesia	15.3	12.2	Pakistan	14.2	14.3	Turkmenistan	17.4	14.5
Central African Republic	32.4	33.6	Iran	32.1	20.5	Palau	4.8		Uganda	27.4	29
Chad	24.1	27.6	Iraq	20.2	20.7	Panama	10	14.3	Ukraine	10.6	13.7
Chile	12.4	12.5	Ireland	4.1	4.1	Papua New Guinea	16.8	14.2	UAE	10.9	18.1
China	18.8	18.2	Israel	3.6	4.2	Paraguay	20.7	22.7	UK and Northern Ireland	2.9	3.1
Colombia	16.8	18.5	Italy	6.1	5.6	Peru	13.9	13.5	Tanzania	32.9	29.2
Comoros	28	26.5	Jamaica	11.5	13.6	Philippines	10.5	12.3	USA	10.6	12.4
Congo	26.4	27.4	Japan	4.7	4.1	Poland	10.3	9.7	Uruguay	16.6	13.4
Cook Islands	24.2	17.3	Jordan	26.3	24.4	Portugal	7.8	7.4	Uzbekistan	11.2	11.5
Costa Rica	13.9	16.7	Kazakhstan	24.2	17.6	Qatar	15.2	9.3	Vanuatu	16.6	15.9
Côte d'Ivoire	24.2	23.6	Kenya	29.1	27.8	Korea	12	9.8	Venezuela	45.1	33.7
Croatia	9.2	8.1	Kiribati	2.9	4.4	Republic of Moldova	12.5	9.7	Viet Nam	24.5	26.4

(continued)

Table 16.1 (continued)

Country	2013	2016	Country	2013	2016	Country	2013	2016	Country	2013	2016
Cuba	7.5	8.5	Kuwait	18.7	17.6	Republic of North Macedonia	9.4	6.4	Yemen	21.5	
Cyprus	5.2	5.1	Kyrgyzstan	22	15.4	Romania	8.7	10.3	Zambia	24.7	
Czechia	6.1	5.9	Lao People's Democratic Republic	14.3	16.6	Russian Federation	18.9	18	Zimbabwe	28.2	34.7
Democratic People's Republic of Korea	20.8		Latvia	10	9.3	Rwanda	32.1	29.7			
Democratic Republic of the Congo	33.2	33.7	Lebanon	22.6	18.1	Saint Lucia	18.1	35.4			

An accident, realistically, is a complex phenomenon that is not supposed to happen. Whenever an accident occurs, the possible reason behind it must be accurately determined. Forensic investigations of accident cases may conveniently be arranged by the responsible government agencies or private insurance companies themselves. The valuable perspectives of an official investigation ostensibly based on the accident case should voluntarily be reported to the legitimate agencies. It may be for an insurance claim, hit and run case, or crash cases. However, in an accident, the rare event could have happened due to contributory negligence. A reasonable person alleges to be arrested and prosecuted (Giummarra et al. 2020).

The results of an accident may be based on a single cause, or it will come by the combination of several causes or incidents in the sequence called the "domino effect" (Bohan 2009). For instance, the outside visibility is low due to excessive rain. Vehicles are running nimbly on the road at their possible speed, and suddenly an animal comes across. Although the driver tried to brake, the vehicle could not stop and collided with a road divider followed by some other vehicles due to a wet road. In this, the vehicle's speed (human negligence), the sudden appearance of the animal, and the rain resist the vehicle's driver visibility and braking system. Knowingly, all of these conditions came into sequence and made enough reasonable cause for the accident.

A vehicle accident gives the investigating officer and forensic fraternity formidable challenges to investigate and reconstruct the accident events aptly. Multiple vehicle crash makes an accident more heinous, and complicated to reconstruct the scene. Efficiently it is justifiable that the suggestion of forensic investigation and analysis of vehicle accident reconstruction narrow down the span of the event phrase. A comprehensive investigation of such vehicle crashes is usually pursued to channelize the human intension or contributory negligence or due to vehicle flaw or road error. Forensic accident investigation is correctly needed where effective techniques and styles are applied to reconstruct the accident scene accurately. The accident investigation process constitutes a necessary part performed by the forensic experts. Investigation of the scene is based on determining the possible causes that lead to the inauspicious event. Reconstruction of any accident event depends on the credibility and performance of an investigator in identifying and collecting physical evidence at the scene. The forensic engineer or investigating officer analyzes the fact and tells why, how, where, and when the accident happened.

Accident investigation has been popularly used for both civil and criminal litigation. Forensic experts opine the report of the event based on evidence found at the scene. Later on, the court will take as per the grant and render their verdict. Criminal action will be promptly taken toward active drivers intimately concerned about the accident. Possible charges may progressively reduce with ordinary negligence. Action may also be taken against the vehicular manufacturer for manufacturing defective vehicle designs. Insomuch, as the possible reconstruction of vehicles accident becomes acceptable, the cause of vehicle accident is precisely known by forensic analysis.

Investigating an accident-related scene should be thoroughly organized with essential elements. Essential elements like an immediate response, proper investigation planning, appropriate public handling during and after an accident occur. A comprehensive collection and documentation of physical evidence will generously help to believe in the causative factors, contributing causes, and reconstructing the gruesome accident scene. Accident investigation techniques may differ subtly from others due to accident types, places, and local conditions. Insomuch, as the possible reconstruction and understanding causation in vehicles accident become acceptable, it is precisely known by the forensic analysis of vehicle accidents.

16.2 Classification of Road Accidents

The accident is a vicious phenomenon whose probability and severity can be defined by the accident classification that helps to maintain valuable accident information. Knowledge of accident classification is essential for planning and establishing priorities in accident investigation. Accidents are classified in the following ways:

1. **Collision with objects**—usually, the collision of a motor vehicle with two types of objects (Struble and Struble 2020).
   (a) Collision with moving objects (another vehicle, pedestrians, animals).
   (b) Collision with stationary objects (road divider, tree, pole, and building on or near the road).
2. **Rigidity of colliding objects**—The object collision compatibility in the combination of momentum disproportion is one of the essential entities to understand the overall damage involved in a road accident. The relative rigidity of any two objects collided in a road accident is classified by three parameters (Jirovsky 2015).
   (a) Vehicle has higher rigidity and weight (momentum)—collision with human, cyclist, small animal, light road barricades, etc.
   (b) Both colliding objects are compatible—collision with same type of vehicle and large animal with similar weight.
   (c) Vehicle has lower rigidity and weight—collision with heavier and larger vehicle, tree, building, etc.
3. **Number of subsequent collisions**—Collisions in accidents carry consequential information. The subsequent collisions are classified into two types (Jirovsky 2015; Kirk 2001).
   (a) Single collision—collision between two object, i.e., vehicle-vehicle or vehicle to obstacles at the same time.
   (b) Multiple collisions—cumulative accident at the same time, i.e., multi-vehicular collision (3 or more vehicle) and multiple collision (2 or more vehicle with a fixed obstacle).
4. **Direction of principal impact force—**Generally, the collision in a road accident occurs between vehicle-vehicle and vehicle-object and vehicle-pedestrian. Collision-caused deformation on a vehicle may be utilized to understand the impact point and principal direction of force. Collision of the vehicle during an accident

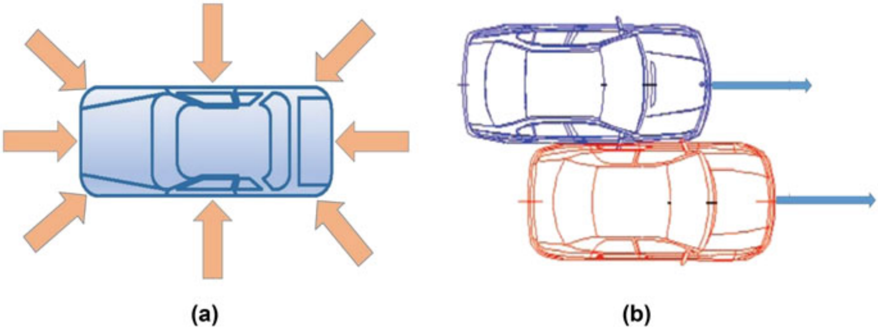

Fig. 16.2 Possible direction of principal impact force in vehicle accident. (**a**) Direct impact on vehicle body. (**b**) Side-to-side impact

is classified as follows (Fig. 16.2) (Eboli et al. 2020; Prentkovskis et al. 2010; Kirk 2001; Jones 1976):
   (a) Frontal impact or head-on collision
   (b) Frontal and side impact combination
   (c) Rear-end impact
   (d) Rear-end and side impact combination
   (e) Side impact (T-bone collision)
   (f) Side-to-side impact
5. **Possible accident condition**—to rate the accident severity and losses, accidents are typically categorized into four distinct conditions (Vincoli 1994):
   (a) **Major accident condition**—accident resulting in hazardous or catastrophic causes major loss of human and economic aspects; e.g., multiple collisions, vehicle pileup, vehicle catches fire after the collision, etc. cause multiple deaths, injury, and massive loss of property.
   (b) **Serious accident condition**—accident resulting in serious injury to humans and property; e.g., a collision between vehicle-vehicle, vehicle-object, vehicle-pedestrian, and vehicle rollover causes death and property loss to participants involved in the accident.
   (c) **Minor accident condition**—accident resulting in disability and damage to a vehicle that is compensable; e.g., breaking of vehicle lights, looking mirror, vehicle deformation, and any physical harm to participants, etc. (Fig. 16.3).
   (d) **"Near misses" accident condition**—an unplanned event that could happen without any detectable injury or resultant damage; e.g., the vehicle losses control, but it is manageable and stops without any damage to a person or property.
6. **Vehicle movement during the accident**—vehicle movement on the road during an accident is classified as follows (Jirovsky 2015):
   (a) Vehicle stays on the road without collision with another obstacle (stops after skidding without collision).
   (b) Vehicle stays on the road due to collision with another obstacle.

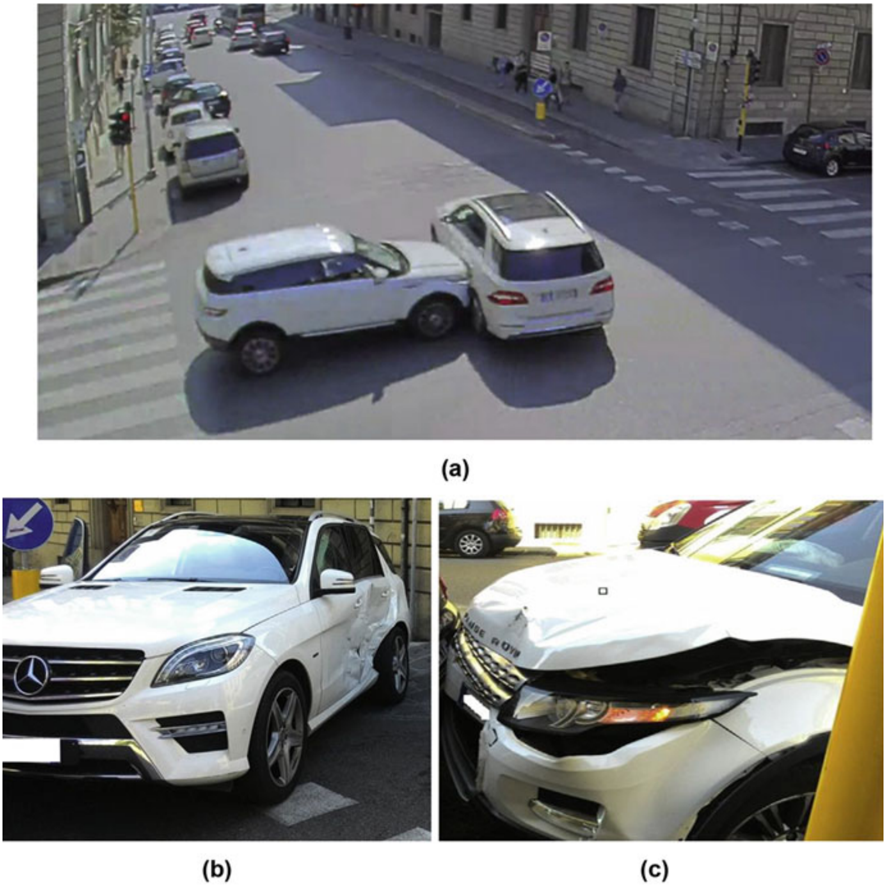

Fig. 16.3 Minor accident between Mercedes and Range Rover. (**a**) Front of Range Rover impacts Mercedes' side (T-bone collision). (**b**) Mercedes side deformations: Analysis and Reconstruction. (**c**) Range Rover front deformation. (Reprinted from D. Vangi, Vehicle Collision Dynamics, Butterworth-Heinemann is an imprint of Elsevier (2020) ISBN: 978-0-12-812750-6. (Vangi 2020). Copyright 2021, with permission from Elsevier)

   (c) Vehicle leaves the road or free-fall without primary collision.
   (d) Vehicle leaves the road due to collision (single or multiple).

7. **Vehicle occupation**—vehicle occupants are discerned as load and its distribution in a vehicle influences vehicle movement. Knowledge of vehicle occupation to an investigating officer during an accident helps to understand possible causes and severity in an accident. Vehicle occupation is classified using the following parameters (Jirovsky 2015):
   Autonomous vehicle driving without any passenger (e.g. taxi).
   (a) Vehicle with only driver.
   (b) Vehicle's load is balanced.

(c) Vehicle liable to pitch due to unbalanced load.
(d) Vehicle liable to roll due to unbalanced load.

The only social characteristic among all types of accident classification is that the resulting event is undesirable. An accident can moreover remain a crime. At the initial stage of the official investigation, it is not apparent that the notable casualty is done due to contributory negligence or by criminal intention. Accidents and organized crimes are discriminated by the possible motive, favorable condition of willfulness, or whether the situation is addressed satisfactorily in the legal code. An investigation must be properly done to determine the cause of the accident and criminal motive liable to prosecution.

16.3 Why Investigation Need

"Why proper investigation needed?" Somehow, the question might have come in everyone's conscious mind. It may sound because of "Procedure of any Law agencies" or "To find evidence" that will help make an opinion for a forensic expert and judgment by the jurisprudence. As in earlier discussion, excessive causality due to accidents is a concern to the forensic fraternity. Where and why an accident happened, and proper investigation of the scene will generously help to understand. The investigation constitutes the initial step and the sole solution to any unfortunate event and incidental things (Horswell 2004). Carefully investigating an accident scene is essential. However, it does not immediately solve the probable cause and continuous sequence of events. But it helps to understand reasonably and develop linkages between pieces of evidence to reconstruct the scene possibly. Impartial investigation of the accident scene may help to develop the following things:

- Investigative leads to forensic expert/investigating officer.
- Specific information to enable a successful prosecution.
- Provide exculpatory, inculpatory, or probative evidence to ascertain the cause and sequence of events.
- Significant evidence that helps in the reconstruction of the event.
- Link intension (negligently, knowingly) of an accident.

Any accident scene is never similar to the previous one and another. Investigation of the accident scene always comes with new challenges. Before starting the investigation, an investigating officer, criminalist, police officer, or forensic expert are devoted to solving the unanticipated event, channelize the objectives, purpose, and investigative questions. Some of the investigative questions include "What happened? When did it happen? Where did it happen? How did it start? Who was involved? How was it performed? Why was it performed? These questions help expand the vision to the comprehensive investigation of the pre-crash, during the crash, and post-crash scenarios (Islam and Kanitpong 2008).

16.4 The Investigator: Role and Responsibilities

Whenever an accident, possible crime, or any unlawful activity happens, the law enforcement agencies assign a person or a team to investigate the event, which is known as an investigator or investigating unit. An investigating team could correctly be forensic experts, police officers, and the criminalist. Forensic scientists, investigators, and crime scene specialists are the individuals whose noble profession is to embrace applied science and modern technology to solve any unlawful act or crime. The function and responsibility of these teams toward investigation are helpful because they possess a certain degree of specialization (Fisher and Fisher 2012). An investigator personally involved in any investigation must have the potential to derive the maximum possible evidence from the scene, and use wisely to determining and accurately reconstructing the complex sequence of accident events. When any vehicle gets into an accident and causes damage to a person or property, it must investigate the scene to collect the possible information. Primarily, an investigator should understand the priority to deal with the accident scene. Evacuate the crowd around the scene to avoid further causality and send the person for medical treatment if needed. Carefully preserving an accident scene to the most significant possible degree is another task for the investigator. An investigator should not allow any private person other than their investigating team. The conviction of teamwork in an accident investigation is a crucial factor to the success of the case. Collecting physical evidence is not as easy because of the complexity of the accident event. The job of the accident investigator is to find the trace or physical evidence and to preserve them wisely. The investigator should keep in mind that "the analysis can be no better than the sample analyzed." Such physical evidence helps the investigator determine the cause of the accident (negligence or criminal intention), involved, sequence of events, etc. Any ignorance with evidence collection and its preservation undoubtedly results in fruitless investigation and often may never be rectified. An accident investigator should not come with a preconceived idea or deduce premature conclusions. Forensic investigation of any scene must proceed deliberately and calmly.

The investigator should objectively analyze every possible inch of the scene on their own for pertinent details. It is worth collecting more evidence than desired, which may not be necessary, but in a later investigation, it becomes imperative. Any bulky or compact body should not overlook any item. A proper investigation helps to collect all the valuable information that substantiates a confession or proves a defense contention raised during the trial. An investigator should not be biased or emotional and adroitly avoid a rush during the investigation that may cause evidence to be overlooked. Every accident scene is different from others; it may not be possible to apply the same absolute for every investigation. However, the leading investigator should figure out the local condition and make outlines to proceed accident scene.

16.5 The Investigation Planning

Pre-planning to fascinate any accident scene is essential that the investigation team make it familiar with the method and sequence of reporting an accident and receiving facts. While investigation planning, wide varieties of activities are involved. Numerous factors may influence the level of investigation planning, such as accident scene, scene distance, and size of investigating team. Nevertheless, the essential steps for investigation planning followed by the many experts were distributed into four quadrants (Vincoli 1994).

1. **Establishing objectives**: establishing clear objectives determines the course and direction of all activities in the investigation. The lack of goals potentially turns to the most significant threat and may divert the investigation.
2. **Understanding priorities**: planning for action priorities to the investigation of the accident scene is another essential step. A clear understanding of priorities will pronounce the methods to achieving the objectives established earlier. It is possibly impalpable to find the myriad facts and information to be collected and evaluated at the heat of investigation. Much of the information may escape that nevertheless turn out to be important for the reconstruction of accident scene later. Proper planning of priorities before the investigation will help to clear the path of objectives. Then the investigating team proceeds with the investigation in a more focused and direct manner instead of haphazard or trial-and-error methods. During the planning, the leading investigator identifies and prioritizes the resource used in the investigation. Knowledge of accident classification, as discussed above, will help to lead the investigator to establish the priorities and organize qualified team for investigation. People with the required skills for certain types of investigation, proper equipment, and materials are also included in the priorities. Investigation with inadequate or inappropriate people and equipment can liquidate the evidence.
3. **Development of actions and schedules**: in this planning process, plan the alternative (personal or equipment) and repetitive course of action following an investigation. As the action plan is versatile and flexible, the investigating officer will offer the greater option to perform the investigation. Continuous consideration of report scheduling and information transfer is also included in action planning to strengthen investigation and further action to be taken. However, the interested officer is provided accurate information that helps to perform suitable action and deduce adverse effect. At the same time, proper scheduling of investigation activities, somewhat, provides control and establishes such milestone. That, later on, must be helpful in adequately accomplishing the investigation promptly. The longer it takes to investigate an accident event, it increases the probability of losing evidence and affects the result.
4. **Preparation of corrective action procedures**: an additional thorough effort may also yield, i.e., the building of courses that will apply in the investigation by the investing team. The disciplinary process identifies the primary program deficiencies and prevents further accidents. Another attractive aspect of corrective

action procedure is flexibility. The course can be in the form of a placard, short and amplified checklists, instructional notebook or guide, detailed operating procedures, manual, or any other condition that facilitates an investigation. At the moment, procedures have been developed, and all the team members in an investigation should be thoroughly familiar with each procedure's contents.

Each of the four steps of the investigation planning process described above for successful accident investigation should exist in one form or another. Except for precise planning and systematic approach, the accident investigation and prevention for further loss of evidence is void.

16.6 Principle of Investigation Process

A forensic accident investigation is an endeavor of attentively examining the possible conditions around the accident scene. Before attempting the accident investigation process, an intuitive understanding of fundamental principles associated with the comprehensive analysis of such incidents is important. Proper reporting is essential to the entire investigation procedure of all the accidents. Therefore, one of the most overarching principles for any accident investigation process is a formal policy typically requiring the proper and consistent reporting of all accidents. The basic statute to a fruitful investigation is knowledge of accident background, properly forming an investigation parameter, securing a scene, frequently searching for physical evidence, proper collection of evidence, and identifying an accident source. It is reasonable that the general objective of investigating a scene is varied. Every crime scene is unique to others. A forensic investigating officer or team should be the empiricist and rationalist to adequately establish the hypothesis and instantly grasp the fundamental principle for the resulting investigation.

16.6.1 Background Understanding and Management

Whenever a massive accident happens, a mishap has undoubtedly resulted from one or a continuous sequence of events. Accidents may be hazardous (major), minor, or "near misses." Before accident investigation is processed, understanding an accident's type, condition, and surroundings is necessary. As accident types and their causes are different, management for investigating the scene is equally varied. The principal objectives of management are proper consideration of property damage, confirmed death or injury of a person, and the leading cause of the accident. Management for the scene investigation is an important factor that helps control the chances of further accidents or injuries. The four prominent management options for accident investigation are: (a) information management, (b) human resources management, (c) technology management, and (d) logistics management. Inadequacy, negligence, or overemphasis of any one of these managements will affect the investigation. Quantifying all these components is based on the background of the accident. The essential component of management has its advantage and disadvantage based on the allocation of personnel and resources, types of accidents, training and expertise, support service available, and jurisdictional issues. Without understanding of accident background, management decision turns to be subjective, which is itself and somewhat dangerous.

16.6.2 Establishing Investigation Parameters

Forensic experts ostensibly have to analyze the parameter within which the impartial investigation is to be followed for making a productive investigation. The successful establishment of necessary parameters through investigation is an important executive decision for reliable identification of the possible cause. Accident investigation is required to satisfactorily establish all possible parameters and a comparative analysis of all the possible reasons that help in decision making. For effective investigation, several fundamental parameters need to be considered such as types of the occurrence, establishing objectives to what to investigate at what extent, possible causes, etc. Factors that affect the establishment of effective accident investigation parameters are faulty communication, improper training, and lack of adequate information. A disciplined and methodological investigation of a scene can be fruitful and productive for the investigating officers. However, the establishment of investigating parameters is equally affected by the misguided and haphazard investigation of the reported accident.

16.6.3 Accident Sources

To understand the fundamental principles of accident investigation, a forensic investigator must also understand the sources of mishaps as it aid the investigating officer to identify the cause, the methods and techniques to be used and the type of evidences to be traced. An extensive collection of physical evidence is essential in any judicial investigation. In accident investigation, the undesired events are caused due to the source of error like human, material, mechanical equipment procedure, and environment. An accident may occur due to the single source of error or a combination of different sources of error in sequence, or may one source affect another source, also known as the "domino effect."

16.6.4 The Investigation Pyramid

The scientific investigation and analysis of an accident are structured like a pyramid. At the beginning of any case, available facts and information seem like scattered pieces of a puzzle. At first, facts and pieces of evidence are merely collected, gathered, and placed at the bottom of the table. These are the exclusive base

Fig. 16.4 Investigation pyramid

foundation for the conclusive pyramid. All the pieces of evidence are sorted and each piece is fitted to all the other evidence until the facts are proven. These facts are formed for the analysis which is proven by the scientific principle and methods. The facts and physical evidence and analysis are taken together that support the conclusion that is the apex of the pyramid (Fig. 16.4). Conclusions should completely be dependent on facts and analysis, and never be on a personal assumption, conclusions, or any other hypotheses that may collapse the logical construction. If the facts and physical evidence are logically and symmetrically arranged, the conclusion appears self-evident and stronger.

16.7 Tools and Techniques for Investigation

Considerable success or evident failure of any accident investigation may depend upon planning and elaborate preparation for the complete investigation. Addressing of proper accident investigation kit is another substantial part of preparation. Before reaching the occurrence, positively assuring of proper tools required for the investigation is essential. The adequacy of necessary tools in investigator suitcase may depend on the distinct type of accident, distance of the accident scene, etc.

The accident investigation toolkit, based on its use, may be divided into four types (Kirk 2001):

1. Basic tools (used in open, cut, or removing)
   - Allen wrench
   - Screwdrivers (different sizes and types)
   - Open and closed-end metric and English wrenches
   - Set of 1/4- and 3/8-in. drive sockets, metric and English
   - Jackknife
2. Special equipment (used in marking, documenting, and preserving)
   - Chalk
   - Pencils and pens (different color)

- Blank card (3 × 5)
- Contour gauge
- Measures (12, 15, and 100 ft)
- Cardboard play card
- Clay
- Graph and plain paper
- Stick-on tape measures
- Menu board
- Surveyor’s pin
- Vehicle trajectory rods
- Handheld compass and magnifying glass
- Tags for label the evidence at the scene
- Accident investigation form
- Duct tape
- Evidence collecting bags

3. Photographic and videographic equipment (used for accurately detailed investigation)
   - SLR camera (35 mm) with 50- or 70- to 115-mm and wide-angle lens (25 mm, 1-in.)/UV filters
   - Motorized unit and data back for dates
   - Standard adjustable angle flash with the detachable hot shoe with a diffuser
   - Ring flash
   - Color film, 100 and 400 DIN, 24 and 36 exposures
   - Panoramic lens camera
   - Monopod or small tripod
   - Backup camera with all the above equipment
   - 8- or Super-8-mm camera with carrying case
   - Spare charged batteries and cassettes
4. Special safety gear or equipment (use by the investigator for his safety)
   - Orange road cones and vests
   - Gloves
   - Flasher for cars
   - Telephone (cellular)
   - Business card and authorization from the client
   - First aid box

16.8 Accident Scene Investigation

A vehicular accident investigation is complicated, outdoor, and generally found in high-traffic areas. Scene investigation and archiving of potential evidence to understand the cause and sequence of accidents have always been challenging. Forensic experts or forensic engineers remain the first individuals to investigate any accidents scene. Acquiring the knowledge of accidents type, vehicles and their dynamic motion, road, geographical area, etc., may help to channelize what they require to observe. Undoubtedly, the accident scene is customarily restricted with traffic, time, nearby construction, or frequent changes in climate (Dong et al. 2018; Topolšek et al. 2014). As discussed earlier in step 3 of investigation planning, they must maintain a backup plan as the situation changes. Perhaps, accident investigation begins at the end of the accident. It is at this point some questions are raised: how did this happen, who and what is responsible for the accident? With the chronological investigation, the investigator gathers, establishes, and assesses evidence to understand how and why the accidents occurred. The events that leading to an accident may be differentiated into pre-accident, during accident, and post-accident. In typical instances, information about pre and post-accident events is reasonably known. Nevertheless, information about the event between pre- and post-accidents is unclear, confusing, or even contradictory (Noon 2009). Assume car A and car B heading north and south and collide in the street and freeze at the same point. However, this pre-accident (heading of a car) and post-accident (point of rest) are clear. The investigator role is to fill the intermediate event sequence and its reason. The intermediate points are usually revealed by the evidence gathered and assessed. The investigators need to assess, sort, and sequence the evidence into a logical and coherent story. Like puzzles, some of the missing or few extra pieces are thrown in from other puzzles, and the investigator considers each piece of evidence with different perspectives and combinations to determine the perfect fit. Reconstruction of accident events depends on the quality of investigation, and that can be concluded by following the steps as in Fig. 16.5 (Cameron 2008). An investigation phase has started adequately after all the immediate rescue and providing medical treatment to any injured person.

The investigator typically collects evidence from accident scenes, which are generally fragile and important in reconstruction. Pieces of evidence at the accident scene may refer to the "four Ps" evidence (Ferry 1988**).** The "four Ps" are people, position, parts, and papers. Peoples are the wellspring of eyewitness testimony to the accident events. Eyewitness evidence is obviously based on their observation and memories that may conflict with others' stories and fade by the passage of time. Positions entrust to the physical relationship, placement, and sequence of events occur during pre - contact, contact and post contact duration of the accident. This includes, for example, location, weather, and roadways condition, physical evidence like scatter parts, tire marks, broken glass or mirror, dent on a vehicle, etc. Parts refer to internal parts of vehicles that can be potential evidence in understanding the cause of an accident. Parts evidence can include improper installation or use of faulty parts or materials or inadvertent abuse of parts, violation of manufacturing standards, etc. Paper evidence invokes as background information of any vehicle like operating instruction, maintenance record, etc. These are the evidence recorded on paper (i.e., "paper trail"), generally destroyed in an accident (Vincoli 1994). Recovery of paper makes it easy to understand the condition of the vehicle before getting in the accident.

While practicing an investigation and collecting physical evidence from the accident scene, the primary step is documentation. Documentation includes

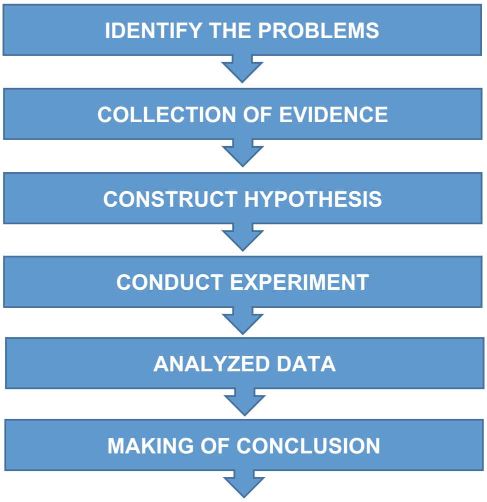

Fig. 16.5 Steps in accident scene investigation

statement recording, noting, sketching, photography, and videography of physical evidence with proper scaling and reference with other pieces of evidence. For example, tire and skid marks, depth and size of crush, paint and gauge marks, and position of all debris pieces are subjects of appropriate documentation or make a note with proper measurements. An aware investigator can primarily use the "Haddon matrix" for meticulously documenting credible evidence and the complex situation of the accident (Struble and Struble 2020). In 1970, Dr. William Haddon typically developed the grid on investigators who may record information before, during, and after an accident. Haddon matrix for accidents allows nine cells which efficiently formed by three columns and three rows. Rows show phases of events such as before the accident, during the accident, and after the accident. Columns recognize the causal factors of an accident in each period like human factors, vehicle and equipment factors, and physical environment factors (Table 16.2 Haddon matrix). The comprehensive forensic investigation of 'four Ps' prorates the evidence as subjective and objective evidence (Bohan 2009).

16.8.1 Subjective Evidence

Subjective evidence matters to the statement of a person physically present during an accident and claiming knowledge of the events (Wach 2013). They are persons apprehended as the witness or fact witness or eye witness. An eyewitness can represent any pedestrian, local passenger, or the drivers and participants themselves. It is the human tendency to remember precisely what they saw by their own eyes. Accounting of leading investigator with eyewitnesses could willingly have sources of valuable information. A valuable piece of evidence is concluded as what somebody was riding, direction, possible speed, and any mechanical failure before the

Table 16.2 Haddon matrix

Phase	Human error	Vehicle/equipment error	Physical environment
Before accident	Experience, overspeed, negligence, drink and driving, poor reaction time	Break failed, poor visibility, active safety vehicle system, vehicle control and technical condition	Road geometry, narrow shoulder, road surface condition, visibility and weather condition, pedestrian and cycling facility
During accident	Not to use safety measures	Impact protection (safety belt and air bag not properly fixed)	Road side safety (improper guardrails, shoulders, and clear zone)
After accident	Emergency response, control of behavior of culprit	Emergency response system "Era-Glonass," victim extraction, means of first aid	Restoration, unwell emergency communication system

collision. But a leading investigator should not rely on witness statements. Very convincing studies have proved that the ability of a human to recognize any events exactly as he/she saw is not permanent (Bohan 2009).

Any statement given by the eyewitness is taken as "corroborative evidence" because "circumstantial facts" of events may be un-followed with the statements. However, the oral testimony may also turn into hostile. They may draw their own story, conclusion, idea, and give incomplete information to the investigator. Statements of an eyewitness may be partial if he/she or any relative of the parties are involved in accidents. However, some important condition is absolutely unknown to any of the eyewitness and participants, though may come to light with a thorough and unbiased investigation. For example, instant or internal mechanical issue in any of vehicles involved in an accident unknown to the eyewitnesses could have increased the stopping distance, improper timing of traffic light, speed limit board, etc. Surprisingly many of "obvious" causes, which are not known to eyewitnesses, can be brought to light with modest investigation of physical evidence and facts.

The key elements in any vehicle accident are speed, skid distance, direction, and elapsed time, which may not be known to the eyewitnesses. They usually do not see or comprehend the latent deficiencies. Eyewitnesses focus on the immediate crash due to its noise and exclude other events and circumstances that existed at the incident site at the same time (Noon 2009). Eyewitness report is not direct, as often it is based on observations. They generally produce conclusions based on what they sensually observe. Sense-based conclusions are often formed by connecting the possible dots of disconnected events they observed. However, some of witness are "hearsay witness." Hearsay witnesses are persons who have not actually witnessed the event but they know what they heard from their friend or neighbors. Over time, they may forget the sequence of events and remember the things that they find interesting. Also it is obvious that some of the witnesses come out for attention who simply lie. With a proper scientific investigation of accidents and carefully analyzing physical evidence, investigators may arbitrate who is embellishing the truth, who is telling truth, and who is not.

16.8.2 Objective Evidence

The physical evidence moreover identifies a piece of objective evidence. A piece of physical evidence may the part or the vehicle itself and the marks formed due to friction between tires and the surface. The physical evidence in vehicular accidents ordinarily includes tire (skid) marks, paint chips, broken glasses and vehicle parts, and dents or sketches. Such credible evidence is examined directly at the scene or through photography and other documentation for later. Objective evidence present at the accident scene are reliable and and can be analyzed by using science and technology (Wach 2013). For example, assume a car caused skid marks of 165 ft (49.5 m) before the direct collision with a big stone and a dent of 15 in. deep created at the car's front end. Visible skid marks and dents on the car can give a clear and complete idea to understand that the car maintains enough velocity to crash by skidding tires after braking hard-to-wheel lockup. The source of the objective evidence in a vehicle accident is mainly two types. The first is the accident scene and surroundings, and the second is the exterior and interior surface of vehicles.

16.8.2.1 Accident Scene and Surrounding

Accident scenes and its surrounding are abundant sources of physical evidence. Evaluation of accident surroundings may turn more difficult due to scatterings of the fragmented particle, forest areas, traffic, etc. (Kirk 2001). Scene investigation is a preliminary step for understanding the direction, speed, and cause of an accident (Islam and Kanitpong 2008). The first logical step for an investigator is to carefully choose a reference point (RP) with all the sketches and accurate measurements satisfactorily performed. The reference point must be close and permanent with the accident scene.

Furthermore, it cannot be changed or moved for years to assist another investigator on a more recent day of the investigation. Reference points could represent a milestone, telephone or utility pole, tree, etc. Another is to identify the point of impact (POI) (vehicle-vehicle POI or vehicle-object POI) and point of rest (POR). POI may be considered the point of exchange, following Locard's exchange principle, where vehicle-vehicle or vehicle-objects impact and exchange their traces. The POI may turn to the point of rest (POR). Point of rest is the place where rolling or skidding of tire freezes. More often than not, the point of rest is one, but it may change in multiple collisions accidents. Tire marks of a vehicle involved in the accident constitute a substantial source of evidence. That wisely helps determine possible direction, wheels (rolling or stopped), and possible speed of the vehicle before the crash.

16.8.2.2 Tire Marks

Tire marks are generic evidence at the accident scene to assume the direction, speed, and load on vehicles on the road (O'Hara and Osterbug 1960). Investigators may search tire marks as per three types, which appear at distinct phases of the accident, such as "Yaw, Skid and Acceleration Marks," mainly in the patent form (2-dimensional impression). The problem with tire marks is it starts fading up within a day or even within hours or maybe messed up with the other vehicle tire marks. Fading of skid marks causes shortening in skid marks length, results in an underestimating of vehicle speed. Furthermore, whether associated with an accident or not, the mixed tire marks should be measured or at least photographed until it is not confirmed. Preservation of tire marks to be done by documentation (photography) with proper measurements (scaling) may assist the later investigator in the reconstruction process. The appearance of tire marks in a vehicular accident is classified into three forms, i.e., yaw marks, skid marks, and acceleration marks.

16.8.2.2.1 Acceleration Marks

The acceleration mark always appears before a collision phase. Sometimes, an investigator gets confused between the acceleration and skid marks made before, during, and after the potential collision. Acceleration marks may carefully be differentiated by their dark pattern. The skid marks start as light in color and turns in dark as the tire get hotter. In acceleration, marks are somehow opposite. Marks at the possible beginning are darker and lighten up as the vehicle moves forward. Acceleration marks depend on the rotating power of the axle and the coefficient of friction between the road surface and tire treads. From a forensic perspective, acceleration marks corroborate to understand the intention of the vehicle driver. The intentional frame did the accident, or it just happened in negligence.

16.8.2.2.2 Skid Marks

Skid marks are the unidirectional visible marks left by the sudden braking of the vehicle (Wang and Lin 2008). It appears due to friction between the road and vehicle tires. The wheel suddenly stops rolling and starts sliding at the road (Fig. 16.6). Skid marks are the most valuable trace evidence at the accident scene for forensic experts or investigating officers. Skids marks could occur before, during, and after a collision. Tire skid marks can appear in three phases, i.e., cleaning, tire heat up, and end with heavy black skid marks. In the cleaning phase, tires skid on the road, but no marks occur, only cleaning the road and tire surface. In the second phase, the tire surface experiences heat up, which makes marks as light to slightly darker. The first two, i.e., skid marks' cleaning and heating phase, are not easily visible unless it is evaluated from different directions. The heavy black mark phase is distinctly visible to the investigator. It forms due to the heating up of tires and sudden end under the tire at the point of rest. All three phases of skids help investigative officers investigate and understand the possible direction and speed of vehicles with more accuracy.

Skid marks appear due to sudden braking or sudden locking up of vehicle wheels. Sometimes more than one unique set of skid marks of the same vehicle that appear at

Fig. 16.6 Skid mark. (Reprinted from YW. Wang, A line-based skid mark segmentation system using image-processing methods, Transportation Research Part C 16 (2008) doi:10.1016/j.trc.2007.09.002. (Wang and Lin 2008). Copyright 2021, with permission from Elsevier)

the scene is difficult to determine resolutely. By a close analysis, an investigator can see that one set of marks usually grows lighter as pressure is released. The reasonable length of skid marks more often depends on the vehicle's kinetic energy (weight and speed), the pressure of the brake pad against the disk or drum, surface, and tire conditions. The vehicle's speed before skidding is calculated by measuring the length of skid marks.

16.8.2.2.3 Yaw Marks

The vehicle's tires rotating and turning simultaneously and leaving a mark are called scuff marks or yaw marks. It forms when a vehicle develops an angle of slip or disparity between its heading and velocity (Siegel and Mirakovits 2016). Striation in yaw marks is very distinctive from other striations. In the case of lockup or full braking, striation is situated by the tire marks and parallel to the direction of vehicle wheel hub movement (Fig. 16.7). Yaw marks can appear before, during, and after the accident. Striation marks of a vehicle can be at various points. It depends on the number of collisions and the amount of "rolling under" the tread while maneuvering. The rear as well front tires both can create the striation and skid marks. The skid marks are usually more dark than the striation marks. The Yaw mark's width, number, and striation angle are critically dependent on the vehicle speed and velocity direction (Franck and Franck 2010). An investigator may differentiate the yaw and side skid marks by measuring the width of the mark. The tire's pitch size appears double as the tires skid sideways. Change set in the position of a vehicle can instantly be recognized by the investigator by analyzing skid or yaw marks that end under the tires at a point of rest.

Fig. 16.7 A yaw or scruff mark. (Reprinted from EM. Robinson, Crime Scene Photography—2nd Edition, Academic Press is an imprint of Elsevier (2010) ISBN: 978-0-12-375728-9. (Robinson 2010). Copyright 2021, with permission from Elsevier)

16.8.2.2.4 Location of Debris

Locating debris of accidental crashes is vital for the investigator. Debris may be of a vehicle door, shattered glass pieces, screws, paint chips, shattered windshield, or any fragmented part of a vehicle. The point of impact and rest, road, shoulders, poles, trees, the vehicle itself, etc. are the most common places from where an investigator can unearth the evidence point of impact, point of rest, road, shoulders, poles, trees, the vehicle itself, etc. (Struble and Struble 2020)**.** Location of debris helps to assume direction, point of impact, point of rest, and vehicle speed. Documentation (sketch) of debris may be performed on an overlay sheet of clean Mylar by framing of vehicle point of rest and reference point. Investigators may find any discrepancy later; they will place the overlay on measurements and reconstruct the scene. The sketch can be enlarged and used as court exhibits by placing overlay in a computer-aided designed (CAD) program or high-speed plotter.

16.8.2.3 Vehicle: Exterior and Interior Surface

An investigating officer often does not include the window of opportunity to evaluate vehicles at the scene. The traffic issue, climate changes, and complexity in the accident scene give trouble searching for necessary scene evidence for reconstruction. After making detailed vehicle documentation concerning the accident scene and other evidence, the vehicle towed away for a later examination.

Vehicles involved in any accidental scene are the considerable body having fundamentally significant evidence for the forensic investigation. An accidental vehicle, inside and outside, have various deformations and scratches. That can give some good sense of idea for accident causation and reconstruct the scene. However, the vehicle not in control and collided with any other vehicle, tree, road divider, pedestrian, etc., mutual exchange of empirical evidence took place (Locard's principle of exchange). The condition of marks, fracture or dent, and exchange of trace on the vehicles tell some story. The investigator may understand all the possible conditions of the accidents by making an effort and evaluating the vehicle's exterior surface and interior deformation. Evidence source at the exterior surface could be the metal fold, tires condition, paint transfer, scrape, scratches, gouges, wheel metal condition, fluid leaks, side marker light, taillights, and headlight and vehicle deterioration condition. Deformed vehicle could indicate the POI and direction of impact force (Fig. 16.8). Vehicle interior deformations include instrument panels, steering column, steering wheel rims, sun visors, sunroof, seat cushions and seatback, smear and blood pooling, windshield, rear window, etc.

Carefully noting, sketching, photography, and videography with proper measurements at every phase is necessary for preserving evidence at accident scenes. The frame of documentation (photography and videotaping) of the accident scene depends on carefully noting, sketching, photography, and videography with proper measurements at every phase necessary for preserving evidence at accident scenes. The frame of documentation (photography and videotaping) of the accident scene depends on the investigation's objectives, as in Tables 16.3 and 16.4 (Shaler 2012). Documentation helps in the more recent examination and reconstruction of the accident scene.

An investigating officer should be aware of the vehicle's extensive evaluation, either the interior or the exterior, and note down all the missing parts. While transporting vehicles to the garage or yard, unrelated damages and modifications may form, such as the door may be cut off to rescue the victim, tire place, axle where towing machine hooked, removing of paint, etc. These are the details investigator should always be aware of on both the crime scene and subsequent vehicle inspections. Instead of all, information of a specific vehicle, model, performance, traffic device and sign, roadways specification, traffic on the road, and date and time of the accident are equally notable.

16.9 Accident Reconstruction

Many people undertake that the accident investigation and accident reconstruction are the same subjects of a thing. Nevertheless, in the investigation, the investigator evaluates the scene strictly and also documents and preserves the evidence at the scene. Reconstruction is building up of accident as approximate with the help of remaining parts of vehicles, credible evidence, and documentation. A forensic examination of the accident scene may come with a qualitative and quantitative description. However, the primary objective of the reconstruction of an accident is to

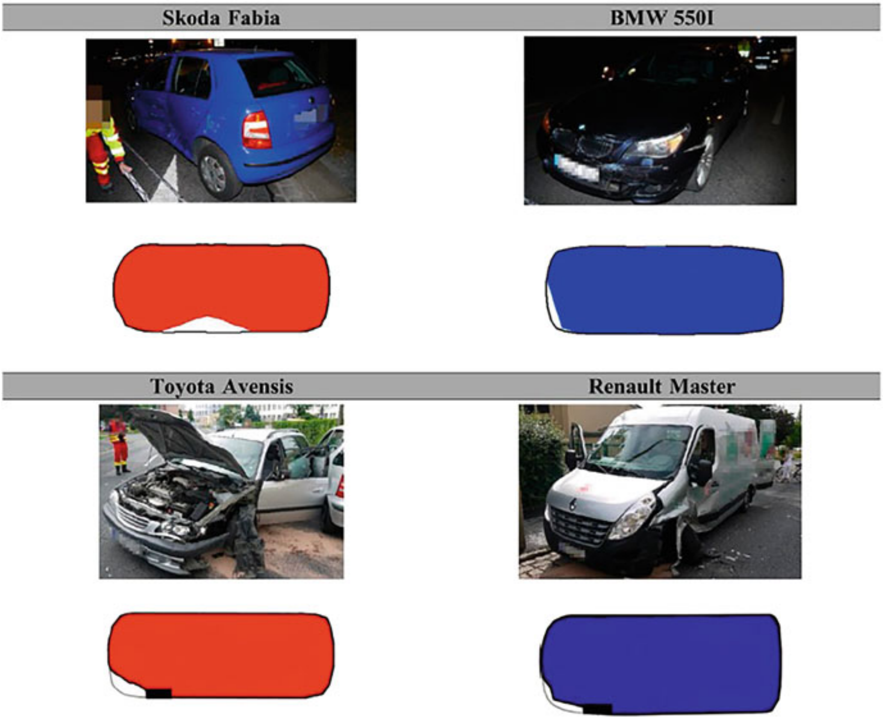

Fig. 16.8 Deformed shapes of vehicle involved in real accident utilized in reconstructing the POI and direction of impact force. (Reprinted from D. Vangi, Vehicle accident reconstruction by a reduced order impact model, Forensic Science International 298 (2019) https://doi.org/10.1016/j.forsciint.2019.02.042 (Vangi et al. 2019). Copyright 2021, with permission from Elsevier)

come by a numerical description (quantitative description) (Bohan 2009). For example, saying "the truck was skidded by the 110 ft and then collide with the street light (quantitative description)" is far worthy to saying that "the truck was skidded to some reasonable distance and then smashed into street light" (qualitative description).

In proceeding to a forensic reconstruction of the accident field the investigating officer requires specific grip in:

- Criminalistics (interpretation to traces)
- Vehicle dynamics and technology, particular reference to steering, rolling, braking, passive and active safety systems
- Basic knowledge of crash-worthiness
- Collision mechanics or collision theories
- Kinematic calculation (time-distance analysis)
- Human factors (individual and age differences, perception and information processing, driver perception-response time)

Table 16.3 Guideline for vehicle accident scenes photography and videography

Object to photograph/ videograph	Reason for photograph/videograph
Point of impact	To relate other aspects of scene and to identify where the hit took place
Traffic lights and board	Their location is important to know
Driver's viewpoint	To understand what the driver was able to saw
Skid marks	To understand the speed and momentum of the vehicle before and after the collision
Roadways condition	To understand aspect of road in accident
Roadways	To know road environment, i.e., slope, defect, distance of debris from impact site, and vehicle position
Tire tracks	Direction and location of tire tracks
Instructions board	To know if any banner, board, obstacle that would have come across the driver
Biological evidence	To know the place of biological evidence
Paint removed	To document possible paint transfer from vehicle, close-up photography
Trace and debris evidence	To understand the location of glass, fiber, plastic and metal or other fragmented particles from reference point and collision place
Interior and exterior photographs of vehicle	Scratches on vehicle surface, position of crush, length and depth of crush, seat position, gear lever position, etc.
Other shots	License plates, VIN number, previous welding place, etc.

Table 16.4 Photography and videography

Documentation must include markers (scale) to identify position of evidence and vehicle	
Overview	To record the story and relationship of evidence to the overall scene
Midrange	To relate the evidence to its nearby evidence, i.e., evidence-to-evidence relationships
Close	To record the proper detailing of evidence with and without scaling

- Computer simulation techniques
- Digital photography, imaging techniques, and photogrammetry
- Road infrastructure
- Basic knowledge regarding accident scene and complementary examination in road accident

Vehicular accident reconstruction represents the exploratory phase. The forensic investigator analyzes an accident and exploits their knowledge of physics, physical fact, and data collected from the accident scene. By utilizing extensive knowledge of the evidence, an investigator can determine the speed of vehicles involved, angle of impact (primary and secondary), mechanical failures, and environmental factors that may have caused and affected an accident's responsibility. Accident reconstruction comprises two types, i.e., damaged-based reconstruction and trajectory-based reconstruction (based on the principle of momentum is conserved). The reconstruction starts with the damaged vehicle and sufficient distance of its debris to skid and yaw marks and road condition. The conjunction of both reconstruction methods typically results in a more accurate reconstruction. The two vital tools for the reconstruction of accident events are the law of conservation of momentum and conservation of energy. With sufficient data, the law of conservation of energy and conservation of momentum makes it possible to determine the speed of vehicles after and before the accident (James and Nordby 2009). According to the law of conservation of energy, the system's energy at a beginning process is equal to the end of the process (Eq. 16.1). In any vehicle accident case scenario, the combined energy at the end is irreversible and cannot be returned into kinetic energy again. Such an example of irreversible work is braking, yawing, skidding, crushing, bending, and twisting vehicles.

$$E_{\text{start}} = E_{\text{end}} \tag{16.1}$$

where E is total energy of system.

Every moving vehicle possesses its own kinetic energy which is directly proportional to the speed and mass of vehicle (Eq. 16.2).

$$\text{KE} = (1/2)mv^2 \tag{16.2}$$

where KE is kinetic energy, m is the mass of vehicle, v is the velocity of the vehicle.

As the eq. 16.2 shows, KE increases to the four times as the velocity doubles. This is why a vehicle traveling at 60 mph requires four times more braking distance to stop than the exact vehicle traveling at 30 mph. As with the braking distance, the severity of accidents and injury is proportional to vehicles kinetic energy. Skid marks are one of the dissipated ways to calculate the initial kinetic energy before braking and how fast the vehicle was during striking with any pedestrian or any other obstacles.

The force applied through the irreversible frictional work done is calculated by the formula.

$$E_{\text{work}} = (mg)fd \tag{16.3}$$

where

E_{work} = work done by skidding
m = vehicle mass
g = gravitational constant
mg = mass of vehicle × acceleration of gravity

f = frictional coefficient between tire and surface (road)
d = distance of skid

As we discussed above, the kinetic energy of vehicle in motion is equal to the energy dissipated by vehicle skidding. By applying Eqs. 16.2 and 16.3 an investigator can simplify the results.

$$\begin{aligned} E_{\text{start}} &= E_{\text{end}} \\ \text{KE} &= E_{\text{work}} \\ (1/2)mv^2 &= mgfd \\ V &= [2gfd]^{1/2} \end{aligned} \tag{16.4}$$

Therefore, by precisely measuring the reasonable length of skid marks, the speed of a vehicle just before skidding can be calculated. This formula is moreover known as the skid formula (Eq. 16.4). During a collision with any pedestrian or object, the length of skid marks formed utilizes to calculate the pre-collision vehicle velocity. Although the vehicle continues to skid, the front end of a vehicle crashes into the wall. Crushing the vehicle's front end causes another way of dissipating the kinetic energy of the vehicle. As we know, the crush at the front end of a vehicle is directly proportional to the vehicle speed. Therefore, the speed and crush relationship varies with the make and model of the vehicle. Government and private organizations produce data of crush rates at different speeds every year. The reliable crush rate versus impact speed data may be directly utilized in determining the accident crush. After skidding some feet, it crashed into the wall and got some deformation if a vehicle is moving forward. It shows that the vehicle must have been going with much more kinetic energy than the skid formula alone would measure skid length. In this, the vehicle's kinetic energy dissipated in skidding and crushing the front end of the car to any wall without hitting any pedestrian, as we can see in Eq. 16.5.

$$\begin{aligned} \text{Kinetic energy} &= \text{Skid work} + \text{Crush work} \\ (1/2)mv^2 &= mgfd + Kx \end{aligned} \tag{16.5}$$

where

K = crush coefficient
x = average crush depth at the front end of vehicle

Solving Eq. 16.5 for the velocity (v) of vehicle gives the following:

$$V^2 = 2gfd + 2(K/m)x \tag{16.6}$$

Investigator can also estimate the deceleration rate of vehicle during collision with wall. By using basic kinematics, the deceleration rate can be computed as follows:

$$a = v^2/2x$$

where

v = velocity
x = crush distance
a = deceleration

Understanding friction coefficient between tire and surface is another challenge for the investigator. To apply in skid formula, the determination of the friction coefficient is essential. Generally, the friction coefficient is untaken into the measure. The investigating officer may directly apply the predetermined friction coefficient to calculate the speed. The friction coefficient varies with place, climate, vehicle model, load on the vehicle, and the surface. The friction coefficient for regular vehicles at dry concrete, dry bricks, wet tar, wet concrete, and wet snow is 0.8, 0.7, 0.5, 0.4, and 0.2 (Sharma 2014).

Nevertheless, the friction coefficient of the vehicle varies with road and vehicle conditions. To establish the vehicle's speed more accurately at the accident time, the investigator performs experimental work for friction coefficient with possibly the same conditions. In most cases, the vehicle involved in the accident is not in the condition to experiment with determining the friction coefficient. If the vehicle tire is affected by the accident, the tire may be used for the experimental tests by shifting it to the test vehicle from the the accidental vehicle. As Newton's third law states, whenever two vehicles collide with each other, they exert equal and opposite force to each other. If the two vehicle has the same mass and velocity and collides with each other, the net force between the two vehicle turns to zero. As follows, the net momentum of a vehicle just before the collision is equal to the net momentum of a vehicle after the collision. The net momentum could be changed by applying external force or due to differences in mass and velocity in a vehicle. This law of conservation of momentum may help in formulating the velocity of a vehicle before the collision. The principle of the law of conservation of momentum is not only used in determining the speed of a vehicle, but it also helps to recognize the conservation of energy. By implementing the conservation of energy method, the "after impact" speed of the vehicle is calculated with the help of skid marks. Whereas the the speed of vehicle (before impact) can be calculated by using the conservation of momentum. To understand, a car of 2700-lb stands hand braked by the roadside and a driver with a mini-truck of 6000-lb not seen the car drives into the rear end at a speed of 36 mph. Before the potential collision, the mini-truck only had the initial energy and considerable momentum. The car was not in momentum before the collision gets pushed onward by a speed of 23 mph, and the mini-truck slows down by 17 mph. Both cars and mini-trucks come to a stop by skidding 31.7-ft and 25.3-ft. Consequently, the total momentum of the truck and car after the collision is the same as the momentum of the truck alone.

Conservation of energy and conservation of momentum more often are used collectively to formulate a mini-truck's speed in an accident more precisely and accurately. The speed (kinetic energy) of the mini-truck "before impact" is equally possible to be determined by measuring the rear and front crush depth of the car and mini-truck.

16.10 Advancement in Accidents Reconstruction Methods

Calculating the accident scene with accuracy is synonymous to the reconstruction of the accident scene. The relationship between reconstructed results and traces left at the accident scene is described best as suitable methodologies. Reconstruction of the accident scene includes five types of methods (Zou et al. 2018). The first method includes theories and empirical formulas that include models based on braking distance, vehicle deformation, the distance of the pedestrian, and injury to the human body. The second method is based on the true vehicle test. In the provision to know more information about the accident, true vehicle tests will be prosecuted evenly as information obtained from the accident scene. Third is allowed to use database based on the crash, injury, and vehicle model, provided by the National Highway Traffic Safety (NHTSA), Research Input for Computer Simulation of Automobiles Collisions (RICSAC), Insurance Institute for Highway Safety (IIHS), Energy Equivalent Speed (EES), Aggregated Homologation proposal for the Event data recorder for Automated Driving (AHEAD), NASS-CDS, Crash Injury Research Engineering Network (CIREN), German In-Depth Accident Study (GIDAS), Co-operative Crash Injury Study (CCIS), and Road Accident Sampling System-India (RASSAI) (Böhm et al. 2020; Pinter and Szalay 2018; Shannon et al. 2018; Vangi et al. 2018; Bhuvanesh et al. 2015; Prasad et al. 2014; Teoh and Lund 2011). The fourth method concludes computer simulation software which is accurate and more reliable to forensic experts. The computer simulation software commercially available includes PC-Crash, Virtual Crash, HVE-3D, V-SIM, MADYMO, Japan Automobile Research Institute (JARI's) car-pedestrian computer simulation model, CarMaker, Simpack, AnalyzerPro, PC-RECT (photogrammetry), MATLAB (based on Brach's model), Computer Reconstruction of Automobile Speed on the Highway (CRASH, CRASH2, or CRASH3) and SMAC (based on McHenry model), DPAM CRASH, Finite Element Method (LS DYNA, Abaqus FEA©, or Ansys©), and Computer-Aided Reconstruction of Accidents in Traffic (CARAT) (Woering et al. 2021; Vangi et al. 2019; Martínez et al. 2016; Gönczi 2013; Topolšek et al. 2014; Roberts et al. 2011; Xinguang et al. 2009; Konosu 2002). Computer simulation software officially produces kinematic and dynamic modeling of collision and vehicle trajectory. Simulation methods employ the rest positions of the vehicle and the traces examined during the accident scene investigation. This simulation software allows crash parameters (point of impact, pre-impact directions, vehicles' position, contact plane angle, contact plane coefficient of friction, and restitution coefficient) in the optimization process. The software allows for optimization and uses three methods, i.e., least square method, Gauss-Seidel (linear algorithm), and Monte Carlo method (Guzek and Lozia 2020; Vossou and Koulocheris 2018; Mozumder et al. 2015; Steffan 2009; Li 2003). The fifth method is based on information extracted from automobiles event data recorder or event data recorder (EDR) tools in vehicles involved in accidents (Nance et al. 2006). EDR records performance and system status data through electrical, audio and video systems. EDR of vehicles senses the pre-crash situation, acceleration during crash, safety restraint system data and driver control input, and post-crash facts such as automatic crash notification (Fay et al. 2002). Such recording tools are vehicle's airbag control module (ACM) (Oga et al. 2018), Black Box, Electronic Control Module (ECM), sensing and diagnostic modules (SDMs) (Singleton et al. 2008), GPS, Residual Speedometer (Chung and Chang 2015), Controller Area Network (CAN), and Tachographs (mainly used in heavy vehicles) (Zago et al. 2020; Baldini et al. 2018; Baek 2016). Some video systems such as DriveCam, MACBox, and BusWatch are installed during the vehicle manufacturing, and the CCTV installation is exterior to the vehicle (Wong et al. 2014; Fay et al. 2002). To reconstruct vehicle accidents, the EDR data is retrieved by a set of hardware and software such as Hexadecimal Translation Tools, Bosh crash data retrieval (CDR) (Singleton et al. 2008; Gazdag et al., 2018), and Vetronix Crash Data Retrieval System (Correia et al. 2001).

Case Study

In November 2004, Danny Hopkins was sentenced to second-degree manslaughter for causing the death of Lindsay Kyle in a car accident. The black box (event information recorder) already installed in Hopkins' vehicle indicated the vehicle was running at 106 miles/h just 4 s before it collided with the rear of Kyle's vehicle, which was halted at a red light. On the off chance that Hopkins' vehicle had not been furnished with an event information recorder, a measurable examination of the physical proof, for example, skid marks and crash harm, could have been utilized to evaluate the vehicle's speed. Nonetheless, the recorded information delivered better accuracy, progressively increasing the forensic investigators' considerable certainty that the vehicle speed was 106 miles/h at the moment of collision.

Accurate reconstruction of the accident scene is entirely dependent on the deformation of an accidental vehicle, skid or yaw marks, body injury of a pedestrian, and traces examined at the accident scene. The first and second methods discussed above are the conventional methods to reconstruct the accident scene. Nowadays, the plastic deformation of a vehicle body and the skid marks is a glimpse of reconstructing the accident scene through conventional methods. Documentation of skid marks cannot always be possible because of the anti-lock braking system in the modern vehicle, or in a case where a driver has not taken measures to make sudden brake or emergency stop, and wet or snowed roadways. In these conditions, vehicles usually do not leave any skid marks. However, performing a crash test to determine vehicle speed at the moment of impact by examining the vehicle's plastic deformation is eventually complicated and more challenging (Zeidler et al. 1985).

On viewing the different conditions and modernization in the vehicle, the field of forensic science is rapidly developing. Before 20–25 years ago, methods for reconstructing any accident scene used by forensic scientists are trivial to modern vehicles. Advancement in accident examination and its reconstruction utilizes advanced methods based on video and images, databases, computer simulation software, and vehicle recording tools (Nogayeva et al. 2020). The change in velocity is often defined in terms of delta-*V* (ΔV) and energy equivalent speed (EES) (Dima and Covaciu 2019; Smit et al. 2019; Vangi 2009). Delta-*V* ultimately depends on the deformation of the vehicle in a crash. NASS-CDS database contains all the delta-*V* estimates using damage-based (Calspan Reconstruction of Accident Speeds on the Highway (CRASH3)) program called Microsoft Windows version of Simulating Motor Vehicle Accident Speeds on the Highway (WinSMASH). Engineering Dynamics Corporation Reconstruction of Accident Speeds on the Highway (EDCRASH) and SLAM are updated version of CRASH3 program (Johnson and Gabler 2014; Iraeus and Lindquist 2013). The post-crash vehicle's Delta-*V* potentially is measured with the help of an event data recorder (EDR) (Nance et al. 2006). The methodology of collision analysis, like energy equivalent speed (EES), is firstly defined by Burg, Martin, and Zeidler (1980) to calculate delta-*V* and EES (Berg et al. 1998). The database as NHTSA, IIHS, EES, etc., provides vehicle types and crash types with images, which can also be maneuvers to calculate the pre-crash velocity of the vehicle (Pinter and Szalay 2018; Gabler and Hinch 2015). Finite Element Method (FEM) and Response Surface Models (RSM) calculate the deformation, but they will take high computational resources and simulation time for kinematic output for the vehicle. Reduced Order Dynamic Model (RODM) can be subsequently employed to reconstruct multiple vehicle accidents. RODM features of simulation of different. The impulse-momentum model combined with RODM assures more accurate and detailed information of velocity and acceleration of any vehicle at every instant (Macurová et al. 2020; Vangi et al. 2019). Mathematical tools of the fuzzy set theory, including general theoretical tasks, are generally used in the reconstruction of accident scene. The main advantage of the fuzzy set theory is to give the possibility of matching the qualitative and quantitative index even under inaccuracy and insufficiency of initial documentation (data) (Vasiliev et al. 2017). In a car-pedestrian accident, the analysis process utilizes the JARI's pedestrian model and validation using Postmortem Human Subject (PMHS) and ITARDA accident data and reconstruction process (Konosu 2002). Given the reconstruction of the vehicle's continuous collision in an accident, trajectory preview iterative algorithm, serial collision, contact position, reconstruction localization algorithm, trace inspection reconstruction algorithm, and vehicle serial collision accident reverse-phase combination algorithm are used (Lang et al. 2013). Other models, such as McHenry, Brach, and Ishikawa, define conservation of energy and conservation of linear or angular momentum. Brach's (Planer Impact Mechanics) collision model integrates with the least square method to calculate impact coefficient and unknown velocity components (Vossou and Koulocheris 2018).

Reconstruction of the accident scene predominantly depends on proper documentation of the accident scene. Conventional documentation methods are less prompt and two dimensionally reconstruct the scene since the measurements are taken along and offset either from road edge or centerline. Recent advancement uses complex total station, laser rangefinder (LRF), Global Positioning (GPS), tachymeters, CCTV, dash camera, prism, photogrammetry (a technique to measure 3D and represent using data stored in a 2D photo and video), and terrestrial laser scanner (TLS) methods for more accurate documentation of accident scene and damaged vehicles. Terrestrial laser scanning (LS) method and photogrammetry method allow 3D documentation of accident scene. Investigating officers can use laser scanners as the safest and fastest method in data collection that can operate in both direct sunlight and darkness (Verolme and Mieremet 2017; Osman and Tahar 2016; Topolšek et al. 2014; Buck et al. 2013; Oguchi et al. 2011, 2013; Lee 2009).

Documentation through sketching of crime scenes carries different significance for later examination. Conventional handheld sketching techniques required colossal time and man-force. Some advanced 3D sketching programs include SketchUp (SU) that is supported by Google Earth's (GE) Digital Elevation Model (DEM), 3D Warehouse (3DW), and Aerial Photography. This SU involves documenting accident scenes imported into HVE as a 3D environment (Roberts III et al. 2011). HVE also has some physics models, such as 2D and 3D total reconstruction solutions, such as SIMON, DyMESH, EDVAP, EDVSM, EDVDS, Engineering Dynamic Corporation Simulation Model of Automobile Collision (EDSMAC), or EDSMAC4 (Fittanto and Rodowicz 2012; Fay et al. 2001). Documentation of pedestrian or person involved in an accident carries significant evidence on their body. Injury inside and outside of the body can also be utilized to reconstruct impact velocity. Tools, such as multi-slice computed tomography (MSCT) and magnetic resonance imaging (MRI), are used for documentation and analysis of internal and external body (Buck et al. 2007). These accident reconstruction tools permit experts to analyze and reconstruct a wide range of accidents scene accurately.

The application of advanced simulated tools for accident reconstruction has significant advantages over conventional methods. The most important benefit is the result of accident reconstruction. The conventional approach is highly reliant on the theoretical and practical knowledge of a forensic expert. Still, advanced simulated tools ease reconstructing accident scenes with more accuracy with minimum human resources. These advanced tools may significantly reduce the overall time taken and the difficulties of accident reconstruction when utilizing conventional techniques (Nogayeva et al. 2020). Another advantage of utilizing advanced tools depends on the intricacy of some accidents. Demonstrating vehicle crush, applying momentum examination to a multivehicle pile-up impact, and three-dimensional models are very likely circumstances that cannot be tackled without a computer. Added intricacy to the code allows the end of certain suppositions, and in this way, makes a more remarkable precision in the reconstruction.

16.11 Conclusions

This chapter represents the introduction to vehicle accidents and techniques to investigate and reconstruct the accident scene. Road accident is as heinous and complicated to reconstruct. Multiple collision and vehicle pileup are even more complicated to reconstruct. Knowledge of accident types comes with essential factor in accident scene investigation. The investigating officer should know the accident background and planning for investigating process and its systematic implementation to succeed in accident investigation. Collecting evidence based on objectives and continuous communication between the investigation team prevent the investigation from diverting and saturating. Sense of four Ps evidence to the investigating officer eases evidence collection and understanding the vehicle situation.

Methods for reconstruction of the accident scene are split into conventional and advanced tools. Conventional methods conclude theories, empirical formulas, and methods based on true vehicle tests (Crash test). Theories and formulas like conservation of momentum, conservation of energy, and friction coefficient of vehicle tire collectively are used to reconstruct the vehicle's speed before, during, and after the collision. The friction coefficient of vehicle tires varies in reference to different surfaces, ages, and conditions published by the manufacturer routinely. Sometimes, the investigating officer performs a crash test by himself to find the friction coefficient of the vehicle. Manually performing any crash test to reconstruct requires the same environmental and vehicle condition, which voids and increases the chances of error in reconstruction. Advancement in technology is utilized in accident investigation to overcome the limitations of conventional methods. The utilization of advanced tools is classified into three classes, i.e., documentation, event data recorder (EDR) of vehicles, and computer simulation software. The pitfalls of applying advanced tools for documentation and computer simulation software for reconstruction work are that the investigating officer becomes less involved and may save money and resources. EDR is a tool installed during the vehicle manufacture that helps to understand the pre-crash, during the crash, and post-crash velocity, and vehicle conditions. Conventional methods only present 2D models but with advanced tools reconstruction can be possible in 2D and 3D models using software. The accident database produced by NHTSA, RICSAC, IIHS, NASS-CDS, etc., is based on accident type, deformation, and vehicle utilization as a reconstruction tool.

Dependency as a daily routine on vehicles increases accident cases around the world. The effectiveness of conventional methods used by investigating officers to investigate and reconstruct accidents is currently limited in its ability to keep with the increasing frequency of accident cases, which diminishes the pendency. Therefore, there is a need for investigators to incorporate advanced tools in accident investigations, enabling them to solve with great accuracy and improve the reconstruction of accident events.

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