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3D Laser Scanners and Point Clouds for Obtaining Car Accident Sketches

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The purpose of this article is to compare classical police work and state-of-the-art technology regarding traffic accident scene investigation. The questions addressed are how can modern technology reduce accident data collection time and if the data collected are of the same quality? A car accident involving two cars and a motorcycle was simulated on the safety polygon Ljubečna, Slovenia. In the simulation, the motorcycle driver was fatally injured, and a team of two police officers made a classical police traffic accident scene investigation using coloured spray paint and a handheld measuring tape. A simple handheld GeoSlam Zeb Revo 3D scanner and sophisticated Riegl VZ-400i 3D laser scanner were also used for data collection and the distance measurements were then compared. The paper compares these three techniques and for obtaining an accident sketch. From this research, it can be concluded that in some straightforward examples, automated data collection is accurate enough for further data analysis. Furthermore, automated techniques are much faster than the classical data collection approach.

Keywords: point cloud, 3D scanner, road accident, accident reconstruction, road safety

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1 Introduction

The number of vehicles on the roads around the world is continuously increasing, which further increases the probability of traffic accidents. The fact is that we live in a turbulent and dynamic world where an increasing number of people spend an increasing amount of time in their cars. Driving a car may even be the most dangerous (social) activity of most people (Bavcon, 2011). The number of road traffic accidents is increasing, which can also be attributed to an increase in the number of vehicles or to a rise in the level of the social economy, as indicated by the increased number of accidents observed in developing countries. Thus, between 1975 and 1998, the number of fatal accidents in Malaysia increased by 44% and in Botswana and Colombia by as much as 200%. On the other hand, the situation in developed countries is precarious; for example, in Canada, the number of fatalities has fallen by 60%, while in most European countries this decline is between 25% and 5% (Kopits & Cropper, 2005). About 1.3 million people die each year on the world's roads and between 20 and 50 million sustain non-fatal injuries (WHO, 2018). The WHO estimates road deaths in Slovenia at 6.4 per 100,000 population (Austria 5.4; Germany 4.3; Croatia 9.1; Italy 6.1, Hungary 7.7) (WHO, 2016), meaning that 130 died due to a road traffic accident in 2016 (Ministrstvo za notranje zadeve, 2017a). The increasing number of injuries and fatalities in road accidents has prompted a number of studies with the overall objective of improving road safety. Experts generally accept and group the causes of traffic accidents into three categories: human behaviour, vehicle characteristics and external conditions (Messelodi & Modena, 2005). Research by Topolšek and Cvahte-Ojsteršek (2017) shows that the cause of critical road traffic situations can be found with the driver; drivers can be classified as safe, reckless, active disorganized, or decommissioned inactive drivers (Polič, 2004). Based on a study of daily driving and traffic accidents, it can be concluded that almost 90% of accidents can be attributed to driver-related factors (Dingus et al., 2016). This is confirmed by another study showing that most critical traffic accidents are driver-related (94%), followed by environmental factors (2%) and 2% unexplained (Singh, 2015). One explanation for these findings is that humans are not capable of managing the speed of modern traffic, which is ten times higher than the normal human realm of 5–10 kilometres per hour (Zupančič, 2015).

Traffic accidents account for a huge proportion of mortality among all age groups, especially those between 15 and 29 years. More than 90% of the world's road fatalities occur in under-developed and developing countries even though these countries only have approximately 54% of the world's vehi-

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cles. People aged between 15 and 44 are responsible for 48% of all fatalities (WHO, 2018). In 2016, over 25,500 people were killed in road accidents in the European Union (European Commission, 2017); as a result, the European Union encourages the establishment of long-term and system-oriented measures adopted at both the union and national level. On the basis of these measures, states could implement traffic safety processes that are effective in solving the problem of road accidents (Zajc & Marinko, 2007). European roads remain the safest in the world, with only 50 road fatalities per one million inhabitants compared with 174 deaths per million globally (European Commission, 2018b). While the decline in the number of road deaths in the EU from 2016 to 2017 was only 2%, some countries made much more progress, such as Estonia (32%) and Slovenia (20%) (European Commission, 2018a).

There were 17,584 road accidents in Slovenia (which is 1.9% less than in 2016 and 7% less than in 2013), in which 104 persons died (which is 20% less than in 2016), 851 persons had seriously injuries (which is comparable to 2016, but increased by 20% compared with 2013) and 7,050 people were slightly injured (7.3% less than in 2016). The majority of deaths in road accidents in 2017 were in the age group 25–34 (24 persons and 23% of all deaths). This is followed by a group of the oldest participants over the age of 64 (21 deaths) and those of 45–54 (20 deaths). In 2017, the increased number of deaths among motorcyclists stands out. By the end of 2017, 29 motorcyclists had died (24 in 2016), a 21% increase from the previous year. This is one of the reasons this simulation includes a motorcyclist.

The most common causes of fatal accidents are unadjusted driving speed, inadequate driving direction, and failing to comply with the rules of priority (Javna agencija Republike Slovenije za varnost prometa, 2018a). To reduce the number of road accidents in Slovenia, it is necessary to follow the 'Resolution' on the national road safety programme for the period 2013–2022, in which the main focus is on Slovenia's transport policy, with the primary goal being that of the EU's transport policy: sustainable mobility. The goal of the European transport policy is to separate mobility from its negative side effects, which is crucial for improving safety and achieving environmental and energy objectives by 2020 (Javna agencija Republike Slovenije za varnost prometa, 2013).

Road traffic accidents have a significant impact on the transportation system and economic development in the country, which is why experts are increasingly involved. Management of the transport system requires the coordination of human and mechanical resources in order to reduce congestion on certain sections while increasing road safety across the country (Jacobson, Legg, & O'Brien, 1992). The World Bank maintains that a reduction in road traffic deaths and injuries could result in substantial long-term income gains for under-developed and developing countries, stating that a significant increase of 7–22% GDP per capita could be achieved over 24 years and is in line with the UN's targets (The World Bank, 2017). Losses to the national economy caused by all accidents may account for 8–10% of GNP (Rantanen, 1982). Traffic accidents lead to significant costs in terms of healthcare, lost productivity, premature death, short/long-term disability etc. (Topolšek & Dragan, 2015).

Socioeconomic costs (taking into account the statistical value of life) in Slovenia can be divided into two groups, namely, 'costs of traffic accidents' (connected with participants in road accidents, e.g. medical costs) and 'costs of consequences of traffic accidents' (connected with an event or a traffic accident, e.g. material damage). Based on a report from the Slovenian Traffic Safety Agency, the costs of consequences of traffic accidents vary from 1.882.161 € per accident for fatal accidents, to 38 EUR per accident for accidents without injured persons (Javna agencija Republike Slovenije za varnost prometa, 2018b). Road traffic crashes cost most countries 3% of their GDP (WHO, 2018). Therefore, shorter accident response times, faster and accurate data capture, rapid debris removal and re-opening of the road section benefit the users and operators of roads. Otherwise, longer travel times and, consequently, higher costs will occur (Forman & Parry, 2001). Besides this, there is also the possibility of secondary crashes and the related issue of safety of response personnel: the longer vehicles involved in a crash remain in place, the longer the responders are vulnerable and exposed to injury (Walton, Barret, & Agent, 2005).

When a traffic accident occurs, the police are called to the scene. They investigate traffic accidents in accordance with standard crime techniques, tactics and methodology regardless of whether a criminal offence is suspected. In other words, the same principles apply as when viewing any crime scene. The number of road accidents is not a reason for the different use of modern technologies, nor is the reason to increase the capacity of police officers. The reason for the introduction of new technologies in police work is, and should exclusively be, faster, more efficient and more consistent work based on professionalism, legality and criminal legislation. Gathering fast and accurate accident data depends on the measuring tools and methods used, and the most commonly applied method is still the measuring tape or measuring wheel, followed by geodetic total stations and laser scanners (Walton et al., 2005). The metric camera, laser scanner, roll wheel and total station are very expensive (Osman & Tahar, 2016). Recently, Close Range Photogrammetry has become an important tool (Topolšek, Herbaj, & Sternad, 2014) to capture image data and build a 3D model (Fraser, Hanley, & Cronk, 2005).

Considering the importance of accuracy and precision, the reliability of accident data and the collection time, there is a need for a study that examines possible errors related to data gathering and reporting. This paper fulfils the above-stated research gap by analysing data on time consumption and accuracy in the collection of data using a simulated traffic accident. Based on the above, the main purpose of this research is to compare different data acquisition techniques for detecting possible measurement errors at the site of a traffic accident and to specify time frames for the duration of data capture and processing.

This article is divided into more sections. This first section presented background information needed to understand the research and the need for it. The next section is a review of literature that addresses the fields of related research and their findings. The development and implementation of an appropriate methodology are presented in the third section. The fourth section reports the results with an analysis and interpretation followed by concluding remarks.

2 Literature Review

The large number of traffic accidents impacts on the collection time and accuracy of data collected at an accident site (Topolšek et al., 2014). In Slovenia, the police play an important role in suppressing criminal acts, ensuring order and peace, and enforcing road traffic regulations. The role of the Slovenian Police in traffic safety is one of the keys to reducing the number of road accidents. Based on this and on basic guidelines for the development of a medium-term work plan for the police, the main goals of the Slovenian Police are: 1) to implement the objectives and measures of the 'Resolution' on the national road safety programme for the period 2013–2022; 2) to reduce the number of dead and severely injured, and ensure the safety of vulnerable road users; 3) to increase efficiency with an innovative approach and the use of new technologies; and 4) to optimise the implementation of offence procedures and to establish the police operation at the National Traffic Management Centre (Javna agencija Republike Slovenije za varnost prometa, 2013).

After the police have been called to an accident scene, they must record it quickly and accurately. In most cities and countries, collecting road crash data is the responsibility of the police (Loo, 2006). Accident investigations must focus on improving the safety of the system and aim to answer five questions: 1) What happened? 2) How did it happen? 3) Why did it happen? 4) What can be done to prevent a reoccurrence? 5) What can be done to minimise accident consequences? (European Transport Safety Council, 2001). In the context of an accident, police authorities have specific tasks, and due to their position and their mandate in society, they have a specific duty and nothing more and nothing less. This leads to a formalised process without adopting specific relationships (Road Sector Working Group to the Plenary, 2006).

Accident site visits and reporting are not always required (Scott & Carroll, 1971) and the process differs between countries. In addition, where accident participants prefer to coordinate the accident between themselves, the police are informed but they do not record the accident (Derriks & Mak, 2017).

The collection of crash information by the police is primarily for administrative purposes. The right choice and proper use of measurement techniques and tools for collecting data at the site of traffic accidents are highly important and relate to the quality of sophisticated statistical and mathematical models (Loo, 2006). Every event must be recorded correctly and adequately while ensuring the data are retained and recorded for any further research (Rolison, Regev, Mourati, & Feeney, 2018) and based on this, legislation can be adapted or at least implemented through various awareness campaigns. The Slovenian Traffic Safety Agency implements and coordinates individual and other preventive activities and traffic education programmes, some of which are traditionally presented in Slovenian schools. In 2018, in accordance with the Periodic Plan, national preventive actions were implemented in the areas of pedestrians, mobile phones ('Do not use your phone while driving'), motorcyclists, coaches, safety belts and child restraints, speed ('Speeding kills'), alcohol ('Think! Alcohol kills'), safety of children, trucks and buses, as well as taking care of the provision of traffic education by kindergartens, primary schools and secondary schools.

There are three main sources of error in road traffic accident information gathering: incomplete data (measurements, photos, etc.), inaccurate data, and false information or incorrect parameters responsible for accident occurrence (Ahmed, Sadullah, & Yahya, in press). Studies from the UK and USA show that false information or incorrect parameters can be found in data collected regarding seatbelt use because the injured often falsely claim that they were wearing a seatbelt in order to avoid a fine (Li, Kim, & Nitz, 1999; Schiff, & Cummings, 2004). The first sources of error relate to the technology and measuring techniques (measuring tools) used by police officers and can be eliminated or at least limited (Ministrstvo za notranje zadeve, 2017b).

All detailed investigations require much data. Police officers must determine the vehicle's trajectory and speed, and the unusual movements of all vehicles involved. They must measure the start and the end of the brake skid lines and their alteration, various wrecks, notches, scratches, warning signs and other potentially relevant details. There are several steps to the accident investigation. When the police or experts are called to the event site, they first search for important metering entities, identify them with coloured spray paint and then measure their relative positions from a chosen reference point (such as a road sign, building corner etc.) as evidence for further analysis. Following their field investigation, the police file a report and recreate the scene in a scale drawing (Jacobson et al., 1992).

The work of police officers and accident investigators vary from state to state. The technology and measuring tools used by police, experts and investigators in different areas are dependent upon the financial resources at their disposal and the interests of individuals. Most foreign investigators and Slovenian police officers use the coordinate method to record traffic accidents, usually the relationship of an individual point perpendicular to the edge of the road. It should be emphasised that several modern measuring tools are used to reconstruct traffic accidents around the world and each depends on the following factors: the purchase and maintenance costs; the number of investigators required; the method of obtaining data; possibilities of operation in all weather conditions; data capture time; and, above all, the accuracy of the collected data.

It is common for specific problems to arise in the measurement and location of sites, and that reliance on police data for road crash injuries can be problematic (Watson, Watson, & Vallmuur, 2015). Although it is usually impossible to measure and document each 'piece' of an accident, it is critical that these should be documented. However, with overlaps and crossings of inhibitory traces, they may cause errors in the calculations if they are incorrectly documented (Casteel & Moos, 1999). Chokotho, Matzopoulos and Myers (2013) demonstrate accident data quality problems, such as missing data, duplication of data and significant underreporting of traffic injury deaths. Their results reveal potential underreporting of factors in existing accident records and the need for accident report forms that are continuously reviewed and updated (Rolison et al., 2018). Problems regarding accuracy and precision, and also the reliability of accident data, were perceived some time ago (Austin, 1993; Shinar & Treat, 1977; Shinar, Treat, & McDonald, 1983) and also in recent times (Ahmed et al., in press). Errors in data gathering and/or reporting can lead to the misidentification of black spots and hazardous road segments, the projection of false estimates pertinent to accidents and fatality rates, and the detection of incorrect parameters responsible for accident occurrence (Ahmed et al., in press).

The second problem with collecting and recording accident data is the time required and the flow-on effects of a road closure, because when roads are closed for significant periods, numerous problems may arise. Traveller delay is the problem most commonly associated with road closures due to an accident. However, secondary crashes resulting from other drivers' curiosity and distraction is another serious problem. It is not unusual for a secondary crash to be more severe than the original one. Another related issue is the danger posed to response personnel serving the public at the scene of a crash. Their vulnerability and exposure to injury are directly correlated with the length of time they are on the scene. All of these problems result in significant costs (Walton et al., 2005).

Traditional measurement using a measuring tape has a number of drawbacks, such as the time needed, number of personnel at the accident site (Xinguang, Xianlong, Xiaoyun, Jie, & Xinyi, 2009), and greater probability for errors. In addition, data gathered using this method cannot be re-checked and additional measures (for example, when we perform an analysis of an accident at the office and we detect some additional traces on photos that we did not measure at the site of the accident) are impossible. The most important advantages of using a measuring tape are its low cost and ease-of-use. Recent research reports other low-cost methods, such as the photogrammetric measurement of 3D objects using data stored in 2D photographs. This method increases efficiency through fast accident data acquisition and requires only one police officer during data capture (Osman & Tahar, 2016); the accuracy is slightly higher than that with measurement type (Randles et al., 2010) and the measurement results obtained are also useful for surveying vehicle deformation (Xinguang et al., 2009). The main disadvantage of this method is in documenting scenes with significant high profiles and in larger traffic accident sites (Stáňa, Tokař, Bucsuházy, & Bilík, 2017).

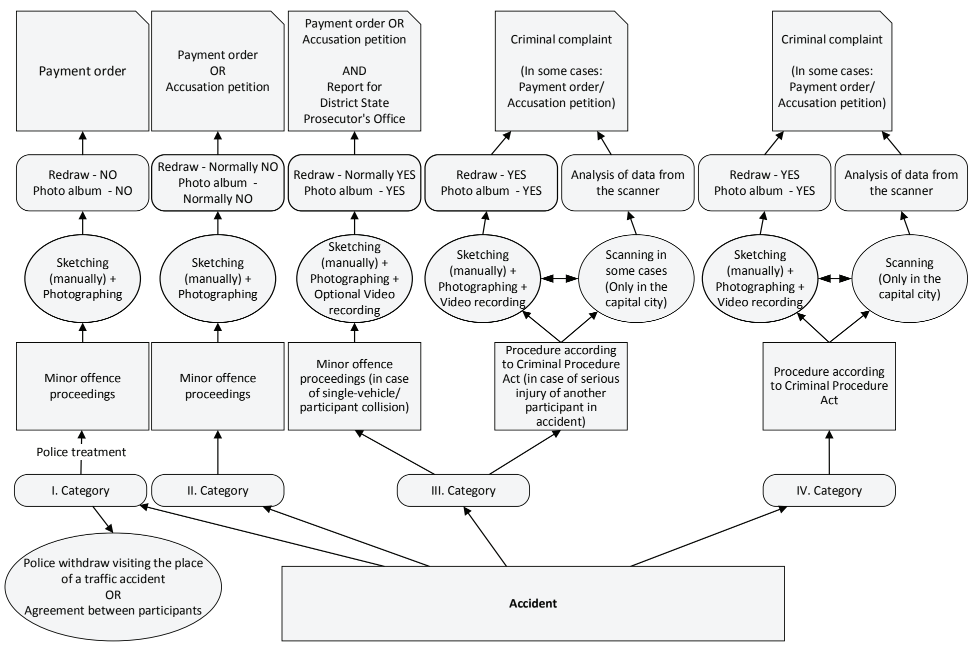
The location of an accident could be recorded in the form of geographic coordinates, route number and the name of the road (Ahmed et al., in press). Based on the critical review of Australasian, European Union, and U.S. crash databases, it can be concluded that the best way to determine a crash location is by global positioning coordinates (GPS). Regarding accidents in rural areas, 36% missed the linear reference and the accuracy levels of accident location in all crashes were only up to 1 km (Montella et al., 2013). The GPS receiver operates with radio signals so line-of-sight is not required and only one police officer is needed.

Different advanced laser 3D scanners are also frequently used to record traffic accident sites. The main downside is their cost, but this technique is automated, very accurate, has high spatial data resolution and can operate day or night, although sensitive to rain (Morales, Gonzales-Aguilera, Gutiérrez, & López, 2015).

A different approach to accident data gathering is in a vehicle's black box, installed to record information that can also be used for accident data. Chung and Chang (2015) investigate the accuracy of police accident data (crash impact location, crash impact speed and crash impact time) recorded by a vehicle's black box. The analysis reveals that the existing method has a spatial difference of 84.48 m with a standard deviation of 157.75 m as well as an average of 29.05 min of temporal error with a standard deviation of 19.24 min; additionally, the average and standard deviation of crash speed errors were found to be 9.03 km/h and 7.21 km/h, respectively. However, these data can be used for further analysis of accident characteristics.

The structure of a typical police traffic accident response process in Slovenia is shown in Figure 1. According to the classification (I, II, III or IV) and the severity of the traffic accident, the approach to the examination of the accident site by the police can vary. Under the Law on Road Traffic Rules (Zakon o pravilih cestnega prometa [ZPrCP], 2010) in category I traffic accidents, police officers do not need to inspect the site of the accident, collect data or identify the facts of the accident. This procedure also applies in cases where the participants in the accident make their own agreement about the accident. In the cases of accident types of II–IV, police officers are required to visit the scene of the traffic accident, ensure the accident site and collect all necessary notices and evidence to clarify the course and the circumstances of the accident. After viewing the scene of the accident, and on the basis of their findings and collateral evidence and circumstances, the police officer takes appropriate action against the person responsible for the accident. This measure, which depends on the category of the accident, can be a payment order, accusation petition or criminal complaint.

The Slovenian Police possess one 3D scanner, which is used to collect data at the site of category III and IV accidents. Because only one scanner is in use in Slovenia, it is used for the area of the Ljubljana Police Administration (the capital of Slovenia); in other regions of Slovenia, when preparing this paper, scanners are not yet in use. The police have recently purchased three more 3D terrestrial laser scanners for the regions of the cities of Maribor, Koper and Celje, and the certification of officers is in progress.



Legend: I. Category – a traffic accident in which only material damage occurred; II. Category – a traffic accident in which at least one person is physically injured; III. Category – a traffic accident in which at least one person is seriously injured; IV. Category – a traffic accident in which someone died or died as a result of the accident within 30 days.

Figure 1: Police traffic accident reporting process in Slovenia

To be able to compare classical police work with modern techniques, a crash scene was simulated. The approach of that investigation and methods used during the simulation are described in the next chapter.

3 Methodology

The present study is divided into five phases. The first phase is focused on preliminary research on possible errors and time taken to record the accident. The second phase focuses on the study area, which was determined by the police, to simulate a traffic accident at the polygon for safe driving. The third phase involves accident data recording. The time taken to collect and analyse crash scene data, and data accuracy, are discussed with respect to which recording method is used, i.e. 1) classical police measurements with the measuring tape, 2) the handheld GeoSlam Zeb Revo 3D terrestrial laser scanner and 3) measurements using the Riegl VZ-400i 3D terrestrial laser scanner. Classical police measurements with a measuring tape are, in general, performed by police officers using either rectangular or triangular measurements. In the case of rectangular measurements, which are faster, only one fixed base point is selected as the starting point of the measurements, whereas two basic starting points are used for triangular measurement. For this reason, it is necessary to perform double measurements to fix the place of the event in triangular measurements so that the event itself is actually fictitious.

The most commonly used method in practice is the rectangular measurement. First, a fixed reference point is selected and a measurement to the first track is made (abscissa) using a steel measuring tape. The measurements are made along the road and perpendicular to each accident track (ordinate axis). Thus, the local orthogonal coordinate system is developed and each track is recorded with two measurements. If the accident is in a turn, then additional measurements are made to obtain the curvature of the turn, and those measurements are used for a final sketch drawn to a selected scale. The road curvature is first drawn to scale and then the tracks are added. Each drawing includes a legend and is supplemented by a photo album containing all situations and traces. The traces of a traffic accident include all signs at the location of the accident and its vicinity that relate with the accident immediately before, during or after the accident (traces left by a vehicle on or near the road, traces of the victim or injured persons, traces left by the vehicle on the victim or by the victim on the vehicle, traces on the involved vehicles, traces on objects that are on or near the road and other objects or traces of a road accident).

A GeoSlam Zeb Revo 3D laser scanner was used as a data collection comparison. This is a simple handheld scanner for quick data collection and no special preparation is needed. It can be used as a static point by mounting it on a pole or vehicle, or just hand carried. It has 3D measurement relative accuracy of 2–3 cm and absolute accuracy of 3–30 cm, with 43,200 points/s. A cloud of points is obtained.

The Riegl VZ-400i 3D terrestrial scanner was also used. This scanner is a professional 3D laser scanner used mainly for architecture and facade measurements, archaeology and cultural heritage documentation, city modelling, civil engineering, building infrastructure management (BIM), emergency management, tunnel surveying, forestry, research monitoring, forensics and crash scene investigations. The scanner's DSLR camera is used to build a cloud of points. The points are stored at a speed of 42,000–500,000/s with a relative accuracy of 5 mm and an absolute precision of 3 mm. It can also include a GNSS (Global Navigation Satellite System) receiver. The output is a set of photos and millions of points in their absolute relationships.

The fourth stage is about data post-processing. For the Riegl measurements, the original RiSolve 2.6.2 software was used. That software enables importing point clouds and photos to build a 3D model and also measurements between individual points to make a sketch. Similar to this is Cloud Compare Software, which was used to obtain 3D models from the Zeb Revo measurements, produce a digital sketch and to make some comparisons between the two different point clouds. Last, the fifth stage is about data analysis and results, which enables an analysis of time consumption.

The simulated traffic accident was conducted in May 2018, at the Safe Driving Centre in Ljubečna, Slovenia. The weather was clear with no wind and measurements took place between 9 am and 1 pm. The simulated accident scene (Figure 2) involved two cars and a motorcycle, where the first car (Car 1; in Figure 3 item No. 9) is driving down the slope, the second car (Car 2; in Figure 3 item No. 8) is driving uphill. The motorcyclist overtakes Car 2 and runs into the front left of Car 1. The motorcyclist flies horizontally from the point of impact, then falls to the ground slides, rolls over and stops at the grass surface. The motorcycle falls to the grass surface a few metres away from the site of the impact and slides along, stopping at the end. Car 1 is slightly turned to the right with the front part. Car 2 is not directly involved in the impact between Car 1 and the motorcycle, and stops in front of the motorcycle and Car 1.

Figure 2: Aerial photo of simulated road accident

After a road accident, all damaged vehicles and casualties remain on site. At the end of the simulated road accident, a police patrol was deployed to capture accident data. First, two police officers carried out measurements with a measuring tape and prepared a situation sketch. They also photographed the scene of the accident. The other two police officers (specially trained to manage the scanner) carried out all the necessary measurements with the Riegl VZ-400i. In the end, one person (who uses the equipment but is not police officer) performed data collection with the GeoSlam Zeb Revo.

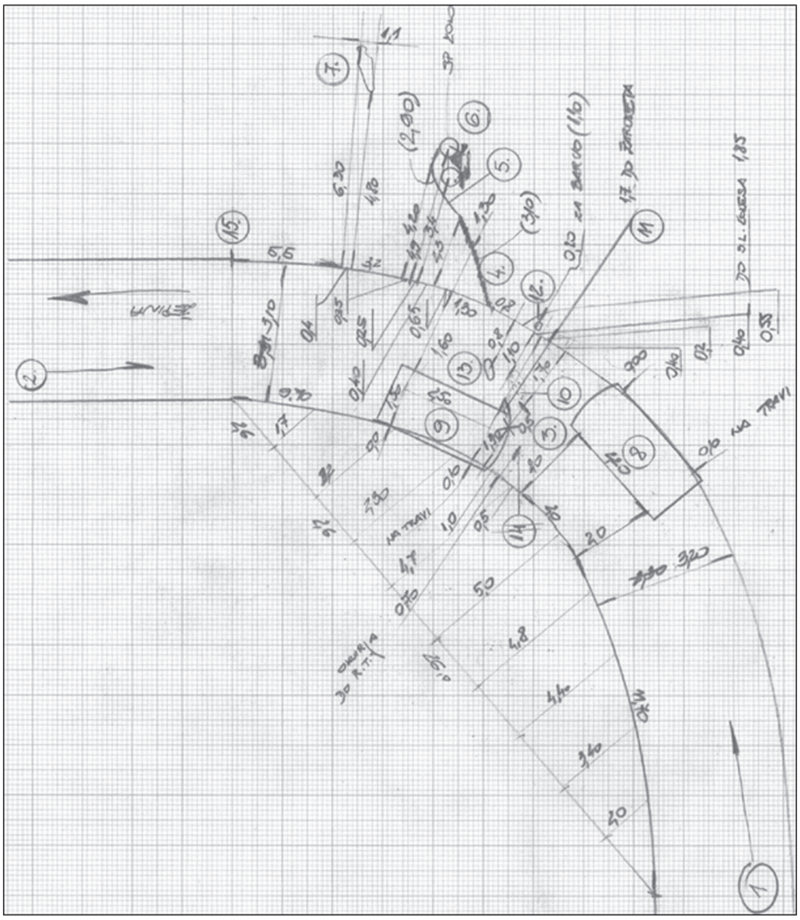
4 Results and Analysis

4.1 Classical Police Measurement with a Measuring Tape

One officer prepared a situation sketch as a rough outline of events (static and then a dynamic part of the overview, followed by shooting photos and/or recording a video) while another officer performed the field measurements. All trace measures must be included in this sketch and photographed, and once the sketching, shooting and/or video recordings are done, the sketch is redrawn to scale (usually the next day at the office).

The tape and scanner measurements were processed separately. Redrawing the sketch made at the traffic accident scene with the measuring tape, occurred the following day in the office. This is redrawing has been done by hand as most police stations in Slovenia lack computer graphing software.

First, the police officers used white spray paint to mark all the details important for further analysis and accident reconstruction. This is done regardless of the measurement technique and took them 12 minutes. The concrete fence was used as the measurement reference point or abscissa (1 on Figure 3). All results from data collected by measuring tape perpendicular to the road are shown in Figure 3. Altogether, 37 measurements were made. Because the majority of all accidents in Slovenia are processed in this way, those measurements in the simulation were taken as a reference with which the scanning results were compared.



Legend: 1 – direction of Car 2 and motorcycle; 2 – direction of Car 1; 3 – Collision point between Car 1 and motorcycle; 4 – sliding track – motorcycle; 5 – driving track – first wheel motorcycle; 6 – position of the motorcycle wheel after the collision; 7 – position of the motorcyclist after the collision; 8 – position of Car 2 after the collision; 9 – position of Car 1 after the collision; 10 – traces of paint/colour; 11 – position of the front left headlight from Car 1; 12 – a piece of plastic scrap from the motorcycle; 13 – position of the front left plastic fender from Car 1; 14 – position of the frame of the front license plate of Car 1

Figure 3: Data collected by measuring tape on a classical police sketch (source: Policijska uprava Celje, 2018)

4.2 GeoSlam Zeb Revo 3D Terrestrial Laser Scanner

The Zeb Revo is very simple to use. The operator carries a backpack containing the batteries and recording device, and handles the scanner, and all that is needed to start the measurements is to walk through the accident scene. In the simulated accident, the walk-through lasted 1 minute and 46 seconds and captured 1,394,924 points. In Figure 4, we see a raw point cloud elevation model from above and, in Figure 5, a side view. Even though more than 1.3 million points were obtained, the point cloud is rather poor for detailed and precise analysis, especially of details. More extended data collection should be used to obtain more points. For that reason, the 3D model was meshed.

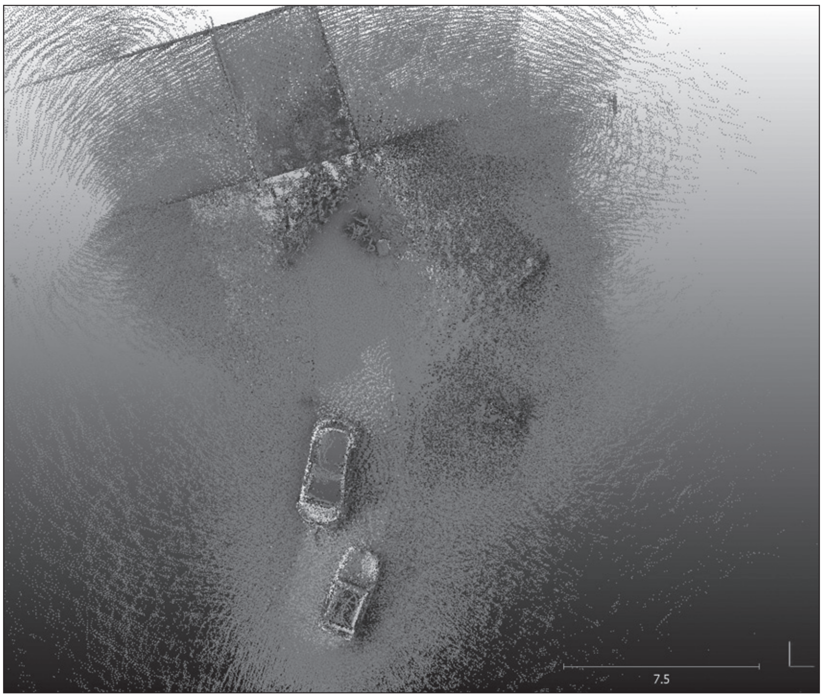


Figure 4: Zeb Revo raw point cloud (aerial view)

Figure 5: Zeb Revo raw point cloud (side view)

A meshed 3D model was obtained using Cloud Compare Software (Figure 6). Such models can also be used to analyse the relationship between observed objects, because they form a continuous model of the terrain and represent it much better than discrete models made of points. Moreover, 3D models can also be used for distance measurements, relations between different objects, etc.; for example, the 3D model took approximately 15 minutes to create but it can be meshed in a few minutes.

and Figure 7 shows the side view. The lack of points under the scanner on a single stand (black circles) is because the scanner cannot measure below itself. As expected, a much better elevation model than in Zeb Revo scanning can be seen. Here, five photographs were also made from each position (45 altogether) using an integrated DSLR camera; photos can be beneficial in later analysis and help obtain points in the point cloud.

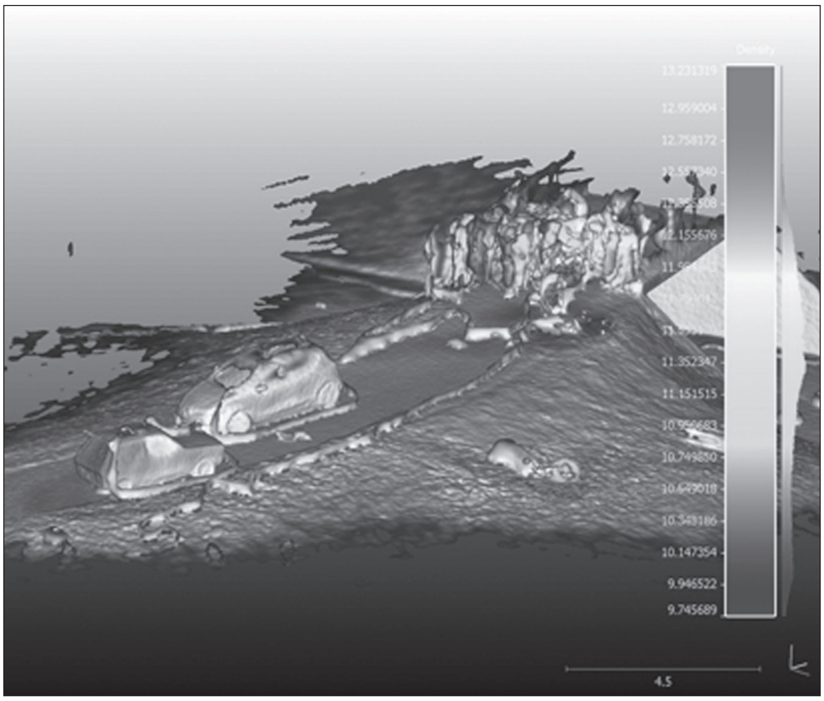


Figure 6: Continuous 3D model of a simulated car accident

4.3 Riegl VZ-400i 3D Terrestrial Laser Scanner

Two police officers used the Riegl VZ-400i 3D laser scanner. Preparation of the scanner takes a little longer than the Zeb Revo because it must be mounted on a tripod and settings must be input to the integrated software. The instrument setup is then placed around the accident scene to capture the data from different angles and obtain all details. For the simulated scene, 58,075,595 points were captured from nine positions in 21 minutes. Figure 6 displays the raw point cloud from above

Figure 7: Riegl raw point cloud (aerial view) (source: Policijska uprava Celje, 2018)

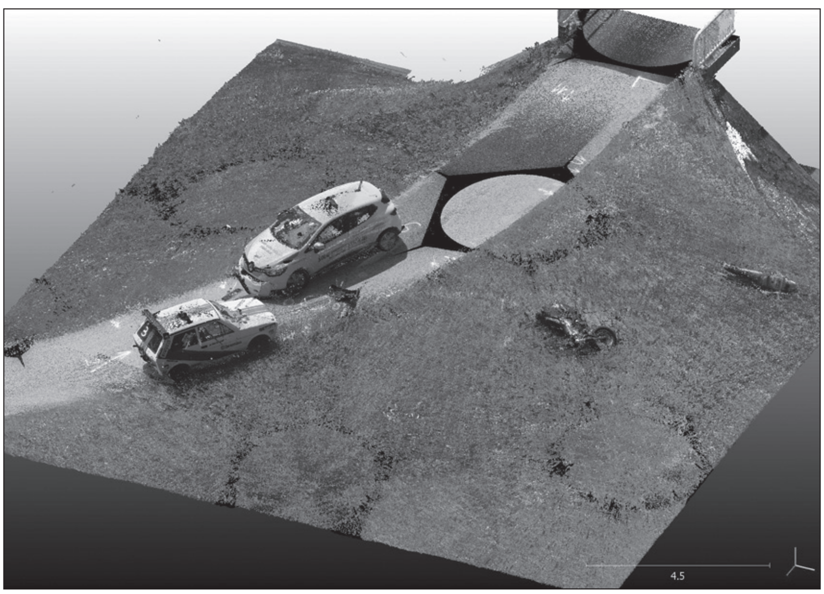


Figure 8: Riegl raw point cloud (side view) (source: Policijska uprava Celje, 2018)

4.4 Comparison of Results

A comparison between data obtained with measuring tape and distance from the scanners is presented in Figures 9–11. It should be emphasised that because this was an experiment, there was a higher motivation for police officers to demonstrate proper procedure; consequently, the accuracy of the measurements performed with the measuring tape in this simulated traffic accident was high. The fact is, however, that such accurate measurements are not made in all traffic accidents, meaning that sketches from real accident scenes would not be as accurate in this simulated accident. In practice, the quality of measurements with the measuring tape depends on what kind of procedure is followed (see Figure 1; Payment order, Accusation petition or criminal complaint). Measured data at the traffic accident site (categories I–III) are usually less precise than the data in case of category IV.

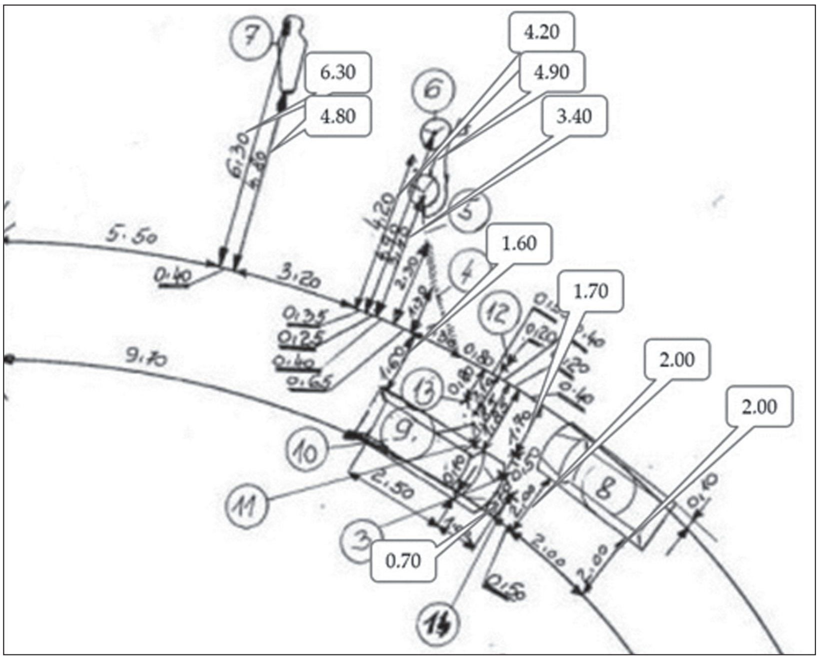


Figure 9: Sketch made from measuring tape measurements (source: Policijska uprava Celje, 2018)

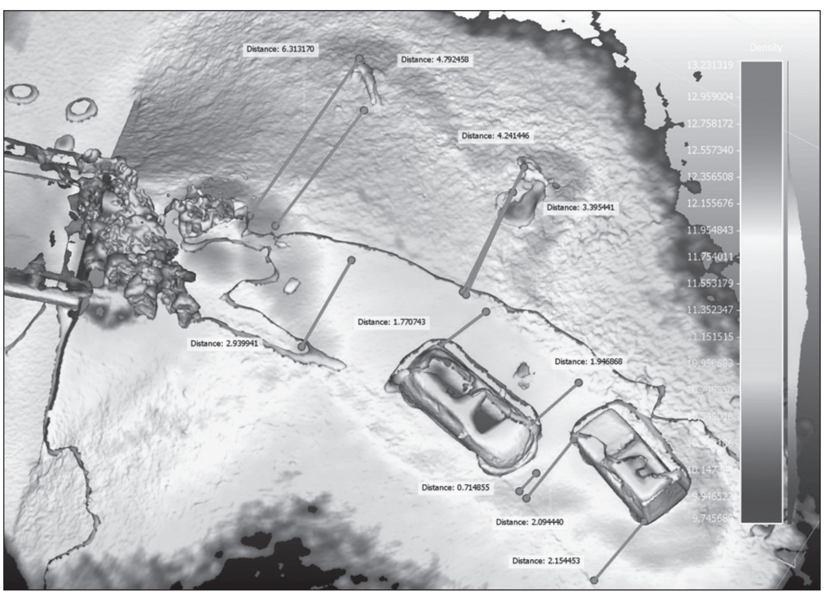


Figure.10: 3D model with measurements obtained from GeoSlam Zeb Revo point cloud

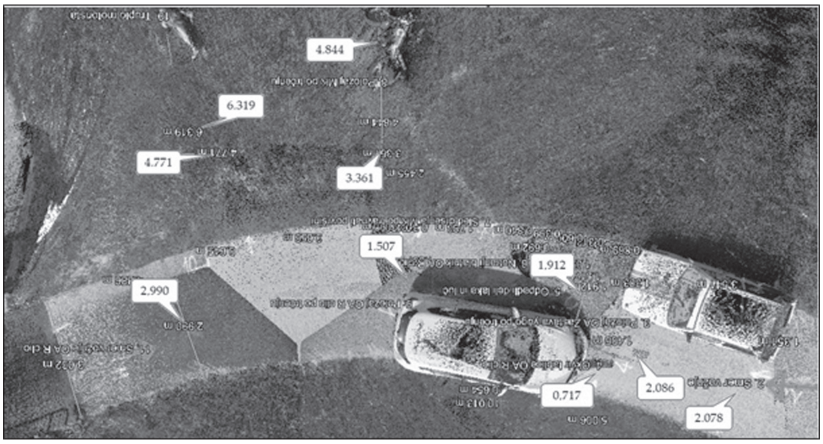


Figure 11: Point cloud with measurements obtained from Riegl 3D scanner (source: Policijska uprava Celje, 2018)

In the simulated example, 10 crucial measurements were compared and are reported in Table 1. As mentioned, police measurements were taken as a reference and then compared with the GeoSlam and Riegl measurements. From that analysis, it can be concluded that all measurements are very similar (within a few centimetres). Selecting the start/end point for measurement in a point cloud can sometimes be a problem due to the numerous points. It must be emphasised that spraying the details with tcolour on the accident site really must be performed. Without the photos, the sketch derived from GeoSlam could not be obtained because the point cloud was too coarse.

Table 1: Comparison of measurement methods

Object*	Distance [m]		
	Police sketch	**GeoSlam**	**Riegl**
Road width	-	2.94	2.99
6) Position of the motorcycle wheel after the collision (rear tyre)	3.40	3.39	3,36
6) Position of the motorcycle wheel after the collision (front tyre)	4.90	4.84	4.84
7) Position of the motorcyclist after the collision (head)	6.30	6.31	6.32
7) Position of the motorcyclist after the collision (legs)	4.80	4.79	4.77
8) Position of Car 2 after the collision (front end)	2.00	2.09	2.09
8) Position of Car 2 after the collision (rear end)	2.00	2.15	2.08
9) Position of Car 1 after the collision (front end)	1.90	1.94	1.91
9) Position of Car 1 after the collision (rear end)	1.50	1.77	1.51
14) Licence plate frame	0.70	0.71	0.72

* see Legend in Figure 3

The time consumed to gather all accident data depends on the measurement method. The classical work by the police begins with a quick tour to grasp the extent of the accident and to get a sense of what will be needed to capture the details. In this example, three minutes were needed for that inspection. The police officers then marked and numbered with coloured spray paint all details important for later analysis (this step is done regardless of the method used). Measurements with the measuring tape required 61 minutes (Table 2), which included sketching, measuring and photographing the different elements of the accident. The instrument setup and measurements made with the Zeb Revo took two minutes and 1 minute 46 seconds, respectively. The Riegl scanner setup took seven minutes because it needs a tripod and a software setup, and the measurements took 21 minutes. Post-processing and rendering took some time, and depend on the operator's competence. The post-production of images taken by different scanners cannot be directly compared with conventional methods (as in the case of post-processing measurements made with a measuring tape) due to a completely different approach.

A summary of the data collected for the simulated scenario is presented in Table 2. We can see that Zeb Revo is much faster, but produces fewer points and no photos.

Advantages of the 3D laser scanners include a short scanning time, fast data acquisition and high accuracy and reliability. In addition, they can be checked and measured long after the accident and used in most situations; however, 3D laser scanning is not possible in extreme weather conditions (e.g. fog, snow) or darkness.

5 Conclusions

The measurement errors, accuracy and time consumption involved in traffic accident reporting depend on the measurement technique used. One of the major errors that arise when using a measuring tape is under-reporting. If the police officer does not make all the measurements (they miss a particular trail/track), then repeat measurements are no longer possible as the accident scene has already been cleared. In the simulated traffic accident, such errors could not be identified as there were no requirements for additional measurements.

A classical sketch of a traffic accident scene is very time-consuming and redrawing such means more time and the possible introduction of errors. The time spent on performing the measurements, sketching the scene of the accident, and then redrawing it at the office also depends on the size of a traffic accident. To make measurements using a measuring tape, two police officers are needed, as one police officer alone cannot operate the tape. In this respect, we can find that police officers use mainly a measuring tape at all police stations in Slovenia and do not even have measuring wheels that can be operated by a single police officer. Each police station has at least one measuring wheel, but not every police patrol has its measuring wheel (because there is only one at the police station for many patrol cars).

Table 2: Summary of data

Instrument/Tool	Time			
	Setup	**Data Collection**	**Data Preparation**	**Post-processing & Rendering**
Measuring tape	-	61'	-	45 min
Zeb Revo	2'	1'46"	5 min	15–30 min
Riegl VZ-400i	7'	21'	30 min	15–30 min

In time comparison, it is evident that modern techniques are very simple and quicker than classical police field work. So far, only one scanner has been used by the Slovenian police in the area of the Ljubljana Police Administration. After presenting a new way of acquiring data with the scanner and the introductory two-month double-sketching (handmade and made with a scanner), both state prosecutors as well as investigative judges, decided that such a method is adequate if not better because a computer review is possible, which provides a greater possibility of presenting the actual situation. Thus, this method is adopted by judges and the road traffic experts called to provide expert opinions.

With 3D laser scanners, the maximum bandwidth is 30 or 50 metres, but they can also be used for measurements smaller than one metre. The execution of such measurements at the site of a traffic accident is long-lasting with this simulated accident. The police officer needed 61 minutes. The sketch drawn at the scene of the accident is still to be redrawn; which required an extra hour of work. This redraw is still done manually and no significant progress has been made, nor is it possible to digitise the data, and additional errors are also possible.

It is very important to emphasise that the reconnaissance of the accident area and marking of the details with a spray colour are required regardless of the method used. When obtaining the measurements from point clouds, comparable results with the police measurements, taken as a reference, can be achieved. Measurements are very similar (within few centimetres except in one example).

When using the Zeb Revo 3D laser scanner, much less observed points were obtained than with the Riegl. This scanner is user-friendly, quick to scan and needs no special expertise or preparation. The disadvantage is that there are no additional photos taken during scanning, which can prolong data capturing, some additional photos must be taken with another camera. In spite of all this, the obtained 3D model can easily be used in cases when smaller accuracy is adequate and there are no tiny details to be recovered.

The model and measurements obtained from Riegl are in accordance with the classical police process, and that is the reason why this scanner has been in use for heavy accidents in one of the Slovenian Police squads since 2016. The advantage of this scanner is also an integrated GNSS for obtaining an absolute position, minimising the absolute position error of an accident site. Three more scanners were recently bought for the Slovenian regions of the cities of Maribor, Celje and Koper.

The time taken for data acquisition should be as short as possible in order to quickly reopen the road, street, highway etc. to traffic. It is obvious that in this comparison the advantage in data collecting is decidedly on the scanner's side. However, the decision of which method will be used should be made during the first reconnaissance in accordance with the accuracy needed and detail size.

The vision for the future is in the efficient and quick use of modern data collection techniques or at least combining them with the classical ones as much as possible. These methods are quick, accurate and precise, and they can be post-processed at any time (even far into the future). There are also some drawbacks, such as detailed precision and environmental extremes, which are common at accident scenes. The use of modern technology does not pose particular problems in criminal proceedings, and positive criminal legislation stipulates that the police will conduct a tour of the crime scene, issue a record and draw a sketch of it. For the record, the content and formality are prescribed, but for the sketch, however, there is no command of how it should be produced.

According to the findings in this research, the use of scanners is highly recommended under several assumptions: good weather conditions (no heavy rain, fog, snow), several standing positions of the scanner.

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3D lasersko skeniranje in točkovni oblaki za pridobitev skic prometnih nesreč

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Namen raziskave je prikazati klasično policijsko delo in ga primerjati z najsodobnejšimi načini zbiranja in analiziranja podatkov v primeru preiskovanja prometnih nesreč, in sicer, kako lahko sodobna tehnologija skrajša čas zbiranja podatkov o prometni nesreči in ali so zbrani podatki enake kakovosti? Na poligonu varne vožnje Ljubečna je bila izvedena simulacija prometne nesreče, kjer so bili udeleženi dva avtomobila in motorist. Simulirana je bila prometna nesreča, v kateri je bil motorist smrtno poškodovan. Policista sta s pomočjo barvnega razpršila in ročnega merilnega traku opravila klasično preiskavo kraja prometne nesreče. Za zbiranje podatkov sta uporabila tudi preprost ročni Geo Slam Zeb Revo in napreden Riegl VZ-400i 3D skener, med katerima so nato primerjali meritve. Prispevek prikaže uporabljene metode preiskovanja nesreče in primerja tri različne načine izdelave skice. Rezultati so pokazali, da je lahko v primeru preprostejših nesreč avtomatizirano pridobivanje podatkov dovolj natančno za nadaljnje analize. Poleg tega so te metode tudi precej hitrejše od klasičnega pristopa.

Ključne besede: točkovni oblak, 3D skener, prometna nesreča, rekonstrukcija nesreče, prometna varnost

UDK: 351.741:614.86