

## Review Paper

# An Overview of Traffic Accident Investigation Using Different Techniques

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## Abstract

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One of the most important aims of incident management is the clearance of the incident scene as fast as possible. The accident investigation provides physical evidence at the accident site for the investigators. This physical evidence is much more reliable than the witness's statements and they are very crucial for the incident reconstruction. The cars accidents investigation is a dangerous activity, so it should be undertaken with suitable, accurate, and fast equipment. Many law enforcement agencies in the world have used different surveying techniques for accident investigations including the coordinate method, total station, photogrammetry, laser scanner, etc. Therefore, this research has been carried out in order to introduce the benefits of using surveying techniques in traffic accident investigations, and show their impacts on evidence documentation and scene clearance. This is done by focusing on the advantages and the disadvantages of each method based on the relevant works of literature and compares between them. Although comparison result shows that the traditional method (coordinate method) is simpler and cheaper than other methods, surveying techniques methods are safer, and faster in clearing the accident scene, fewer investigators are needed, the scale can be provided directly, high accuracy measurements can be obtained, and three dimensions models can be produced. So it's worth using the surveying equipment in cars accidents investigations.

**Keywords:** Accident investigation; Total station; Reconstruction; Coordinate method; Laser scanner; Photogrammetry

## 1. Introduction

A traffic accident occurs while traveling by a vehicle and causes an injury or a fatality [1], [2]. Traffic accidents are classified into three types: minor accidents which cause vehicles or goods damages, moderate accidents which cause minor injuries and minor damages to vehicles or goods, and heavy accidents which cause death or serious injuries [3]. Traffic reconstruction is an evolving discipline, with new techniques, knowledge, and tools, that gains depth and breadth from its practitioner's experience [4]. The reconstruction of the traffic accident is based basically on indirect methods which depend on the use of accident marks and witness's report [5]–[7]. The accident investigation is a vital part of incident

management and response. Many strategies and many techniques have been used to improve incident management [3], [8]. Management of incidents can be defined as the coordinated preplanned that is used by human and mechanical resources to achieve many benefits including full capacity restoration after the incident occurs, incident verification and detection, providing information and directions to motorists until the site is cleared, clearance of accident site, and motorist information [8].

Vehicles crash has classified into four types based on the type of collision: side sweep, rear-end, right angle, and head-on collisions [9]. Much research has been carried out in order to identify the causes and the characteristics of crashes in



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different parts of the world. Mohamed *et al.* [9] described that the main factors of rear-end crashes are the driver's visibility and inattention to the next vehicle. In addition, they illustrated the other causes of the traffic accidents such as The division of highway, highway characters, time of the accident, road surface condition, number of lanes, and urban/rural area. Furthermore, the factors related to the striking role had been introduced including driver age, vehicle type, alcohol/drug use, gender, driver residence, volumes of traffic, right and left-turn proportion, and speed.

A multinomial logic model (BN approach) had been developed to investigate the factors that contribute to rear-end crash severity, these factors include the number of vehicles involved, truck involvement, weather conditions, bad lighting conditions, etc. [9], [10]. In traffic accidents, many techniques of investigation have been adopted in order to determine the accident's causes. To determine these causes a large amount of data is required such as the travel direction, speed, any unusual movement of all involved vehicles, the skid marks, change direction, debris pattern, starting curves or their end, warning signs, gouges, scratches, intersections, and any other details that have to be measured [8]. Investigators in some countries are still confused about the exact methods that can be used to have an accurate investigation result of a traffic accident. As a traffic accident starts with a violation and ends with fatalities or material loss, the investigators are required to be professional in their work and choose accurate methods in their investigations [3]. With the interesting growth in road safety programs around the world, it has become crucial to obtain an accurate, reliable, timely data technique, to make decisions about traffic safety and countermeasures [11]. Several techniques have been used in order to investigate the elements that affect the occurrence of an accident [12].

Therefore, this paper has focused on the surveying techniques methods and their ability to improve incident clearance when details investigations are required. It has identified the advantages and disadvantages of each method. In addition, a comparison has been done between these methods and the traditional method depending on previous works of literature and the specification of each piece of equipment. This

comparison helps to show the benefits of using surveying equipment in traffic accident investigations.

## 2. Reconstruction of Traffic Accidents

A traffic accident is an unplanned incident event that is resulting in unintentional injury, death, or property damage [13]. It occurs when two cars have collided, or a car with a human or an animal, or any other obstruction [2]. The police accident report considers the main core of the accident analysis. This report contains the data that is collected by law enforcement officers at the accident scene which includes information about the accident [14]. In order to recreate the causal link between the outcomes of the accident and the leading circumstances leading to it, accident reconstruction is used [13].

Reconstruction can be defined as the forensic science to determine the factors that caused the accident [15]. The main concept of accident reconstruction is that each event leaves evidence behind, and collecting this evidence helps to recreate the event [4]. Making the work easy and offering an accurate result is the main aim of the reconstructionist, and this can be done by using different reconstruction methods [16]. In many countries, training personnel for traffic accident investigation has been developed by Police agencies. Police officers go through additional hours of training in order to gain the skills that are needed to become crash reconstructionists.

Mezquita [17] mentioned that it is impossible to complete the reconstruction in a strict sense. So the basic mission of the police accident reconstructionist is finding and documenting the factors and the evidence in safe conditions. The accident investigation starts at the scene by law enforcement. The first important thing that the officers have to do is secure the accident area as soon as possible and start the investigation after all injured parties have assisted. Then, field investigation and interviews are conducted in order to determine what had occurred from involved witnesses and parties. When an accident causes death or serious injury, additional investigation is conducted because small details are required in these types of incidents [18]. Specialized investigator police are utilized for this additional assessment of the accident scene. Normally, evidence is collected at the scene

starting by photographing all details at the incident scene including car locations, signals, and roadway markings (slides, skids, yaws, and gouges, etc.). After that, investigators begin to record the scene by using forensic mapping. Vehicle crash scene mapping is important in order to analyze the accident, incident evidence, and vehicle locations [19]. There are various means for road traffic accidents reconstruction such as:

### 2.1. Numerical Modelling

From the provided data from the accident scene, an algorithm is adapted from the determination analysis of the vehicle's dynamic and kinematic parameters. Then many laws are used in order to determine the following: The pre- and post-collision vehicle's travel velocity, evaluate the pre-collision of vehicles and traveled distance by using braking tracks, evaluate the traveled distance with the time in different stages of the event, numerical modeling for the vehicle-pedestrian collision and the vehicle-motorcycle collision, etc [16].

### 2.2. Computational Simulation

Getting an interaction simulation between the car and other elements in the environment in order to simulate the behavior of the car at first without any interferences. Then, a series of parameters are introduced to have an accurate picture of the real collision [4], [16].

### 2.3. Video Recording

By video analysis which is recorded during the accident, the dynamic parameters of the collision are determined. This can be done by images' calibration [20]–[22].

### 2.4. Crash Data Retrieval

Several parameters including :car's system statue, driver inputs, car crash signature, the activity of the automatic crash notification, and the time (in seconds) before the accident occurring can be given by the Event Data Retrieval (EDR) [16], [23]. EDR is a mounted device on the road vehicles (According to the National Highway Traffic Safety Administration, NHTSA). This system is used in the United States and the European Union and it is very important and useful in preventing the traffic accidents [16].

In general, the accident site details have to be measured and transferred into a visual two-dimensional map. Mapping of the accident scene has been developed from using tape to using many advanced technologies and methods in order to obtain precise data pertaining to measuring the scene details [24]. There are different measuring methods and tools related to traffic accident investigation. The methods that have been mentioned in this paper include a coordinate method, total stations, a laser scanner, and photogrammetry. Each method has a direct effect on the number of requirements such as investigators, range, time of data collection, scope, process, etc. The accuracy of the collected data is important for the traffic accident participants in court, because inaccurate data may cause an unjust sentence [25].

## 3. The General Important Steps for Accident Investigation

Traffic accident investigation is very important in identifying the involved people because the responsible person of the accident will face criminal and civil consequences. When a traffic accident occurs, the accident investigation is started to identify the responsible person for the accident and the causes of it [2].The general important steps for the accident investigation as illustrated in the vehicle accident investigation reference booklet [26] and mentioned in [11] include the following:

### 3.1. Before Leaving the Office

It's vital to prepare suitable equipment for the investigation such as health and safety equipment, color camera and video, measuring tools, high-power torches, marking equipment, and reporting equipment.

### 3.2. At the Scene

The steps that must be taken into account at the scene include:

**Health and safety steps** - Parking in a safe area, the dynamic risk assessments have to be taken by determining if the videos, photographs, and measurements can be taken safely.

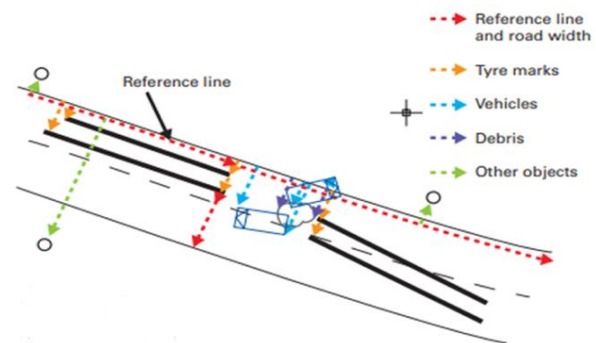
**Identifying the scene evidences** - Car model, its position, its wheels marks, cat scratch marks on the road and surrounding area, debris, the

environment of the road, vegetation damage, the limited speed of the road, etc.

**Evidence measurements** - In order to measure the evidence correctly, the scene location must be marked and recorded in a way that can be identified easily to be visited later. Then finding a fixed feature as a reference point to take all the site measurements relative to this point. At the reference point, the reading is recorded as zero on the measuring wheel, and along the road edge reference line is located. All distances have to be measured across the road from each piece of evidence to the reference point by using a metal tape measure. For instance, measuring the distances from the reference point to four corners of each involved car, gouge, and scratch marks, tire marks, the outer edges of each mark for curved tire marks at several locations, etc. **Figure 1** is an example of an accident scene to show the reference point, the required measurement in the accident site, and the reference line.

**Evidence photographing** - Taking photos is very important at the accident scene and is often taken part as a priority. Photos are very useful in providing significant details and evidence of the accident site [27]. Taking many color photographs of the accident site is important in order to give the investigation the best possible understanding

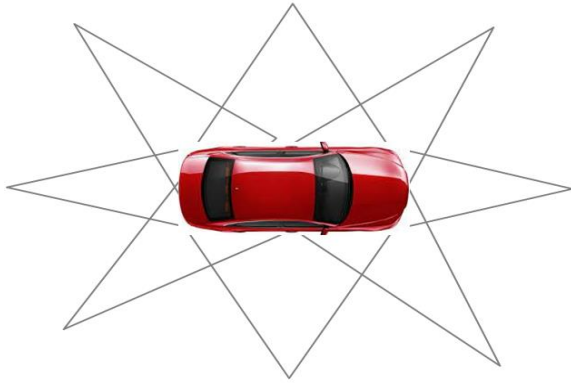
of the scene. Every detail must be photographed such as key evidence, crashed vehicle, vehicle path, driver view, etc. In order to ensure accurate distances, photos have to be taken along the path of each involved car and a measured wheel must be used. As taking additional photos is important to show any visible restrictions, photos should be taken at regular intervals distances such as every 10 or 25 m from the impact point to a distance of around 100 or 150 meters away as shown in **Figure 2**. Standard photos for the crashed car should be taken in a square and at oblique angles, so the required car fills in a frame as shown in **Figure 3**. Additional photos may be required in order to show the detail of any damage.



**Figure 1.** The reference point, the required measurement in accident site, and reference line [26]



**Figure 2.** Accident scene photos from regular intervals distances [26]



**Figure 3.** Crashed car photos positions that should be taken in a square and oblique angles

#### 4. Accident Investigation Methods

Finding quicker and more reliable techniques for incident management is vital. There are different methods to measure data at the crash site. Although all methods can be used in all situations, each method has weaknesses and strengths. Around the world, many techniques have been developed in order to reduce the time of clearing blocked lanes after an accident occurs, because these accidents result in delays for all motorists on the road [28]. As the judicial system requires an accurate and comprehensive investigation, a large amount of data must be collected. Techniques that are used to collect data in the accident site which have been used around the world and mentioned in this paper include:

##### 4.1. Coordinate Method

The first important concept is creating a coordinate system for the accident site because without it any mechanical analysis can't be done correctly. The coordinate system is used to have a reference frame that allows the creation of a clear description of the object's positions that are involved in the accident scene [4],[13]. In this method, all object's locations in the accident site have to be measured. This is done by choosing a reference point and reference line. Then measure the distances that are perpendicular to a tape(baseline) which is laid down straightly through the accident scene. Two or three people are required in this method. These collected data are used to recreate the accident scene by hand. The starting is by drawing the established baseline plotted in the scene and then drawing every object in the site by using a suitable scale [26]. The

coordinate method process is straightforward and simple, but it has many disadvantages such as safety lack because measurements must be done in the street which may put the investigators in dangerous conditions. In addition, it is time-consuming, causes a delay for motorists, and may cause secondary collisions. Furthermore, in some cases, measurements maybe not be very accurate and incomplete. This is because these measurements have to be done at precise right angles from the baseline and it may be difficult to clear the baseline tape path or keep it steady [29]. In addition, it is time consuming, causes delay for motorists, and may causes secondary collisions. Furthermore, in some cases measurements maybe not very accurate and incomplete. This is because these measurements have to be done at precise right angles from the baseline and it may be difficult to clear the baseline tape path or keep it steady [29]. Besides, usually not all detailed information about the accident environment is collected, and if it is so, the information will have a qualitative nature, not quantitative nature [14].

##### 4.2. Total Station Method

The total station is an electronic surveying instrument, it is a combination of an electronic distance meter (EDM) with an electronic theodolite. A theodolite measures the angles in two directions by reading two circle scales, the horizontal circular scale, and the vertical circular scale. The electronic distance meter (EDM) measures the distances by using the laser that reflects the pack from the prism or from the target itself [30]–[32]. In this method total station must be located at a place where all the objects required to be measured are visible. All the distances, vertical and horizontal angles, must be measured simultaneously [25], [31]. The measurements can be done by using the prism over the top of the moving traffic. When all measurements are done, all the data are loaded onto a computer for diagramming the accident scene. Time use of the total station system requires less than the time that is required by using the coordinate method by nearly half to make the same measurements [29]. **Table 1** present the advantages and the disadvantages of using total station depending on the reference [25], [29], [31]–[33] and the general specification of the total station.

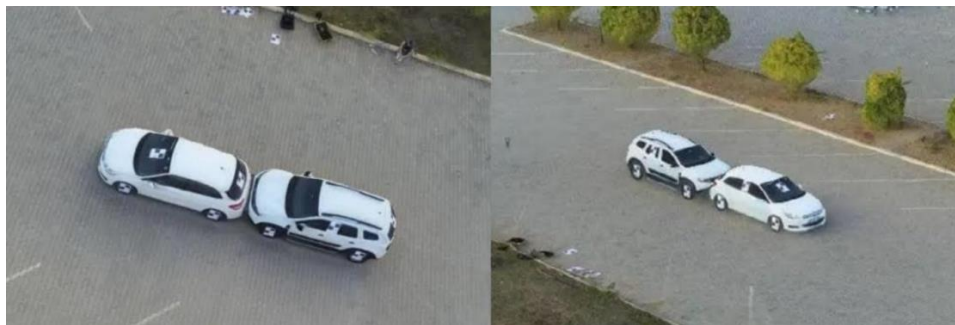
### 4.3. Photogrammetry Method

This technique can be divided into close-range photogrammetry and UAV-based photogrammetry methods. Since the use of remote-controlled drones offers different capabilities for automatic flying, UAV-based photogrammetry has been widely used in various applications including traffic accident investigations [5], [34], [35]. In this technique, the images are processed by using the SfM Software or other software which can produce point clouds automatically and provide 3D modeling of accident scenes [34]. UAV-based photogrammetry can provide a complete 3D model because it can acquire data from above and around the accident scene as shown in Figure 4.

In the close-range photogrammetry method, objects are measured from digital images or from photographs. Recently, digital imaging development has made it possible to obtain sufficient accuracy measurements by using affordable equipment and commercially available [36]. This method is used in accident investigation and reconstruction in many countries by law enforcement. Close-range photogrammetry is a valuable technique to provide 3D modeling. It provides sufficient models and is more realistic [5], [36]. Figure 5 shows the textured model of cars accident obtained by using the close-range photogrammetry method. Camera resolution that is used in traffic investigation plays a crucial role in geo-referencing the close-range photogrammetric data [5].

**Table 1.** The advantages and disadvantages of total station method

No.	Advantages	Disadvantages
1	Requires less time from coordinate method	Requires an extensive training
2	Two people are required in this method	High cost to buy the equipment comparing with the coordinate method tools
3	Allows the roadway to be cleared faster	
4	Safe method for the investigators	
5	Total station leaves little space for error and provides scaled diagram in order to be used directly	
6	High accuracy	



**Figure 4.** Textured model obtained by using UAV-based photogrammetry method [5]



**Figure 5.** Textured model obtained by using close-range photogrammetry method

This method is simply done by three steps [29]:

- First, taking photographs of the site of the accident including all the relevant objects designated and the evidence markers in order to get a three-dimensional representation of the accident scene. These evidence markers must be appeared in at least three or four different photographs that are taken at wide-range angles.
- Secondly, measuring photos: This step is done in the office, and photos are imported into specialized software. Then measurements are developed in a scaled diagram to generate the final pictures for the required scene.
- Finally, all measurements are processed in order to produce an accurate diagram of the accident scene.

The main disadvantage of this method is the long-distance accident scene which requires excessive office time for analysis [5]. This is a problem as there are normally a limited number of accident investigation teams because they are usually at the accident sites. There is also limited office time for conducting the analysis [29]. The

advantages and the disadvantages of the photogrammetry method in traffic accident investigation depending on references [5], [29], [35]–[37] can be shown in Table 2.

#### 4.4. Laser Method

The laser scanner is a powerful tool to collect a large amount of data in a short time and extract information with high accuracy. This technique has become widely used in many applications, applications where a large amount of data able to be captured rapidly [38], [39]. By using a laser scanner, 3D models can be obtained. This technique is useful to obtain detailed, reliable, and accurate information about scanned objects [11]. Recently, laser Scanner has become popular in law enforcement because of its mobility, availability of grant funding, reduced scene time, and short traffic disruption periods [26], [39]. The 3D visual details that are recorded at the traffic accident scene are the main advantage of the laser scanner technique. In addition, realistic models can be produced [11]. Figure 6 shows point cloud obtained by using laser scanner.

**Table 2.** The advantages and disadvantages of photogrammetry method

No	Advantages	Disadvantages
1	Requires less time on scene	Requires more analysis time in office.
2	Diagram of scene is only as needed	In some cases lighting may cause problematic.
3	Less cost	There is a problematic when use in long accident scenes
4	Obtaining acceptable accuracy level	Analysis of data requires steep learning curve.
5	Doesn't need much training	
6	photos can be taken by one officer	Sometimes data is difficult to be Qualified for courtroom purposes
7	Can be used in any location	Large scenes must be broken into many zones and then have to be merged
8	The reconstructed of vehicles are more realistically	A specific lighting level is required to obtain adequate photographs.
9	The main advantage of this method is recording all the information at the scene, which may be needed later.	Skid marks and many other evidence at the accident site need to be enhanced, especially at night to be visible in the photos.
10	It is suitable for sites when police need to get out of the road quickly due to the unsafe and difficult conditions (weather condition)	
11	Quick photographs taking can preserve unstable data in the scene such as: snow, tire marks in gravel, and slush which may be obliterated by diverted traffic and rescue vehicles	
12	It's suitable for compact crashes.	



**Figure 6.** Point cloud obtained by using laser scanner method [5]

The Laser method can be operated by one person which reduces the number of investigators exposed to the dangers of traffic. The required time to complete the scan depends on the scan density. The high-density scan requires a long scan time to record large amounts of data. The end product is generating the points cloud where the analysis can be performed [38]. This analysis is necessary to determine the objects' locations on the roadway. The time for data processing is significantly less than other methods and data can be managed by the computer easily [40]. The 3D Laser Scanner is a photo-like production. It has to be imported into computer-aided diagramming (CAD) software, and the investigator can view the required scene from different points of view in the scan. This method requires extensive training in order to become proficient in the field. In addition, it requires extensive training to process data and use the software correctly [40]. Depending on the

previous references [38]–[43] and the specifications of laser scanner equipment, the advantages and the disadvantages of this method can be shown in Table 3.

## 5. Results and Discussion

Based on the previous research and on the specification of each piece of equipment, the comparison has been done between the four methods (three surveying techniques methods and the traditional method) which can be shown in Figure 7. The comparison factors include time, number of investigators, training, cost, safety, scale of diagram, simple use, and accuracy. The comparison shows that the coordinate method requires more time in an accident scene than other methods. For the number of investigators, it's clear that laser scanner and photogrammetry methods require fewer people on the scene.

**Table 3.** The advantages and disadvantages of laser scanner method

No.	Advantages	Disadvantages
1	This method provides quickly clearing traffic crashes	Limited by weather conditions
2	Enables the three dimensions documentation of accident site in a safe way	Requires extensive training
3	The information can be collected without closing the road	Expensive tool
4	Can be operate in darkness and in direct sunlight.	Requires extensive training for data processing
5	Has the capability to record such infrastructures in reliable and fast way, where a lot of different information are required.	Has difficulties in reflectance with some types of surfaces (low reflectance surfaces) which affect the accuracy of measurements [15]
6	Allow to capture a large amount of data in short time	
7	Laser scanner result can be used for accident prevention purposes	
8	It is more accurate than close range photogrammetry method	



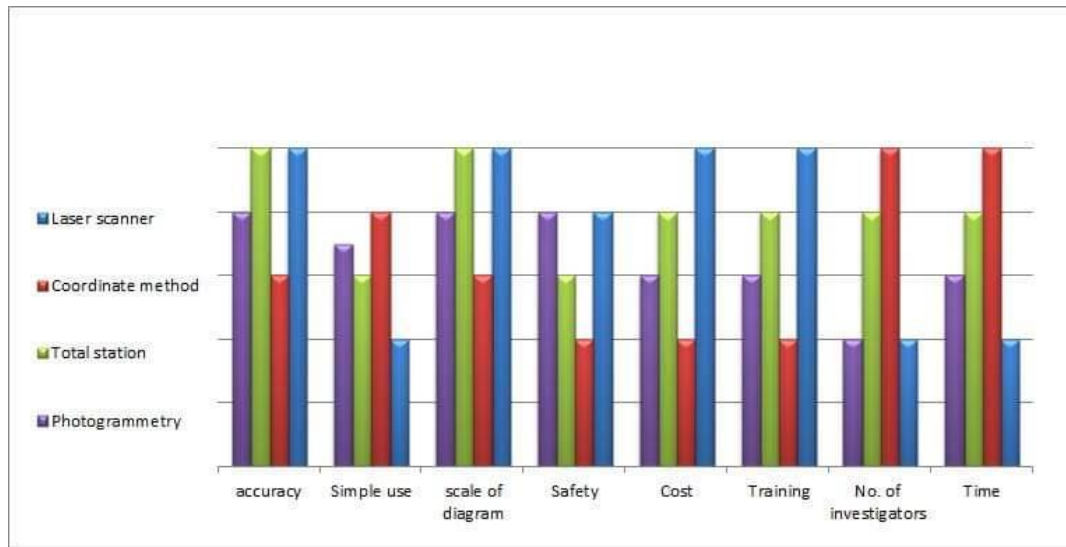


Figure 7. Comparison between the four methods

As far as training is concerned, total station and laser scanner methods require training to use. In addition, laser scanner requires excessive training for data process. In terms of cost, the laser scanner tool is an expensive tool followed by the total station, while the coordinate method is the cheapest one. The most safer methods to use are the photogrammetry method and the laser scanner method.

For the scale diagram factor, the total station and laser scanner provide scale directly. The simplest method for use and process is the coordinate method. Finally, laser scanner and total station methods can provide high-accuracy measurements, while the photogrammetry method provides acceptable accuracy. In general, close-range photogrammetry and terrestrial laser scanning techniques offer perfect and quick solutions in traffic accident investigations. In these two methods, three dimensions models can be produced, which consider the best solution for detailed and fast documentation of traffic accidents [5].

By comparing the traditional method (coordinate method) and the surveying techniques methods in general, it's clear that the coordinate method is the cheapest and the simplest one. But using the surveying methods has many advantages such as they are safe methods, don't require too much time to clear the scene, less investigators are needed, scale can be provided directly, acceptable or high accuracy measurements can be obtained depending on the surveying equipment that are used in the

investigation, and models with three dimensions can be produced when using the surveying equipment.

## 6. Conclusion

Clearance of the incident scene quickly is an important aim of incident management. Different strategies and techniques have been used around the world to improve incident management. As surveying techniques have become more preferable in many applications, they have been used in cars accidents investigations in different parts of the world. This paper has focused on the benefits of using these techniques in accident investigations, it shows the advantages and disadvantages of each one, and compares them with the traditional method. Although the traditional method is cheap, simple, and doesn't require much training, using surveying equipment is most beneficial. By using these surveying techniques in accident investigations three dimension models can be produced, which consider the best solution for detailed and fast documentation of traffic accidents. The use of these methods results in fast and easy data collecting, they allow to store of data in computer systems, fewer investigators in the scene are needed, the scale can be provided directly, and acceptable or high accuracy measurements can be obtained depending on the surveying equipment that is used in the investigation.

As each method has advantages and disadvantages, choosing the suitable method depends on many factors such as the country that

the accident occurs in, the kind of accident, weather conditions, and the accident location if it occurs on a highway road or others. Not all methods are suitable for all locations, some locations when using specific methods may cause problems for both the traffic officers and the motoring public.

In some countries, the reconstruction of the traffic accident is still based in principle on the indirect method which depends on the use of the accident marks and witness reports. None of the mentioned methods are used. Even the coordinate method isn't used in a very accurate way. So it is important to use at least one of these methods for traffic accident investigation. This research has been carried out mainly to introduce these techniques and raise awareness about the advantages of using them in traffic accidents investigation. Further research has been carried out to use Leica's total station in specific car accident investigations and the results will be published in the next research.

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## Author's Declaration

### Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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All data are available from the authors.

### Competing interests

The authors declare no competing interest.

### Additional information

No additional information from the authors.

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