The Benefits of Laser Scanning and 3D Modelling in Accident Investigation: In a Mining Context

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Abstract

The mining industry is committed to operating safely and reducing accident numbers, however mining is predominantly dangerous due to unknowns. With this in mind, understanding accidents is essential to learn from them to develop robust Health and Safety Management Systems and proactive Risk Assessments.

Effective accident investigation and training is essential in order to accomplish this, while providing a record of the incident in order to help explain the situation to people unconnected to the event itself. Over a number of years there have been considerable innovations in survey instrumentation and software used to record data. However, the final deliverable data has remained the same, with surveyors tasked to represent a 3D environment using 2D deliverables.

This paper explores the benefits in which can be obtained using 3D data capture and representation with regard to accident investigation. With discussion on accuracy, time, witness verification and reduction in human error.

Keywords: *Laser Scanning; Accident Investigation; Point Cloud Data; Mining; Safety*

1.0 Introduction

1.1. The Problem

Within the mining industry, fatalities have been on steady decline in many countries for a number of years. Data gathered by the US Department of Labor, Mine Safety and Health Administration show that there were 70 fatalities in 2002, in comparison to 36 in 2012 (US Department of Labor, 2013). Additionally, statistics gathered from the UK Health and Safety Executive show that there were 54 fatalities in 1981, in comparison to 10 in 2011, within the extractive and utility industries (HSE, 2012). The same story is demonstrated in South Africa, where there were 774 fatal accidents in 1984, in comparison to 168 in 2008 (Chamber of Mines South Affica, 2009).

Although the mining industry is committed to reducing accident rates through safe working practices and robust health and safety management systems, accidents are still occurring. With safety being the number one value within mining, civil, commercial and industrial setting it is imperative that any breach of safety resulting in an accident or loss of life is investigated thoroughly. Reasons for these accidents can be varied and different (MacNeill, 2008). Undertaking an accident investigation also provides clarity and fosters a deeper understanding of the risks that are associated with the workplace (HSE, 2004).

1.2. Accident Investigation

Through pre-planning and efficient investigation, a dynamic health and safety management system can be incorporated into a workplace to reduce incident numbers. For example, through the use of effective risk control measures, adequate supervision, monitoring and management, work activities can be safely engineered (HSE, 2004). Undertaking an accident investigation also provides clarity and fosters a deeper understanding of the risks that are associated with the workplace (HSE, 2004), identifying both immediate and underlying causes. The process requires "a methodical, structured approach to information gathering, collation and analysis" (HSE, 2004). In addition, suitable safety controls need to be developed in order to prevent the accident from happening again or to improve the overall management of risk within the workplace (HSE, 2001). This then forms a link with risk assessment which is a legal duty under the Management of Health and Safety at Work Regulations 1999.

2.0 Surveying of Accidents

In most accident investigations, it is necessary for the scene to be recorded. Depending on the complexity or severity of an accident, this could range from a sketch of the environment and the locations of objects, to a detailed plan prepared from measurements taken by a qualified surveyor. In road traffic collisions and within the mining industry, the latter is common practice. The surveyor should provide sufficient geospatial information in order to allow investigators to determine the factors that may have had an influence on the event (Mine surveyor.net, 2010). It is an important note that a surveyor should be used within the recording of accidents to ensure the integrity of the measured data and the equipment use is to a sufficient standard.

The integration of conventional surveying techniques in relation to the accident investigation process is shown in

Figure 1.

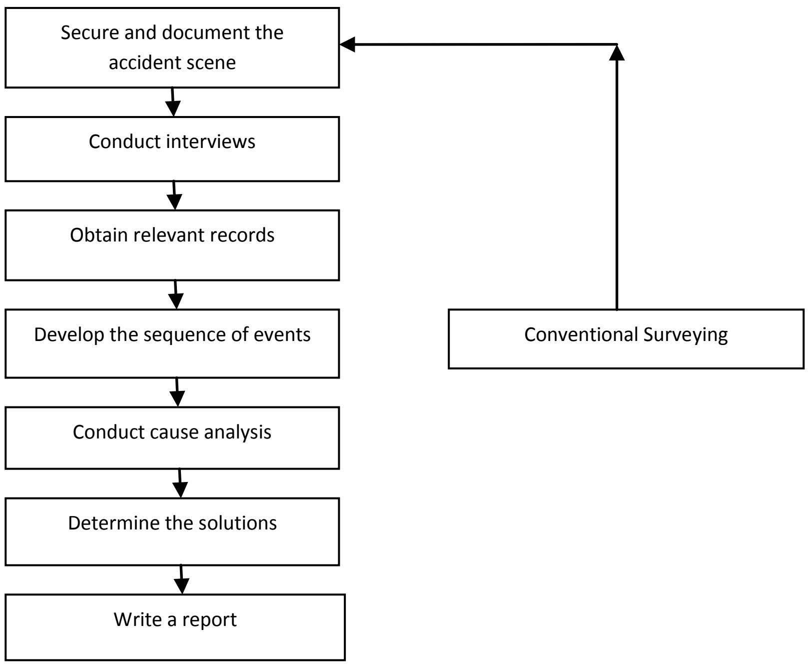

Figure 1: The integration of surveying within the accident investigation process

In addition, the survey can aid the development of risk assessments and safe operating procedures that relate to the geospatial factors which have contributed to previous accidents (Minesurveyor.net 2010).

When conducting an accident investigation survey, it is crucial to consider what information may be regarded as important by the accident investigator and also what may be useful for future reference (HSE, 2004). This, however, may lead to human error and details within the accident site may be improperly recorded, which may be as a result of the surveyor's opinion of what had been perceived as a contributory factor or miss-measurement. Additionally, errors can occur because of a number of factors, the major factor being time. As soon as the accident occurs the scene begins to deteriorate. In addition, there can be pressure to finish the investigation process (Helmricks, 2010), which may result in a rushed survey and again influence such error. Other errors can occur with discrete data collection from conventional surveying, for example if a surveyor was to record a vehicle, a measurement shot would be taken at the end of each axle and corner of the vehicle (Helmricks, 2010), from this the car would be drawn. This method could create error for example in recording an uneven or non-geometric surface, for example if the car had a dent this would not be represented. Also, with discrete data collection, information may be missed.

Upon arrival at an accident scene, the surveyor should undertake four key activities. Firstly, the surveyor needs to briefed by the accident investigator about what has happened and the nature of the incident. Then a rapid reconnaissance of the site should be undertaken and a rough sketch made. Finally, a control survey should be established in which a detail survey can be undertaken (Helmricks, 2010).

The following information should be recorded when undertaking a survey in mining accident and also in road traffic collisions (Mine surveyor.net, 2010):

- Accurate positioning of the scene and the topography of the surrounding area
- Signage which is related to the accident
- Features on the roads or surroundings
- Objects or features that may have contributed to the accident
- Orientations, appropriate scaling and information necessary for investigators

It can be seen from the review of survey methodology and deliverable data over the last two centuries that little has changed in order to explain the circumstances surrounding accidents. This has largely been based on the instrumentation that has been available to surveyors, the equipment has largely been linear based in terms of measurement with theodolites used for angular measurements. This has restricted the possibility of enhancing the survey deliverables, due to subjective, discrete point collection from equipment available. However, recent developments in survey equipment such as laser scanning technology allow diverse data capture in 3D and could have a profound effect on accident investigation.

3.0 Move to 3D Data Capture: Laser Scanning

It has become accepted that the use of 3D data can provide help in analysing what has happened in accident investigation (Pagounis, Tsakiri, Palaskas, Biza, & Zaloumi, 2006). Also, there are a number of time related problems that are encountered when undertaking a accident survey in relation to the scene decaying and surrounding pressures in relation to restoring the scene, this can also become a factor when an investigator generally has to revisit the scene numerous times (Helmricks, 2010). Human error should also be considered in reference to mis-measurement and interpretation of surfaces taken subjectively by a surveyor.

With this in mind, a solution needs to be established that allows a surveyor to obtain data quickly and in 3D to aid in the accident investigation process, while simultaneously reducing the propensity for human error. A technology that has the potential to offer indisriminate data collection of up to 1 million points per second (Ramsey, 2007) with consecutive modelling capabilities in 3D can be found in laser scanning.

Laser scanning is a process where a surface is sampled or scanned using laser technology. The data collected can be used in order to create 2D plans or 3D models of a scene where, 3D laser scanning is likened to taking a photograph with depth information (Quintero et al., 2008). The survey data collected is referred to as a point cloud.

Most laser scanners offer at least 360° x 270° data collection (Ramsey, 2007). The range, accuracy and speed of laser scanners vary greatly, and thus equipment selection is essential for the accident scene to be recorded. For example, incidents that have been a result of a fall of ground and the area could still be unsafe a laser scanner with considerable range may have to be considered.

3.1. 3D Surveying an Accident Scene with Laser Scanners

Upon arrival at an accident scene the surveyor should produce a quick sketch of the accident area with relative positions of the objects in the scene. It is important to do this early as the scene may change or deteriorate.

Following this, the laser scanner set up positions should be decided in order to obtain detail of the whole reference area. The surveyor should consider the following when choosing scanner locations, those that (Quintero et al., 2008):

- provide a large coverage with limited obstructions
- are within range limits of the instrument
- optimise the number of scan positions
- locate the instrument in a safe position
- take into account environmental conditions
- afford good visibility of target locations

Upon completion of the above, the surveyor can undertake the laser scans and take photographs for the overlay onto the point cloud if required.

3.1.1. Data Processing

Data processing can include registration of the data and assigning photographs or extracting information. The registration process involves constraining the individual point clouds to each other, in which an alignment error will occur, as no registration will form perfectly and requires careful consideration by the surveyor. There are two principal methods of registration, the singular scans can be joined to each other using common geometry within the point clouds or through the use of targets. However, in advanced registration, a combination of the two methods can be used. There have been a number of papers published on the accuracies of data acquisition, target setup and registration notably (Becerik-Gerber, Jazizadeh, Kavulya, & Calis, 2011), with laser scanning accuracy comparable to the accuracies achieved by total stations.

Additionally, if photographs were taken on site, photographic overlay of the point cloud can now be performed to provide geodetic photorealistic models. This involves assigning common points within the photograph to that of the point cloud. The result is a 3D scene that is not only accurate geometrically but also visually.

3.1.2. Deliverable Data

Once the data has been captured and combined, information can be extracted from it (although the required results should be considered early within the investigation process).

The resulting data from a laser scanned scene can be very rich. A number of deliverables with reference to accident investigation can be produced including:

- 3D fly through or walkthrough simulations
- 3D models and scene reconstruction
- 2D plans and sections
- views from specific or arbitrary angles (witness verification)
- physical 3D models
- videos combining photography, point cloud data and 3D models

Many of these deliverables can be created directly from the point cloud data. However, 3D models and scene reconstruction require the points to be triangulated to form a solid mesh.

4.0 Case Study: Staged Electrocution

In order to demonstrate the potential of 3D surveying in relation to accident investigation a staged fatal injury was created by the authors in a working mine in 2012.

The staged accident was an electrocution to a maintenance worker who had been tasked to replace the metal cage doors on the entrance to a switch gear chamber. Through initial inspection, it was apparent that there were a number of elements that could have had a influence on the accident. A laser scanner and photography were used in order to demonstrate the advantages of this technology in providing an accurate, photorealistic reconstruction of the model that could be revisited, while providing the ability to explain the scene to lay people.

Although, the accident has been staged within a mine, due to the nature of the incident, similarities can be expressed over a number of industries. As the "worker" was undertaking a maintenance operation involving common electrical switch gear and therefore could be in an industrial setting.

Illustrations of various deliverable data from a staged accident scenario are shown in Figures 6-10.

The data provides an accurate record of the scene in terms of angular and distance measurement. In terms of accident investigation this provides an accurate 3D environment in which measurements between elements can be taken and the scene can be virtually revisited any number of times.

When undertaking the survey, digital photographs were taken from the same position in which the laser is emitted from the scanner. This allows the point cloud to be accurately overlaid with the photographs this is shown in Figure 2 and provides geodetic realism where measurements can be taken. In addition, using photographs can aid in the explanation of the scene to persons unrelated to the event.

Figure 2: Laser scan data with photographic overlay

Photographs were taken from key locations in the accident area in order to provide additional information, an example is shown in Figure 3. In addition, these provide an extra level of integrity to the survey, while conforming to conventional survey practices.

Figure 3: Photograph from set location

From the point cloud and photographs a highly accurate 3D model can be produced, an example is shown in Figure 4. The model not only provides additional clarity to the scene, but also the combination of all the above can be made into a video format, which can help navigate a jury, for example around the scene stopping at key areas of interest.

Figure 4: 3D model of staged accident

In addition, a 3D model can be used to reconstruct the accident and may help to illustrate the sequence of events prior to the incident, by producing an animation of the events as they unfolded. Also, it can be used in order to form a training aid to assist with accident prevention, by producing an accurate virtual environment that could be using in a simulator training suite. The process involved to create a solid 3D model of the scene can be extensive, with this in mind 3D models may only be appropriate in cases that require further analysis. The data collection is the first stage, after this extensive post processing work has to be undertaken in a variety of different software applications in order the data's integrity and produce a final model.

Once a 3D model has been created sections can be removed such as the roof of the accident area to demonstrate the locality of elements within the accident. This is demonstrated in Figure 5.

Figure 5: 3D model with roof removed

Although the data is captured in 3D, it can be used to produce 2D deliverables in the form of plans and sections. Therefore, conventional deliverables are retained if the need for the 2D plans arises and they can be extracted from the dataset.

The 2D deliverable produced from point cloud data is a precise representation of the scene and not an interpretation. An example of a 2D plan is shown in Figure 6.

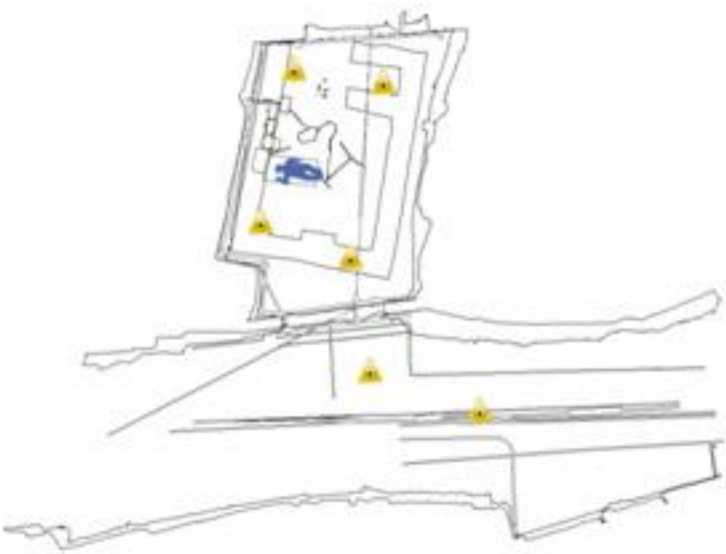

Figure 6: 2D plan created from point cloud data

5.0 Benefits of Laser Scanning in Accident Investigation

Based on the staged case study, there are a number of benefits that laser scanning provides over conventional survey methods within an accident scene:

3D Data Collection

This can be key in the explanation of an environment to people or persons that were unconnected to the event. 3D data allows the observer to see an realistic and spatial view of the full scene, rather a singular planner view in plan or section.

In addition, the data can be used to create a highly accurate 3D model that can be used in reconstruction of an accident scene to assist in reducing the probability of re-occurrence. This is done by using the laser scan data as a reference to model around to produce a virtual reconstruction.

Indiscriminate Data Collection

It is hard to distinguish what is relevant within an accident scene. Data collection using conventional survey methods is subjective and is influenced by the surveyors judgement as to what points need to be recorded. As a laser scanner will record virtually a full dome 360° point of view from the scanners location and is free from bias as the equipment is indiscriminate in the points it records. Some data may be picked up, the relevance of which become apparent late in the investigation.

Surveying of Complex Structures or Unnatural Environments

Using a conventional surveying instrument, a surveyor records self selected, discrete points. In order to record a complex surface a surveyor would have to record every material change in an object's surface, which could take a considerable amount of time. For example, a surveyor using a total station may be able to capture 500 points in 4 hours by comparison (Van der Merwe & Andersen, 2012).

However, a laser scanner can record a vast amount of data, offering up to a million points a second with minimal point spacing, therefore as long as blinding is taken into consideration a highly accurate representation of a complex structure can be produced. For the above example, 7 set up locations were recorded on high with a total number of points in access of 31 million. In addition, the equipment selected undertook each laser scan in 3.5 minutes, the photographs were taken and then the process was completed for each location.

Reduction in Human Error

Laser scanning can reduce the element of human error that may occur in the surveying process. The laser scanner is indiscriminate with regard to data collection, since once positioned the instrument will record a substantial proportion of the surrounding scene. Providing the surveyor is accurate when deciding on the location of instrument positions, the whole scene can be recorded with millimetre accuracy.

Speed of Data Collection

An accident survey must be efficient and effective. Modern laser scanners can perform a high resolution full dome scan in approximately 4 minutes depending on the make and model.

Witness Statement Verification/ First Person Viewpoints

By positioning a camera at the location of an witness, within an accurate 3D surveyed environment, it is possible to show what would have been seen. This can then be used to assess the reliability of the witness account. In addition the same methodology can be used in order to establish what the driver of a vehicle could see for example, to determine "blind spot" locations.

Large Density of Data Collected

Laser scanning offers the ability to obtain a vast amount of data far more accurately than using conventional methods. The use of a laser scanner can provide a far more comprehensive survey of the scene in comparison to conventional methods.

Scene Revisits

With the use of laser scanning the data is captured, which allows the investigator to revisit the scene virtually any number of times.

Safety

Accident scenes can sometimes be unsafe areas in which to operate, for example if a fall of ground or land slip has occurred. Some modern laser scanners offer a large range e.g. the VZ-6000 laser scanner developed by Riegl offers a range of 6km (Riegl, 2012). Additionally, most modern laser scanners have the ability to operate them remotely via an internet connection. Once setup in position this can be used in order to limit the surveyors exposure to a hazard. Also, devices are available that can carry a laser scanner to its scanning location.

Data Clarity

With the incorporation of a 3D model which has been photographically overlaid, a person can observe the relationship between everything in the scene within a 3D environment. A fly through into the 3D scene stopping at key areas with photographs and scan data, can bring clarity to an observers mind. Additionally, the use of photographs with the scan data provides further integrity to the 3D model, since the recreated scene can be justified in the photographs, while also within the registration and instrumentation accuracy reports.

Conventional Deliverables Retained

Although the data is captured in 3D, it can easily be reprocessed to produce 2D representations of the accident scene, as there are certain circumstances in which the data has to be represented in a 2D form. This may be a personal preference of the person observing the data or if a plan is required to be shown within a formal incident report.

Enables Incident Reconstruction

When the data is collected using a laser scanner the data can be used as a base to make accurate 3D models. Using this model the accident can be reconstructed and different scenarios can be staged and tested within a virtual space, establishing full incident reconstruction. This can be particularly useful to establish the reach of machinery in relation to the surveyed environment for example.

Illustrative Purposes for Court Proceedings

Depending on the severity of an incident sometimes the persons involved will be in breach of the law and can be subject to judicial review. Laser scanning gives the ability to demonstrate the scene accurately to an audience that is unconnected to the event for example a jury.

The use of laser scanning in accident investigation can change the way in which surveying will integrate within the process. This is demonstrated in Figure 11.

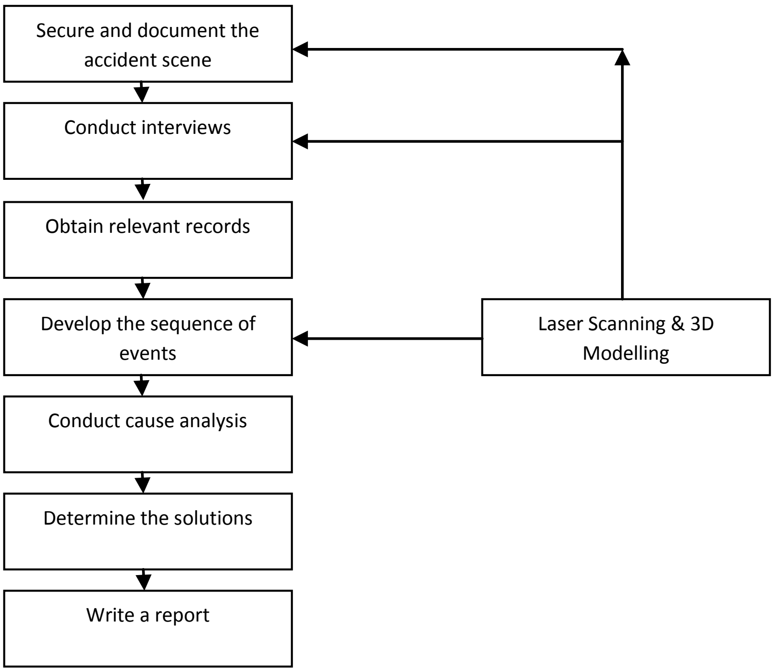

Figure 7: The integration laser scanning in the accident investigation process

Rather than just recording the scene, the data collected using a laser scanner is rich and can therefore be used for a number of different applications within the accident investigation process. Additionally, once captured the data is stored, this provides the possibility of information extracted for a different use in the future. For example, an accident on the highway may have an influence on road design.

6.0 Conclusions

Laser scanning and 3D modelling does have a place within the accident investigation process as a new methodology for capturing/ presenting data, while providing a real world environment to test possible hypotheses. As a laser scanner has the ability to capture data in 3D it has considerable benefits in clarity and understanding of the incident scene. With the ability to observe the relationships between every object in the environment from any possible angle that may not be possible in the actual environment. While providing a archived record of the scene that can be used to educate others on the every changing risks found within the industrial setting. In addition, as a laser scanner is indiscriminate in its data collection, the possible human error and personal interpretation of surfaces can be reduced, with the complete scene recorded rather than discrete selected points.

Recent developments in the geospatial industry has provided the opportunity to gather data to an unprecedented level of detail in which could only previously imagined. This is changing the way the environments are being recorded with a massive influx in data. In addition, as a result of the rapid progression of 3D capture technology new software and solutions are being explored daily, with innovate new ways to capture and present data for wide ranging solutions. This leads for exciting times ahead from industry developments, where companies aim to secure a competitive edge over rivals.

However, there are still a number of limitations to the technology and with solutions being obtained daily. With this in mind, it is important for research to stay ahead of the technological advancements in order to examine the reliability and accuracy of new systems of data management and capture, this has particular relevance to accident investigation where the integrity of the data is key.

In order to prevent accidents we need to understand them and laser scanning has the ability to bring the scene alive, allowing the investigation to identify immediate and underlying failures.

Bibliography

Becerik-Gerber, B., Jazizadeh, F., Kavulya, G., & Calis, G. (2011). Assessment of target types and layouts in 3D laser scanning for registration accuracy. *Automation in Construction*, *20*(5), 649–658. doi:10.1016/j.autcon.2010.12.008

Chamber of Mines South Affica. (2009). *Annual Report 2009*.

Helmricks, D. R. (2010). Motor Vehicle Accident Forensic Survey. In *FIG Congress 2010: Facing Challenges- Buolding Capacity* (pp. 11–16). Sydney, Austrailia. Retrieved from http://www.fig.net/pub/fig2010/papers/fs03c%5Cfs03c_helmricks_4669.pdf

HSE. (2004). *Investigating accidents and incidents* (pp. 1–89). HSE.

HSE. (2012). *Statistics on fatal injuries in the workplace 2012/13* (pp. 1–11).

MacNeill, P. (2008). *International Mining Fatality Database Project Report Overview of the project undertaken at the NSW Department of Primary Industries*. Retrieved from http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/182484/International-Mining-Fatality-Database-project-report.pdf

Mine surveyor.net. (2010). Accident Investigation Surveys. Retrieved February 01, 2013, from http://www.minesurveyor.net/gsaccident.php

Pagounis, V., Tsakiri, M., Palaskas, S., Biza, B., & Zaloumi, E. (2006). 3D Laser Scanning for Road Safety and Accident Reconstruction 3D Laser Scanning for Road Safety and Accident Reconstruction. In *Engineering Surevys for Constrution Works* (pp. 1–15).

Quintero, M. S., Genechten, B. Van, Bruyne, M. De, Poelman, R., Hankar, M., Barnes, S., … Taronger, J. M. B. (2008). *3D Risk Mapping: Theory and practice on Terrestrial Laser Scanning* (Version 4., p. 241). Leonardo da Vinci (EU) - Community Vocational Training Action Programme. Retrieved from https://lirias.kuleuven.be/bitstream/123456789/201130/2/Leonardo_Tutorial_Final_vers5_ENGLISH.pdf

Ramsey, S. (2007). High Definition Surveying. In *Leica Geosystems: HDS Seminars*.

Riegl. (2012). Riegl VZ-6000. Retrieved February 04, 2013, from http://www.riegl.com/nc/products/terrestrial-scanning/produktdetail/product/scanner/33/

US Department of Labor. (2013). Mine Safety and Health Administration Fatality Statistics. Retrieved February 14, 2013, from http://www.msha.gov/stats/charts/allstates.pdf

Van der Merwe, J. W., & Andersen, D. C. (2012). Applications and Benefits of 3D Laser Scanning for the Mining Industry. In *The Southern African Institute of Mining and Metallurgy Platinum 2012* (pp. 501–518).