AN ABSTRACT OF THE THESIS OF

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Title: The Human Factor in Crime Scene Measurement Accuracy: A Comparison of Four Measuring Devices and Three Crime Scenes

Thesis Chair: Dr. Melissa M. Bailey

Abstract Approved: ______________________________

Measurements in crime scene sketches need to be accurate, as they are used in court and to recreate a scene. The accuracy of devices used in crime scene measurements has been studied; however, there is little research on the amount of measurement variability introduced by the user. This research investigated the average human error along with the accuracy of three different measuring devices. Three mock crime scenes were set up – 2 indoor scenes (with and without furniture) and 1 outdoor scene. Twenty-one volunteers were used to measure 10 predetermined measurements in each of the three scenes using 3 different measuring devices. Volunteers had no previous experience measuring crime scenes and were provided with the same instructions. Each volunteer measured all three scenes. Measurements were taken in the same sequence first using a class 2 measuring tape (a TR Industrial 88016 FX Measuring Wheel™ was used on the outdoor scene), then Bosch GLM 35™ and Leica DISTO 810™ electronic measuring devices. The data from each measurement was averaged for each measuring device within a scene and compared. Angles and the presence of furniture increased measurement variability in indoor scenes. In the outdoor scene, measurements that were

not taken along walls (e.g. from one marker to another) had significant variability. The measuring device used does not appear to have a significant impact on measurement variability when scenes are “easy” to measure but may make a difference in large scenes or scenes with angles or obstacles, particularly in novice investigators.

The Human Factor in Crime Scene Measurement Accuracy:

A Comparison of Four Measuring Devices and Three Crime Scenes

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by

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Table of Contents

		Page
ACKNOWLEDGEMENTS		iii
TABLE OF CONTENTS		iv
LIST OF FIGURES		v
Chapter		
1	Introduction	1
2	Methods and Materials	11
3	Results	26
4	Discussion	33
5	References	38

List of Figures:

Figure 1: Baseline Measuring Method Example

Figure 2: Triangulation Measuring Method Example

Figure 3: Polar/Grid Measuring Method Example

Figure 4: Rectangular Measuring Method Example

Figure 5: Leica P40 3-D Laser Scanner Overhead View of IS1

Figure 6: Indoor Mock Crime Scene 1

Figure 7: Leica P40 3-D Laser Scanner Overhead View of IS2

Figure 8: Indoor Mock Crime Scene 2

Figure 9: Leica P40 3-D Laser Scanner Sideview of OS

Figure 10: Outdoor Mock Crime Scene

Figure 11: Bosch GLM™ Excel Worksheet for IS1

Figure 12: Leica DISTO 810™ Excel Worksheet for IS2

Figure 13 TR Industrial 88016 FX Measuring Wheel™ Excel Worksheet for OS

Figure 14: Indoor Scene 1 Measurements Graph

Figure 15: Indoor Scene 2 Measurements Graph

Figure 16: Outdoor Scene Measurements Graph

Introduction:

Documentation is one of the most important steps in crime scene investigation [1]. The purpose of documentation is to record and preserve the location and relationship of discovered evidence. The most critical step in the process of creating a crime scene diagram is accurately measuring the position of every item of evidence at a scene [2]. The crime scene diagram, created from a crime scene sketch, is used in court to show the condition of the crime scene when the documenter was observing it [1]. The crime scene diagram is a permanent record of the scene and is usually admissible in court. It can be used to assist an interrogation or interview of a person and to corroborate stories. The sketch helps to create a mental picture of the scene for those who were not present at the scene, such as a judge or jury.

There are four different methods that can be used to measure a scene, triangulation, baseline, rectangular, and polar/grid methods [1]. The two most commonly methods used at a crime scene are the triangulation or baseline methods [2]. Before any measurements are taken, the method that will be used needs to be determined. Factors such as weather, size of the scene, reference point availability, personnel availability, and the types of objects in the scene can determine which method should be used. The triangulation method is considered to be the most accurate way to measure a scene, but it can require more people measuring the scene and reference points are needed. Reference points are permanent structures or areas that will not be moved at any time while creating a crime scene sketch. For example, light poles, intersections, and room corners are usable reference points. Crime scene sketches can be drawn from four different views: overhead view, side view, 3-dimentional view, or a combination of the three [1]. Most commonly, scenes are sketched from the overhead view of the scene.

The baseline method is typically used when there are either no suitable reference points or only a limited number of personnel is available to measure the scene [2]. A single reference point is established, usually located at one end of a crime scene. A tape measure is extended from this baseline point across the entire scene to an end point which becomes a second reference point. The end point should be chosen such that all objects are included within the line. Measurements are then made from a point on the tape to an object (center mass) in the scene. This is done at a 90-degree angle to the measuring tape and recorded according to geological location (Figure 1). A major drawback with this method is that significant error can be introduced if objects are at angles other than 90 degrees relative to the tape measure angle.

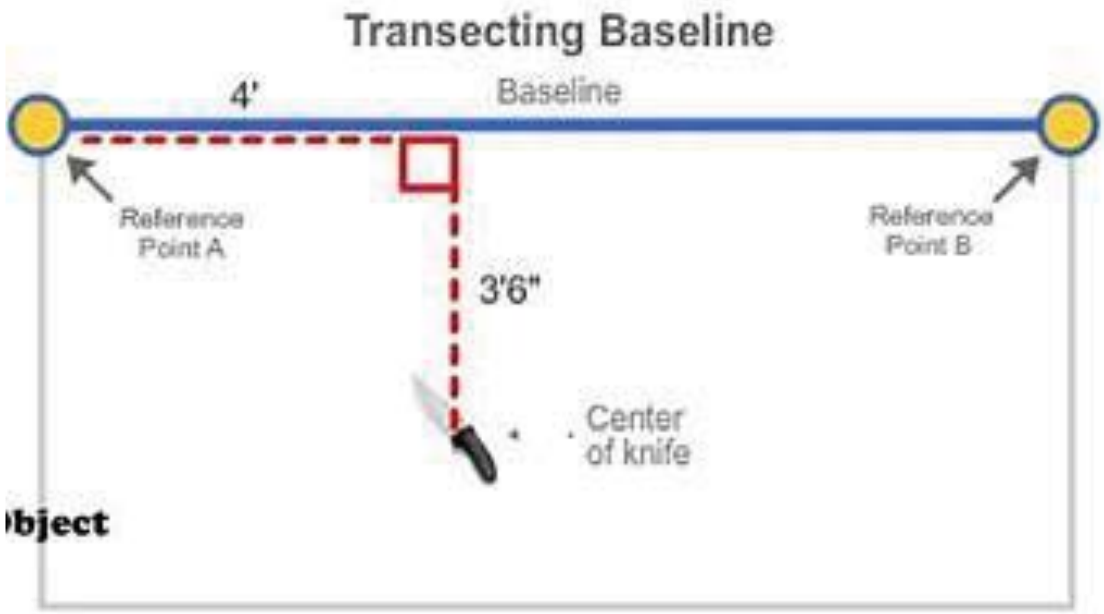

Figure 1

Baseline Measuring Method Example

The triangulation method, generally considered the most accurate method for measuring the relative position of an object within a crime scene, uses 2 or more reference points within a scene to establish positions of objects [2]. A line is drawn to connect two reference points, then a line is extended from each of the reference points to the object being measured, forming a triangle (Figure 2). For example, if measuring to an object there would be a measurement from reference point 1 to the objects center mass, from reference point 2 to the objects center mass, and then a measurement from reference point 1 to reference point 2. While this method is more accurate than the baseline method, it usually requires more than one person (if a tape measure is used) and requires more measurements to be taken.

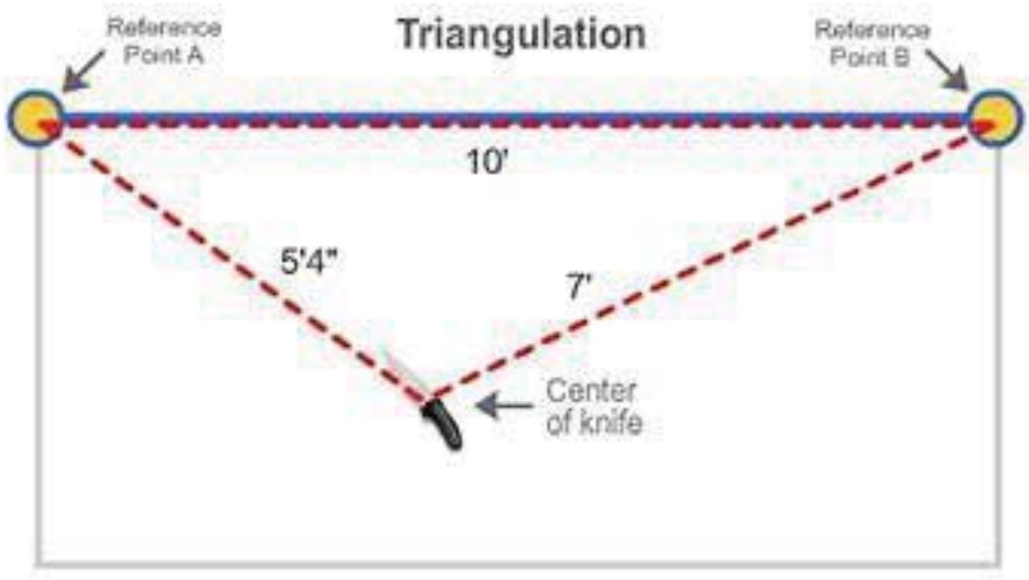

Figure 2

Triangulation Measuring Method Example

The polar/grid method is typically used for very large scenes, such as airplane crashes in fields. This method indicates the location of objects by providing the angle and distance from fixed or known points (Figure 3). The rectangular method is a variation of the baseline method but uses two baselines instead of one. This method is usually used in smaller scenes located in buildings. It is more accurate than the baseline method because it ensures that each object is measured at a 90-degree angle to the baselines used (Figure 4).

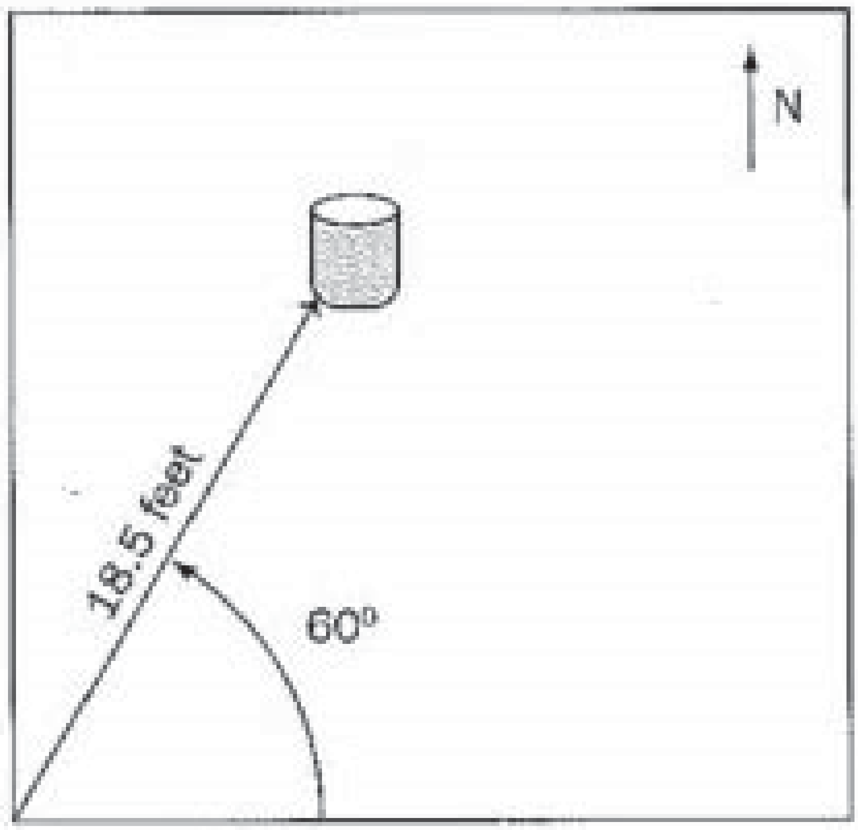

Figure 3

Polar/Grid Measuring Method Example

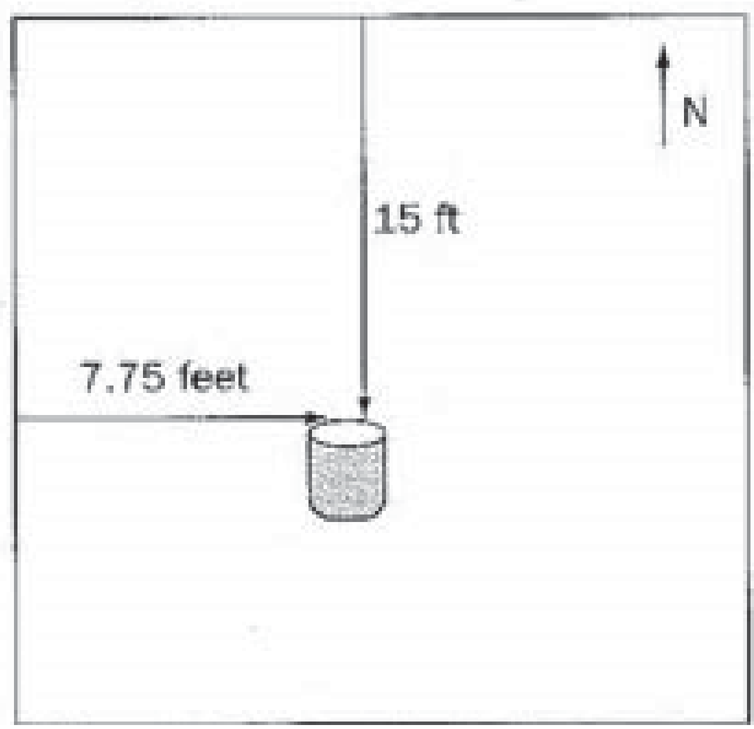

Figure 4

Rectangular Measuring Method Example

While the method of documentation chosen can affect the accuracy of the sketch produced, another variable is the instrument used to take the measurements. There are a wide range of devices available, all of which incorporates varying amounts of technology. Measuring tapes and measuring wheels (for outdoor scenes) are considered manual. Electronic measuring devices are being used commonly now because of their ease of use. These come in a wide range of price ranges and features and can be purchased anywhere from hardware stores to instrument companies. Finally, 3-dimensional laser scanners are used by some departments. These are the most accurate and most technologically advanced devices used in crime scene documentation, but cost considerably more to purchase, operate, and store data than low-tech or no-tech options. Their cost, amount of training required, and data storage and processing requirements often put them out of the reach of smaller departments.

Measuring devices, whether technologically advanced or not, have known accuracy (the closeness of a measured value to a standard value) and precision (the ability to give the same measurement repeatedly). The accuracy of most standard measuring devices is considered adequate for documentation purposes and are typically accepted in the courtroom. However, there is one more source of uncertainty that is not known, and that is the amount of variability introduced by the user of these devices. The way that the device is used is what makes it accurate or not. There are proper ways to use each device and guidelines for device selection, and if the recommended guidelines are not used, error is introduced within the measurements. For example, when a measuring wheel is used it is recommended that a single wheeled tape be used when the ground is not even, while a double wheeled tape is better for paved surface because they roll with more stability. It is also more accurate if a person pulls a double wheel over pushing it, but single wheeled tapes should be pushed, not pulled [3]. When using a measuring tape, it is important to make sure that the tape is flat and stretched as tight as possible or error can be introduced into the measurement. Even options such as 3D laser scanners are not exempt from human error. While much of the "human factor" has been removed in the measurement with these instruments, they are not easy to operate, and the usefulness of the data gathered is still only as good as the operator using the scanner.

While the accuracy and often precision of a particular device is usually known, the amount of variability or error introduced by the human operator has never been thoroughly investigated. The purpose of this research project is to investigate the amount of variability introduced into measurements taken by volunteers given standardized training, measuring the same scenes, and using the same devices and documentation methods.

Methods and Materials:

Mock Crime Scenes

A total of three mock crime scenes were set up. There were two indoor crime scenes and one outdoor crime scene. The two indoor scenes were located on the fourth floor of Morse Hall at Emporia State University. The outdoor scene was located outside Morse Hall at Emporia State University. Each scene had 5 evidence representations, requiring a total of 10 measurements to be made.

In each of the indoor scenes, the Xs (representing evidence to be measured [EX]) were marked on the floor with black electrical tape. At the center of each EX, a pink dot was placed. Each X was randomly placed, but points were chosen so that they required equivalent skillsets in each scene (e.g. long-distance measurement, short distance measurement, angled measurement). An evidence marker was placed next to each EX. The boundaries of each mock scene were marked with evidence tape. Each scene had 3 immovable walls, with the 4th wall being represented by the evidence tape boundary with a concrete pillar. On each of the three immovable walls and the pillar, an X was placed in the center of the wall above the floor and marked with center pink dots in the same manner as the EXs. These Xs gave specific reference points (RX) and volunteers were told to measure from these points to each piece of "evidence." Both the EX and RX points were assigned numbers.

In indoor scene 1 (IS1), no furniture or other obstacles were present (Figure 5-6). Indoor scene 2 (IS2) (Figure 7-8), was set up the same way as IS1, with 5 EXs and 4

RXs. A couch, larger chair, table, and two smaller chairs were added to IS2 so that obstacles were present, introducing a level of difficulty in collecting the measurements.

Figure 5

Leica P40 3-D Laser Scanner Overhead View of IS1

Figure 6

Indoor Mock Crime Scene 1

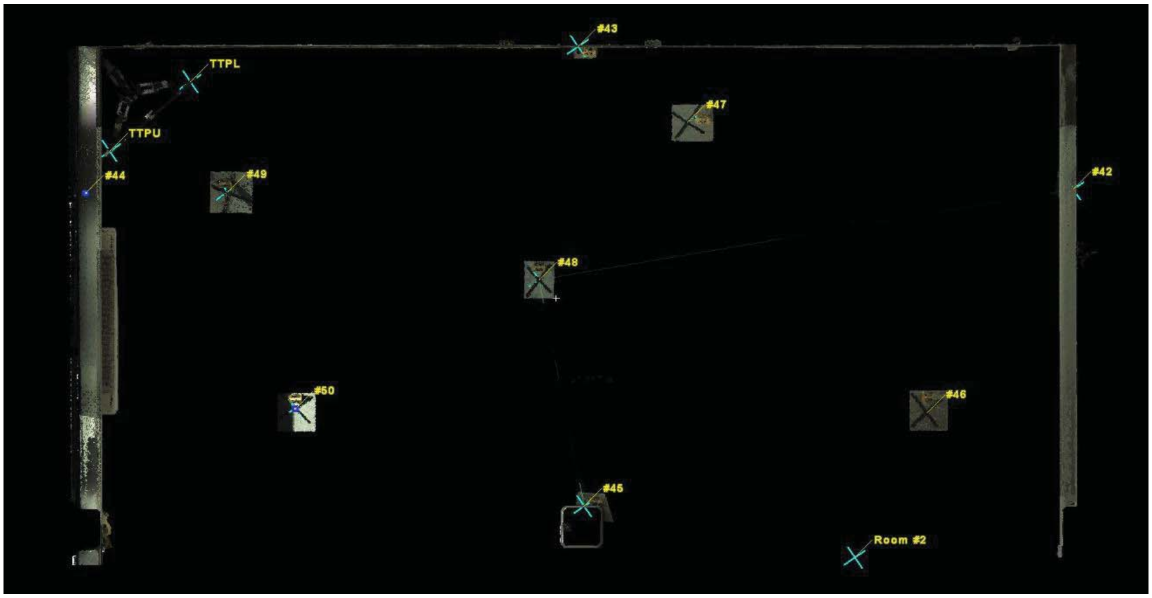

Figure 7

Leica P40 3-D Laser Scanner Overhead View of IS2

Figure 8

Indoor Mock Crime Scene 2

The third scene set up was an outdoor scene (OS) (Figure 9-10). For this scene 2 x 2 wooden stakes were placed into the ground leaving approximately 1 ft of the stake above ground. A nail was hammered into the top of the stake so that approximately 2 inches of the nail was above the stake. The top of the nail was painted pink. The top of the wooden stakes were labeled 1, 2, 3, R1, and R2. The 1, 2, and 3 were to represent pieces of evidence and the R1 and R2 were used as reference points. The outdoor scene also used the walls of the building surrounding the scene as reference points for the placement of the stakes, which had to be removed periodically due to grounds keeping. When the stakes were removed for the first-time orange spray paint was used on the ground to mark the spots of the stakes.

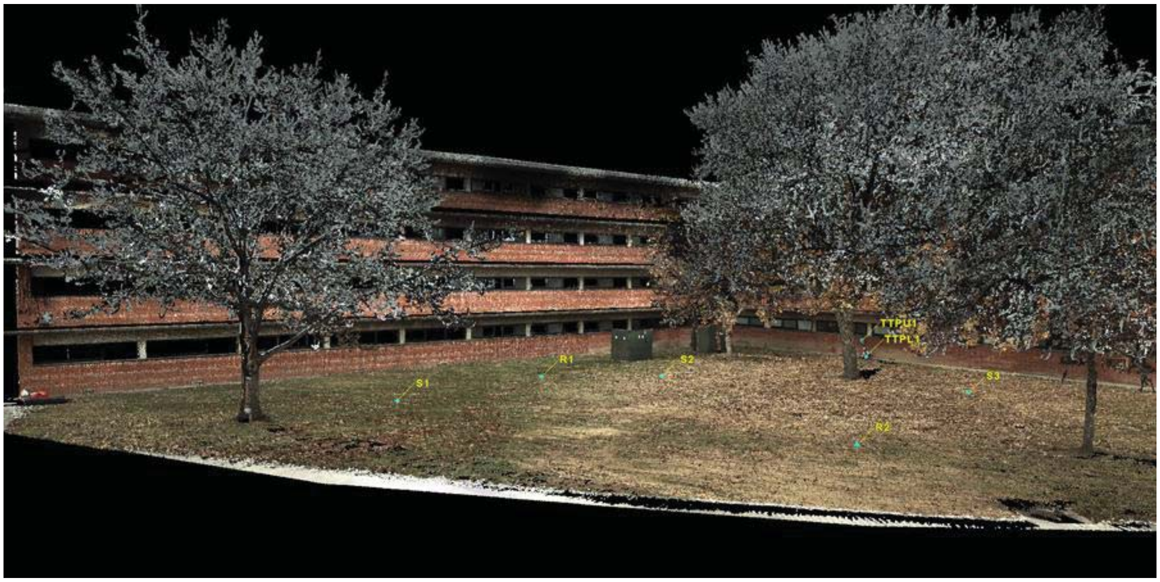

Figure 9

Leica P40 3-D Laser Scanner Sideview of the OS

Figure 10

Outdoor Mock Crime Scene

Documentation

An Excel worksheet was prepared for each participant to fill out with their measurements for each of the crime scenes. Figures 11-13, show examples of the worksheets for IS1, IS2, and OS, respectively. There was one worksheet for each measuring device used for each crime scene.

Name:
Room 1: No Obstacles

Each measurement will be made from the center of the X. The walls are also marked with small X's to show where to measure too. Measure from the evidence to the wall listed below. Measurements will be in feet.

Bosch Electronic				
Evidence #	Wall #	Measurement(ft)	Wall #	Measurement (ft)
37	33		32	
38	36		32	
39	36		32	
40	33		34	
41	33		34	

Figure 11

Bosch GLM 35™ Excel Worksheet for Indoor Scene 1

Name:

Room 2: Obstacles.

Each measurement will be made from the center of the X. The walls are also marked with small X's to show where to measure too. Measure from the evidence to the wall listed below. Measurements will be in feet.

Leica Electronic				
Evidence #	Wall #	Measurement(ft)	Wall #	Measurement (ft)
46	42		43	
47	42		45	
48	42		45	
49	44		45	
50	43		44	

Figure 12

Leica DISTO 810^{TM} Excel Worksheet for Indoor Scene 2

Name: Wheel

S=stake R=reference stake

S1 to R1= S1 to R2=

S2 to R1= S2 to R2=

S3 to R1= S3 to R2=

Long wall=

Short wall=

End long wall to inside first panel=

Length first 3 windows long wall=

Figure 13

TR Industrial 88016 FX Measuring Wheel™ Excel Worksheet for the Outdoor Scene

Measurement Procedures

A total of 21 people from Emporia State University participated in this research project. Instructions on how to properly use each measuring device were given to each member that was doing the measuring before each device was used. When the measuring tape was used, a single person, the author, held the "non-measuring" end of the tape each time to avoid introducing unnecessary variability. The author was also present each time that a scene was measured to ensure that the scenes and points within a scene were measured in the same order.

Each indoor scene was measured by a class II measuring tape first, followed by a Bosch GLM 35™ electronic measuring device, and lastly by a Leica DISTO 810™ electronic measuring device. In the outdoor scene, a TR Industrial 88016 FX Series Collapsible Measuring Wheel™ was used in place of the class II measuring tape. This was used first, followed by the two electronic measuring devices as with the indoor scenes. If a subject appeared to not be using a device correctly, they were given remedial instructions. Care was also taken to ensure that the laser beam was, in fact, hitting the intended target, and not the floor. If a measurement was taken and it seemed the intended target was not hit (it reflected off the floor), the person was able to repeat that measurement. If any points did not seem to be done correctly and were not caught during the measuring process that data was removed from the project.

Measurement Standard

A P40 Leica Laser Scanner was used by Ryan Rezzelle, an expert in laser scanning measurements, to document and measure each scene. These measurements were used as the standard measurements for each crime scene and all data collected by the participants were compared to these measurements.

Statistical Analysis:

Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) software. Each measurement was analyzed individually using one-way ANOVA and LSD post-hoc tests to determine specific significant differences. The measuring device was treated as the unit of analysis, with the variability of measurements taken with a particular device as an indication of the amount of user variability introduced.

Results:

When looking at IS1 there was only one measurement that differed significantly among the three different measuring devices used to measure the scene. Measuring from evidence number 41 to wall number 34, the three devices used were significantly different with a p-value of 0.003. The Bosch GLM 35™ significantly differed from the measuring tape, and the Leica DISTO 810™ significantly differed from the measuring tape. The Bosch GLM 35™ and Leica DISTO 810™ did not significantly differ from one another. Measurement 41 to 34 involved a tight angle to the measurement. The Leica P40 measurements (measurement standard) fell within the range of measurements given by the three devices and do not appear to be significantly different (Figure 14).

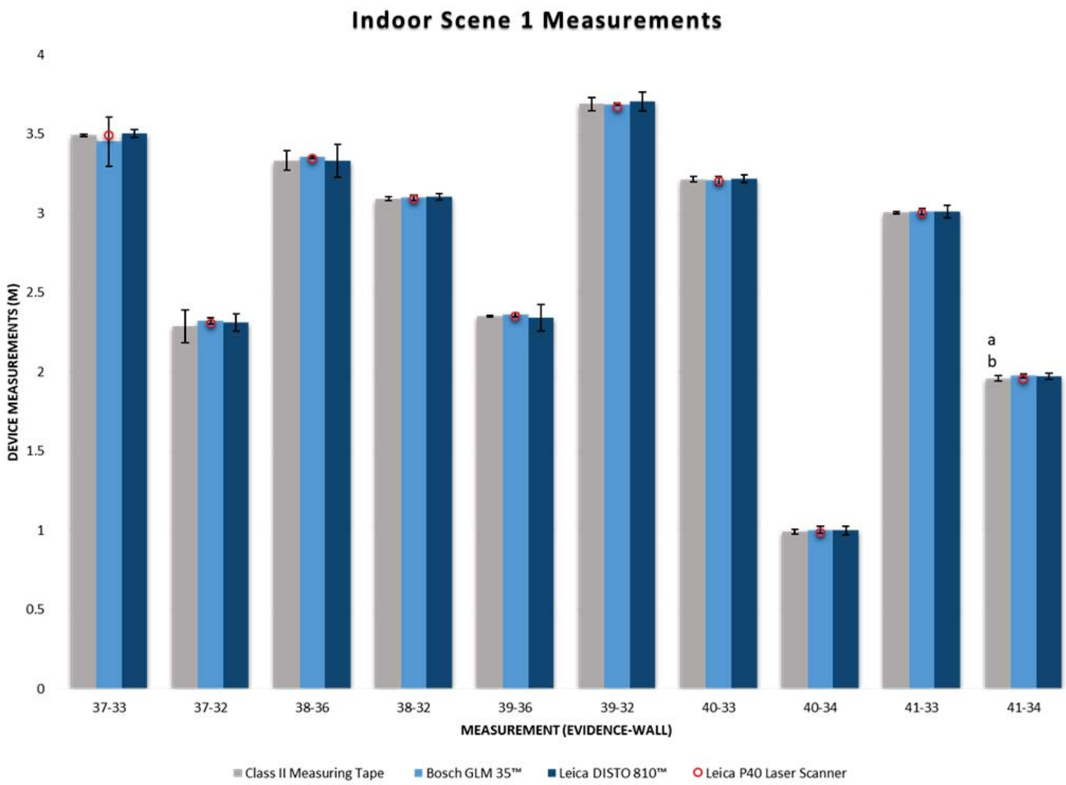

Figure 14

Average device measurement for each measurement using a Class II Measuring Tape, Bosch GLM 35™, and Leica DISTO 810™. The standard measurement made by the Leica P40 Laser Scanner is also shown. [a]Differs significantly from Bosch GLM 35™ ($P<0.05$), and [b]differs significantly from Leica DISTO 810™ ($P<0.05$).

The addition of obstacles did not appear to introduce additional error. When looking at IS2 there was only one measurement that significantly differed among the three measuring devices. Measuring from evidence number 47 to wall number 42, the measuring devices were significantly different with a p-value of 0.004. Again, the Bosch GLM 35™ differed significantly from the measuring tape, and the Leica DISTO 810™ differed significantly from the measuring tape. The Bosch GLM 35™ and Leica DISTO 810™ did not significantly differ from one another. Measurement 47 to 42 was one of the measurements involving an obstacle. The subject taking the measurement could not measure on the floor; instead, they had to hold the device and measure above a couch that was between the evidence being measured from and the wall being measured to. The Leica P40 measurements (measurement standard) fell within the range of measurements given by the three devices and do not appear to be significantly different (Figure 15).

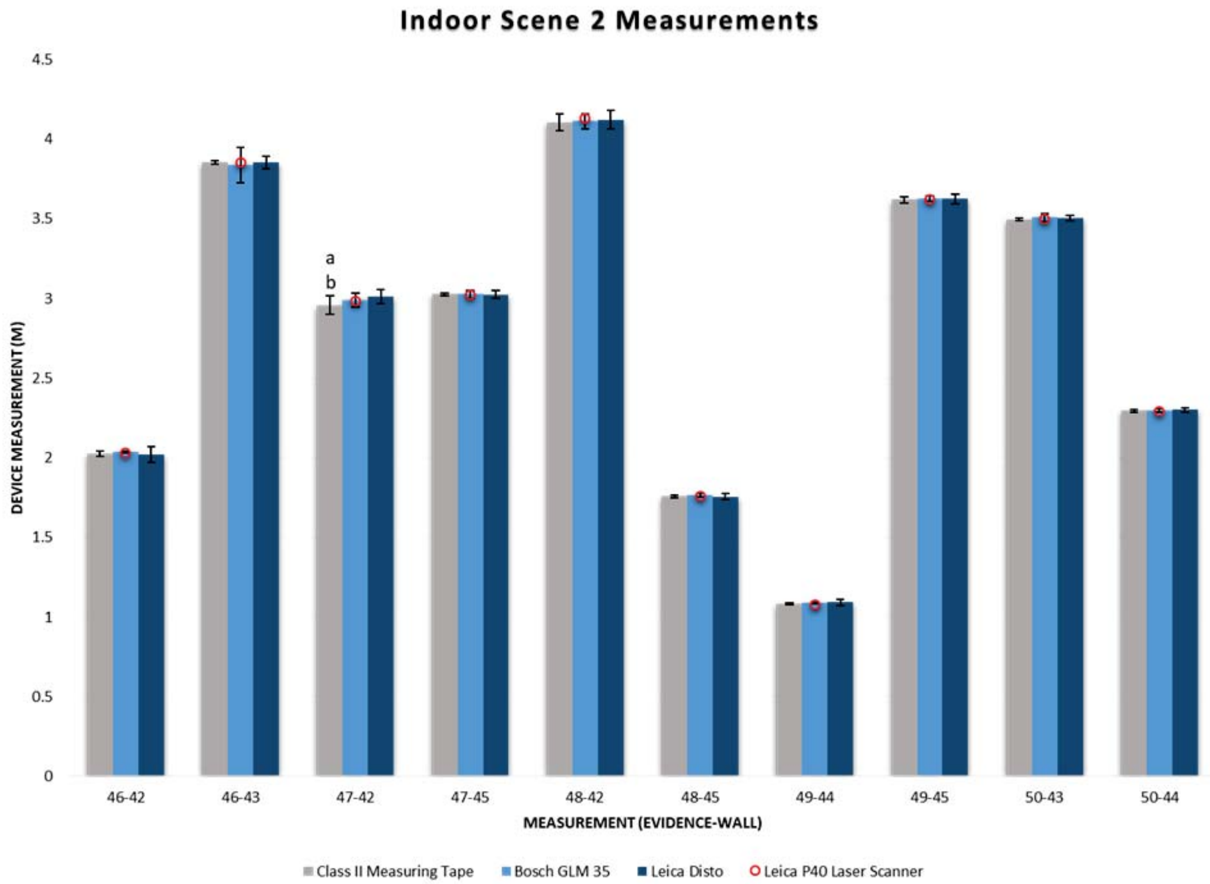

Figure 15

Average device measurement for each measurement using a Class II Measuring Tape, Bosch GLM 35™, and Leica DISTO 810™. The standard measurement made by the Leica P40 Laser Scanner is also shown. [a]Differs significantly from Bosch GLM 35™ ($P<0.05$), and [b]differs significantly from Leica DISTO 810™ ($P<0.05$).

The OS involved much larger measurements and introduced significant variability in the measurements taken. There were 5 different measurements that differed significantly among the three measuring devices used. Measuring from Stake 1 to Reference Stake 1 there was a significant difference among the three devices used with a p-value of 0.046, with the TR Industrial 88016 FX Measuring Wheel™ measurements being significantly different from the Bosch GLM 35™. The Bosch GLM 35™ to Leica DISTO 810™and the Leica DISTO 810™ to the TR Industrial 88016 FX Measuring Wheel™ did not significantly differ from one another. Measuring from Stake 1 to Reference Stake 2, there was a significant difference among the three measuring devices with a p-value of less than 0.001. The Bosch GLM 35™ significantly differed from the measuring wheel, and the Leica DISTO 810™ measuring device significantly differed from the measuring wheel. The Bosch GLM 35™ and Leica DISTO 810™ did not differ significantly from one another. Measuring from Stake 2 to Reference Stake 2, there was a significant difference among the measuring devices with a p-value of 0.017. The Bosch GLM 35™ significantly differed from the measuring wheel. The Bosch GLM 35™ to Leica DISTO 810™ and the Leica DISTO 810™ to the TR Industrial 88016 FX Measuring Wheel™ did not significantly differ from one another. Measuring from Stake 3 to Reference Stake 1, there was a significant difference among the measuring devices with a p-value of less than 0.001. The Bosch GLM 35™ significantly differed from the measuring wheel, and the Leica DISTO 810™ significantly differed from the measuring wheel. The Bosch GLM 35™ and Leica DISTO 810™ did not differ significantly from one another. Measuring from Stake 3 to Reference Stake 2, there was a significant difference among the measuring devices with a p-value of 0.003. The Bosch GLM 35™

significantly differed from the measuring wheel, and the Leica DISTO 810^{TM} significantly differed from the measuring wheel. The Bosch GLM 35^{TM} and Leica DISTO 810^{TM} did not differ significantly from one another. Out of the six stake measurements used only one did not have any significant difference among the devices used to measure the scene. The one measurement that did not differ significantly was a short distance to measure compared to the rest of the stake measurements. None of the wall measurements significantly differed from one device to another. By eye the Leica P40 measurements (standard measurements) do not seem to differ significantly when compared to the average measurements of each device (figure 16).

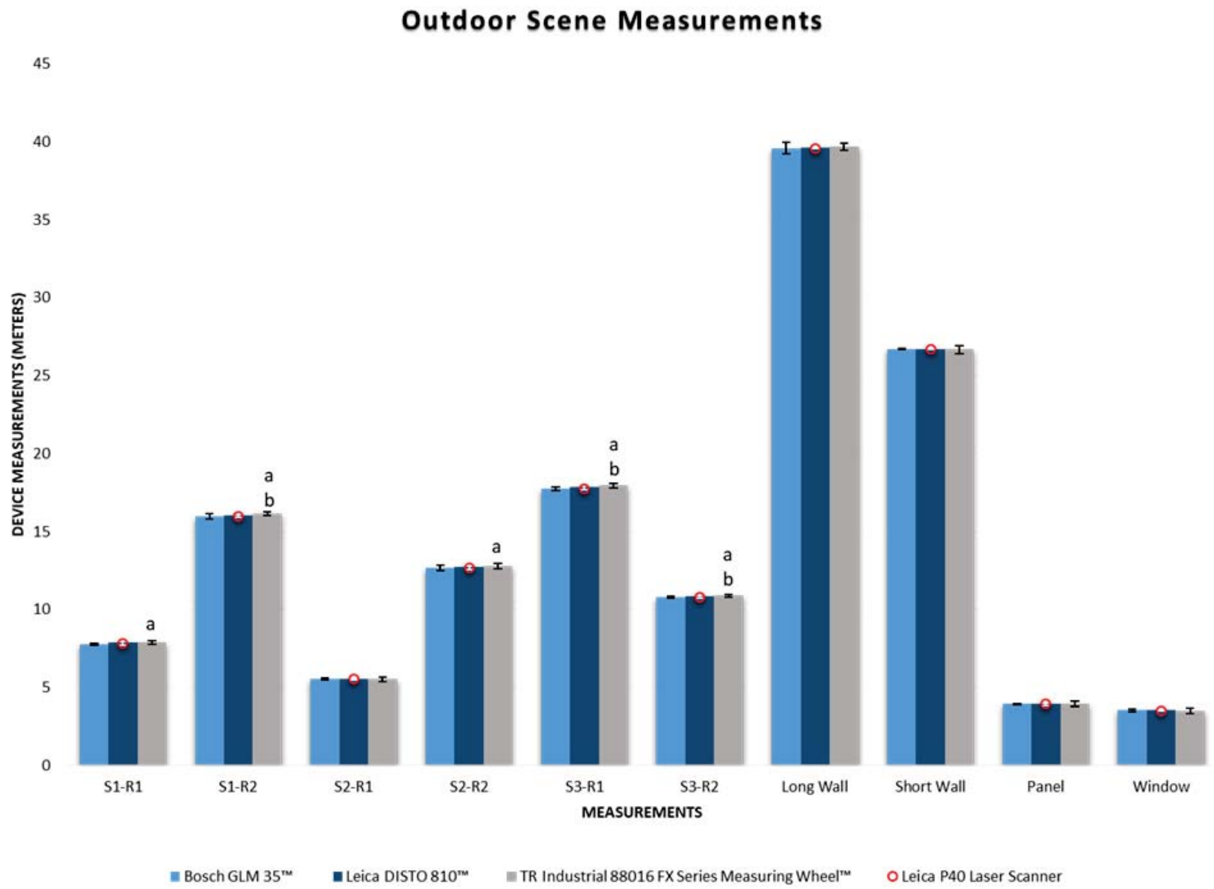

Figure 16

The bars show the average device measurement for each measurement using a Bosch GLM 35™, Leica DISTO 810™, and TR Industrial 88016 FX Series Measuring Wheel. The standard measurement made by the Leica P40 Laser Scanner is also shown. [a]Differs significantly from Bosch GLM 35™ ($P<0.05$), and [b]differs significantly from Leica DISTO 810™ ($P<0.05$).

DISCUSSION

The results of this research project brought to light several sources of error when measuring crime scenes: angled measurements, surface unevenness (particularly when using electronic measuring devices), and very large measurements. Measurement 41 to wall number 34 was significantly different among the devices because of the angle of the measurement or the unevenness of the floor. The angle made it harder to measure this measurement, to hit perfectly on the pink dot on the X. The floors in the indoor mock scenes were also not even, forcing the volunteers to hold the electronic devices slightly off the ground to hit the wall without reflecting off the floor. This made lining up the device with the pink dot on the evidence EX and hitting the pink dot on the wall X more challenging.

On IS2 measuring from evidence number 47 to wall number 42 was significantly different, likely due to the measurement having to go around an obstacle. This measurement required the subject to go through a couch located between the evidence EX and the wall X. The subject had to hold the device by hand and attempt to stay still enough to get the measurement. The placement of the device over the pink dot was done by eye, so it is possible one subject measured from a slightly different starting point then another subject, given differences in volunteer height or body position. Obstacles such as furniture are commonly encountered at crime scenes and may have to be measured around if moving them is not recommended or possible. Interestingly, measurement 48-42 also involved accommodating an obstacle, but there was no significant difference among the measurements. In comparing the data from IS1 and IS2, the presence of furniture in the scene did not appear have an effect on the amount of human error associated with the measuring devices. Each of the scenes only had one measurement that was significantly different among the measuring devices.

The OS there involved several measurements that were significantly different as shown in figure 16. All measurements involving stakes, except measurement from Stake 2 to Reference Stake 1, were significantly different among the three devices used to measure the scene. This may not be a reflection of the ease of use of one device over another or of user error. The stakes had to be removed and placed back between subjects measuring due to grounds keeping, and although every effort was made to place them back in the same location, this may have introduced significant variability. If there was not error introduced moving the stakes, it is possible the angles at which subjects measured could have been different. When using the measuring wheel, going from one evidence stake to a reference stake, the same path might not have been followed between subjects. For example, one person could have gone in a perfect straight line from the evidence stake to the reference stake and another person might have curved slightly on the walk to the reference stake. This resembles an actual outdoor crime scene and is a reason a measuring wheel is not considered to be the most accurate device to measure a scene.

When examining the measurements located along the walls surrounding the OS, there was no significant difference among the three devices used to measure the scene. This further supports the idea that removing the stakes or having the angles within the stake measurements could be a possibility. The wall could not be moved or the points measuring from and to could not be moved. The measurements located along the wall, including the long wall, short wall, panel, and window measurements, could be used to follow in a straight line from one point to the other. This removes the angles that are present within the stake measurements.

No significant difference was found between the Bosch GLM 35^{TM} and the Leica DISTO 810^{TM} in any of the measurements, meaning that users were able to take measurements that had a large degree of precision despite notable differences in features between the two products. Qualitatively, volunteers felt that the Leica DISTO 810^{TM} was easier to use because the camera (not available on the Bosch GLM 35^{TM}) was a useful feature that allowed them to better see what the laser was hitting. The fact that the Leica DISTO 810^{TM} also measured longer distances caused it to rank higher among volunteers, especially when the devices were used to measure the outdoor scene. Volunteers also gathered measurements faster with the Leica DISTO 810^{TM} than when using the Bosch GLM 35^{TM}; however, the Leica DISTO 810^{TM} was always used after the Bosch GLM 35^{TM} for measurements, so the experience gained first on the Bosch device may have impacted the Leica time. While the Leica device had several features that the volunteers found valuable, it is approximately 10 times more expensive than a standard device that can be purchased at a hardware store like the Bosch GLM 35^{TM}. If the Leica DISTO 810^{TM} was cost prohibitive for a department, this research has shown that cheaper electronic alternatives are viable solutions. The two devices have the same accuracy, (+/-) 1.5875mm [4] [5], and in this study, the human error rate was not significantly different between the two devices for any of the measurements taken.

In all three crime scenes there was at least one measurement in which the class II measuring tape or TR Industrial 88016 FX Measuring Wheel™ differed significantly from the Bosch GLM 35^{TM} and/or the Leica DISTO 810^{TM}. There was more human error associated with the class II measuring tape and the TR Industrial 88016 FX Measuring Wheel™ then with the Bosch GLM 35™ and Leica DISTO 810™. It is easier and quicker to use an electronic device over using a measuring tape, but it is quicker and easier to use a measuring wheel over an electronic measuring device. Measuring wheels are widely used today in outdoor scenes because they are quick and easy to use, but this research shows an electronic measuring device is more accurate and has less human error associated with it. The stated accuracy of the TR Industrial 88016 FX Series Measuring Wheel is (+/-) 3 inches at 100 feet [6]. The Bosch GLM 35™ and the Leica DISTO 810™ both had an accuracy of (+/-) 1.5875mm [4][5]. Since there was more error in the wheel, it would be better to measure with an electronic device over a measuring wheel.

If this research was done again there are a few things that should be changed. The two indoor scenes would be changed to an area with level floors. For IS2 a tripod could be available to use to get around obstacles. The outdoor scene would be changed to a place where the stakes did not need to be removed or all volunteers would measure on the same day, so there would not be any movement of the stakes between subjects. There was a possible source of error using the Leica P40 Laser Scanner. When taking measurements there are so many different points to choose from, such as when picking a point on the stakes for the OS there is hundreds of points to choose from located on the top of the stake. Based on visual inspection the point chosen was the one that appeared to be the center of the top of the stake. This was also the case for the indoor scenes. The pink dot on the X still had many points to choose from. For this, two small lines were drawn on the X on the scanning device and where those two lines intercept that was the point chosen. Next time it would be better to have smaller points to specify where to measure from and to.

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