

Validating Google Earth Pro as a Scientific Utility for Use in Accident Reconstruction

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ABSTRACT

With the prevalence of satellite imagery in the analysis of collision events growing in the field of accident reconstruction, this research aims to quantify, refine, and compare the accuracies of measurements obtained utilizing conventional instruments to the measurements obtained using Google Earth Pro software. Researchers documented and obtained 1305 unique measurements from 68 locations in 25 states and provinces in the United States, Canada, and Australia using measuring wheels and tape measures. Measurements of relevant features at each location (crosswalks, curved roadways, off-road features, etc.) were documented and subdivided into three groups: On-Road, Off-Road, and Curved Path measurements. These measurements were compared to the measurements obtained of the same features from current and historical satellite imagery within Google Earth Pro. The accuracy of the relative measurements was divided into distance-based subsets within the three groups; for example, the error of measurements ranging from 0 - 12 feet to over 1000 feet both On- and Off-road were quantified and compared. These comparisons established the rate of error for each distance-based subset for the On-Road, Off-Road, and Curved Path measurement groupings taken from Google Earth Pro versus conventionally-obtained measurements.

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INTRODUCTION

The ability to accurately measure specific distances of varying lengths with a known error rate is important in any survey-based application; specifically, this measurement ability is foundational in the field of accident reconstruction. Lengths and widths of crosswalks, visual sightline obstructions, eyewitness locations relative to fixed objects, and the distance a vehicle traveled from the point of impact to the point of final rest are all important measurements that are quantified in accident reconstruction analyses.

Google Earth (Google Inc., Mountain View, CA), released in 2005, is a satellite imagery-based mapping service that has gained widespread use in the field of accident reconstruction. The software creates a virtual globe by combining several different file formats and imaging methods including aerial photography, satellite imagery, and geographic information system (GIS) technology. Google Earth Pro is a feature-rich version of the Google Earth software and includes advanced measurement tools as well as other features for commercial use of the program.

Within the field of accident reconstruction, the utilization of satellite imagery within Google Earth Pro is gaining relevance as a scientific utility for acquiring case-specific measurements. Google Earth Pro often provides clear images of sites that are either difficult to access or have been altered since the date of the accident being analyzed. As intersections, painted lane delineations, and other roadway features are constantly changing, the historical imaging feature of Google

Earth Pro is sometimes the only way to accurately depict a collision site's condition at the time of the accident being studied. In addition, using Google Earth Pro to take case-specific measurements of the subject intersection can be more cost efficient than conventional methods and can limit unnecessary travel.

The images in the Google Earth Pro software are constantly updating. Both the image quality and accuracy of measurements taken from Google Earth Pro, however, can vary from one location to another. The best image quality is found in highly populated areas and important landmarks. Although some urban locations are cited to have as high as sub-meter resolution, there is no single measure of image or measurement accuracy listed by Google.

Previous literature attempted to quantify the rate of error of using programs such as Google Earth Pro as a measurement technique. A 2013 study focused on the positional accuracy of Google Earth. The study used a Trimble 1800 surveying GPS receiver to compare measured coordinates to those provided on Google Earth. The researchers concluded that Google Earth provided sufficient accuracy to be used to derive planimetric and topographical maps [1]. A similar study from 2014 used LEICA-SR530 GPS equipment to measure latitudinal and longitudinal coordinates. This research compared these coordinates with those provided on Google Earth and concluded that the program is a reasonable tool to use in the production of contour maps with a 1:50,000 or smaller scale.

A 2015 SAE paper assessed Google Earth Pro's accuracy as a tool for accident reconstruction [3]. The researchers compared 114 measurements of roadway features taken with Google Earth Pro with those taken on Total Station survey equipment of previously-documented collision sites. This research concluded that Google Earth Pro is an effective tool for obtaining measurements relied upon for accident reconstruction, but their conclusions were limited to On-Road areas of paved roadways and adjacent shoulders. Of the 114 total measurements, 54 were less than 25 feet and the largest measurement distance was 547.570 feet. There were only 16 measurements taken over 100 feet (Table 1).

Table 1. Results from SAE 2015-01-1435.

Measurement (ft)	Number of Measurements	RMSE (ft)	Average % Difference
5 to 25	54	0.227	1.23%
25 to 50	19	0.580	1.39%
50 to 75	17	0.405	0.48%
75 to 100	8	0.530	0.50%
Over 100	16	1.192	0.70%

This research aims to expand and improve upon the work of these previous studies. By utilizing a larger sampling of measurements taken from Google Earth Pro that considers different distance ranges, locations, curved path measurements, and relevant on- and off-road features, this paper will quantify the rate of error from measurements taken with Google Earth Pro compared to conventional instruments, and validate Google Earth Pro's scientific utility as a tool in accident reconstruction over short- and long-distances.

METHODOLOGY

To thoroughly quantify the accuracy of measurements taken from Google Earth Pro, measurements from Google Earth Pro were compared to measurements taken from 68 unique locations across 25 North American and Australian states and provinces: Arizona, California, Colorado, Connecticut, Delaware, Florida, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Nevada, North Carolina, Ohio, Ontario, Oregon, Pennsylvania, Rhode Island, New South Wales, Victoria, Virginia, Utah, and Washington. Specific relevant roadway features such as on-road crosswalks, curved paths on roadways, and off-road measurements were focused on and highlighted for individual analysis.

Each measurement was taken from Google Earth Pro version 7.1.5.1557 using the 'Line' and 'Path' functions of the ruler feature within the program. The ground-length measurement, which takes into account elevation changes of the terrain, was used as opposed to the map-length measurement within the software. Each Google Earth Pro measurement was saved digitally as an image with the measurement (straight-line or curved sequential path) clearly shown as a yellow line with a highlighted beginning and endpoint(s). In addition, the ruler feature displaying the measured distance was saved in the image. Researchers zoomed, tilted, and rotated the images as

necessary to clearly display each measurement's start and end location. The '3D Buildings' layer was also utilized when necessary to clearly display the best perspective of the measurement of interest.

Measurements were taken in feet for consistency, but other units, including metric units, are available within the software. The historical imagery feature was used as necessary for locations that were either modified since the time of the physical measurements or contained poor image quality in the most recent imagery. Each location was marked and saved in the 'My Places' section of Google Earth Pro to ensure the ability to easily revisit the specific location if needed.

Due to the number of measurements obtained, and the magnitude of the distances acquired, measuring wheels were utilized to collect data for the majority of the comparisons with the measurements obtained from Google Earth Pro. Utilization of a measuring wheel is an accepted analog method of acquiring large measurements in land surveying and accident reconstruction as it is efficient, accurate, and can be used for a broad range of distances [4, 5]. The measuring wheel senses fractional increments of a revolution, and based on the diameter of the wheel, converts this into the linear distance that the wheel was rolled. Approximately one percent of the data collected utilized a standard 25-foot steel tape measure.

Although the use of measuring wheels as the primary instrument for documenting physical evidence at scenes has declined with the rise of more precise digital acquisition methods, i.e. laser scanning and total station data, they are still used in the field of accident reconstruction for acquiring both short- and long-distance measurements. Whether it be the simplicity and immediacy of rolling a 300-foot measurement of a witnesses perspective to the area of impact, the relative ease of traveling with a measuring wheel compared to a laser scanner, tripod, and spheres for travel purposes, or a case which only requires a singular measurement compared to fully digitizing a 500-foot scene into a project point cloud, measuring wheels are still utilized in the field of accident reconstruction for analyses. Their use in this research was for all of the reasons stated above. Specifically, measuring wheels provided the ability to acquire geographically-diverse measurements quickly and accurately in order to quantify the accuracy of the available imagery in Google Earth Pro.

Each measurement was rolled between two unique objects or roadway features that were either relevant to the field of accident reconstruction or easy to locate within Google Earth Pro. Some of these objects and roadway features included light posts, street signs, crack seals, off-road fixed objects, crosswalks, roadway edges, fog lines, and lane lines. Researchers took a series of photographs for each specific measurement; an overall, beginning, end, and documentation perspective of each measurement was taken where applicable. This methodology ensured that the beginning and end points of each measurement would be consistent with the measurement obtained from Google Earth Pro. The measuring wheels used in this research displayed distance in feet and inches; researchers converted the measurements into feet to the hundredth of a foot. Some of the different measuring wheels utilized included the Lufkin Pro Series PSMW48, Trumeter 5505E, Tooltyme 01594L, Lufkin Pro Series PSMW18N, Calculated Industries Wheel Master Pro, Lufkin

Pro Series PSMW28, TR Industrial 88016 FX Series, and the Lufkin Pro Series PSMW18. Twelve researchers participated in the collection and processing of measurements and data.

The accuracy of each of the measuring wheels utilized in this research was verified through the use of a 25-foot steel tape. In addition, the two most-utilized measuring wheels, the Lufkin Pro Series PSMW48 and Calculated Industries Wheel Master Pro, were measured against a known fixed distance on a 100-meter (328.08 feet) track. For example, the Lufkin Pro Series PSMW48 measured 329.33 feet over this distance for a rate of error of 0.38%; similarly, the Calculated Industries Wheel Master Pro PSMW48 measured 329.0 feet over this distance for a rate of error of 0.28%. The measurements of the 100-meter track were repeated with the two previously-mentioned measuring wheels yielding consistent results and error rates.

A rolled measurement was accepted even when it was affected by a small rock, ditch, or any other imperfection in the roadway, as these were considered as part of the error of the measuring wheel technique and are commonly seen in the field. If an abnormal imperfection during the roll affected a measurement, however, the researcher rerolled the measurement, and avoided the disturbance when possible. If a measurement was physically obstructed by a vehicle or other object, it was omitted from the research as a proper comparison could not be made.

Figures 1, 2, 3, 4 represent the overall, beginning, end, and documentation photographs for a measurement taken at the intersection of George Washington Highway and Victory Boulevard in Portsmouth, Virginia. The measurement was obtained using the Lufkin Pro Series PSMW48 measuring wheel and the measurement was recorded as 124.79 feet.

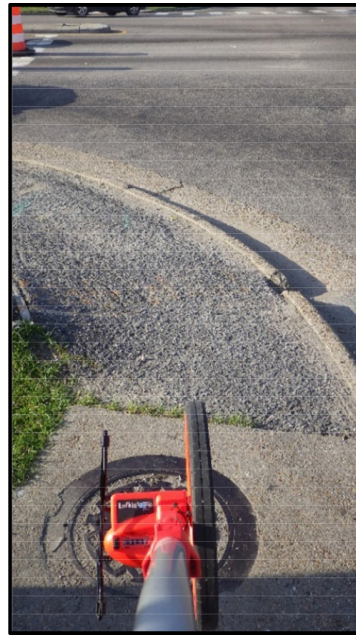


Figure 2. Beginning perspective depicting the starting reference point for the measurement.



Figure 3. End perspective depicting the reference point for the end of the measurement.



Figure 1. Overall perspective depicting the intended direction of the measurement by the researcher.



Figure 4. Documentation perspective depicting the length of the rolled measurement.

Figure 5 is a screen capture of the measurement obtained from Google Earth Pro of the measurement documented in Figures 1, 2, 3, 4 at the intersection of George Washington Highway and Victory Boulevard in Portsmouth, Virginia. It shows the on-road straight-line that was measured to be 124.62 feet in the Google Earth Pro software utilizing the '3D Buildings' layer and a zoomed, tilted, and rotated perspective. The methodology documented in Figures 1, 2, 3, 4, 5 was utilized for obtaining on- and off-road straight-line measurements within Google Earth Pro.

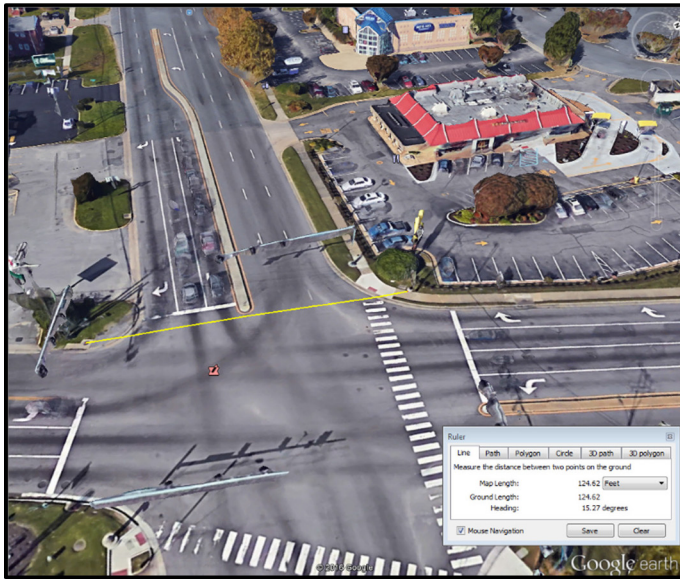


Figure 5. Google Earth Pro image and corresponding measurement of the intersection in Portsmouth, Virginia.

For curved measurements, a best-fit approach was taken in the Google Earth Pro software to match the beginning, arc, and endpoint of the curved measurement to the measurement that was obtained using the measuring wheel. Figures 6, 7, 8, 9 represent the overall, beginning, end, and documentation photographs for a curved measurement taken at the Floral Clock in Ontario, Canada. The measurement was obtained using the Lufkin Pro Series PSMW18N measuring wheel and the measurement was recorded as 21.79 feet.



Figure 6. Overall perspective depicting the intended direction of the curved measurement by the researcher.



Figure 7. Beginning perspective depicting the starting reference point for the curved measurement.



Figure 8. End perspective depicting the reference point for the end of the curved measurement.



Figure 9. Documentation perspective depicting the length of the rolled curved measurement.

Figure 10 is a screen capture of the measurement obtained from Google Earth Pro of the curved measurement documented in Figures 6, 7, 8, 9 at the Floral Clock in Ontario, Canada. It shows the curved path that was measured to be 21.40 feet in the Google Earth Pro software utilizing the '3D Buildings' layer and a zoomed, tilted, and

rotated perspective. The methodology documented in Figures 6, 7, 8, 9, 10 was utilized for obtaining curved-path measurements within Google Earth Pro.

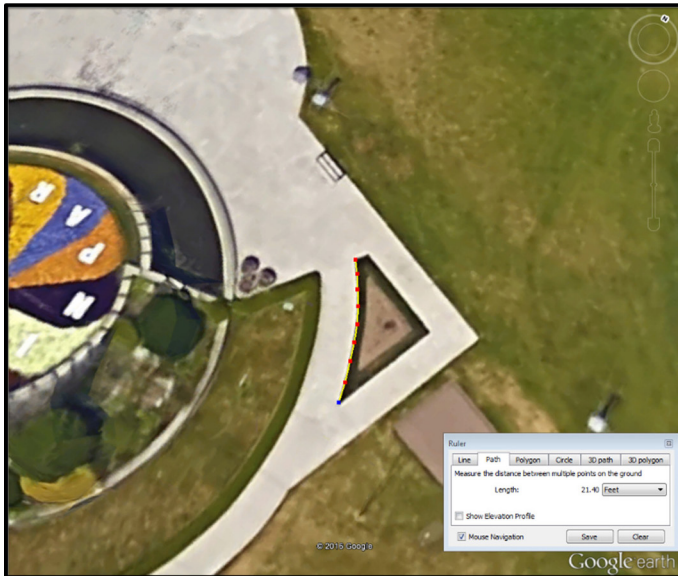


Figure 10. Google Earth Pro image and corresponding measurement of the curved path in Ontario, Canada.

RESULTS

The total data set from this study contains 1305 valid measurements ranging from 2.24 - 2147.63 feet. The measurements were taken from 68 unique sites including urban, rural, and suburban locations spanning 25 states and provinces in North America and Australia. The total data set and the results are presented in tabular format in the [Appendix](#).

Operator bias, specifically whether certain researchers and the dataset as a whole were biased towards either over- or under-estimating the measurements obtained via the measuring wheel versus the measurements obtained using Google Earth Pro was evaluated. Out of the 1305 measurements obtained, 618 Google Earth Pro measurements over-estimated the distance measured compared to the measuring wheel. Similarly, 678 Google Earth Pro measurements under-estimated the distance measured compared to the measuring wheel and nine measurements were equal.

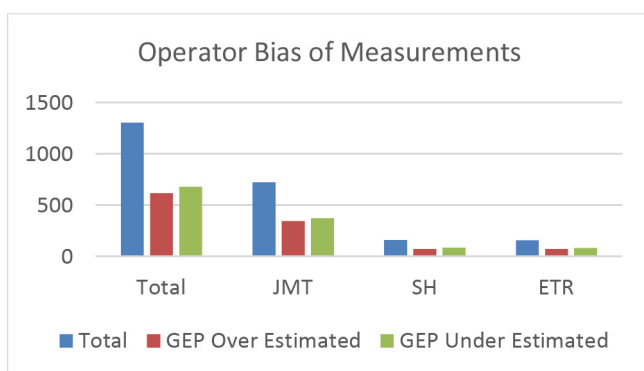


Figure 11. Operator bias for the three researchers with the most measurements and the dataset as a whole.

In general, the error rates were balanced about zero (i.e. equal amount of over-and under-estimated measurements), which is confirmation that there was no bias in the research.

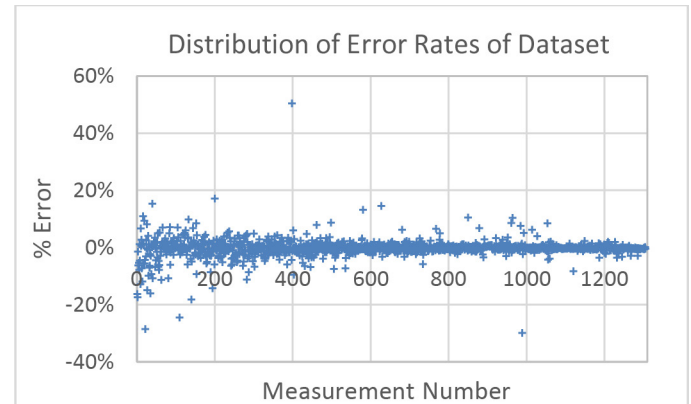


Figure 12. Distribution of error rates for the entire dataset.

The measurements were divided into three main groups, On-Road, Off-Road, and Curved Path measurements. On-Road measurements included any measurement that spanned the majority of a roadway-type surface; asphalt roadways, concrete sidewalks, and paved brick crosswalks are examples that qualified as On-Road surfaces. Off-Road measurements included any measurement that spanned a non-roadway-type surface; grassy areas and fields, sand-composed shoulders, rock and/or pebble-filled areas are examples of areas that qualified as Off-Road surfaces. Finally, Curved Path measurements included any measurements that had some radius of curvature in their delineation; rounded sidewalk corners, S-type turns in roadways, and curved fog lines are examples of areas that qualified as Curved Path measurements.

A total of 802 On-Road measurements, 226 Off-Road measurements, and 277 Curved Path measurements were obtained. 1296 measurements were obtained using a measuring wheel, and 9 measurements were obtained using a standard tape measure. These measurements were subdivided into eight distance-based subsets; 0 to less than 12 feet, 12 to less than 25 feet, 25 to less than 50 feet, 50 to less than 100 feet, 100 to less than 250 feet, 250 to less than 500 feet, 500 to less than 1000 feet, and over 1000 feet.

Table 2. Distribution of the On-Road, Off-Road, and Curved Path measurements.

Subset	Number of Measurements (n)		
	On-Road	Off-Road	Curved Path
0 – <12 (ft):	72	23	32
12 – <25 (ft):	100	24	40
25 – <50 (ft):	181	26	44
50 – <100 (ft):	131	33	29
100 – <250 (ft):	182	70	48
250 – <500 (ft):	74	23	47
500 – <1000 (ft):	35	19	20
1000+ (ft):	27	8	17
Total:	802	226	277

The error of each measurement was defined as the delta between the control measurement (the measurement obtained via a conventional methodology [CONV]) and the experimental measurement (the measurement obtained via Google Earth Pro [GEP]). The percentage error of each measurement was calculated using the formula:

$$\% \text{ Error} = \frac{|GEP - CONV|}{CONV} \times 100$$

Table 3. Average error of the On-Road, Off-Road, and Curved Path measurements.

Subset	Average Error (%)		
	On-Road	Off-Road	Curved Path
0 – <12 (ft):	3.35	5.47	4.14
12 – <25 (ft):	2.99	2.47	2.07
25 – <50 (ft):	1.75	1.72	1.95
50 – <100 (ft):	1.03	1.42	1.22
100 – <250 (ft):	0.70	0.60	1.69
250 – <500 (ft):	0.35	0.37	0.98
500 – <1000 (ft):	0.31	1.55	0.49
1000+ (ft):	0.26	1.05	0.30

The Root Mean Square Error [RMSE] for each distance-based subset was calculated using the Google Earth Pro (GEP) and Measuring Wheel (MW) measurements utilizing the formula:

$$RMSE = \sqrt{\frac{\sum_{t=1}^n (GEP_t - MW_t)^2}{n}}$$

Table 4. Root Mean Square Error of the On-Road, Off-Road, and Curved Path measurements.

Subset	Root Mean Square Error (feet)		
	On-Road	Off-Road	Curved Path
0 – <12 (ft):	0.34	0.50	0.52
12 – <25 (ft):	0.78	0.55	0.62
25 – <50 (ft):	1.12	0.75	1.12
50 – <100 (ft):	1.08	1.67	1.26
100 – <250 (ft):	1.96	1.51	4.86
250 – <500 (ft):	1.92	1.70	6.32
500 – <1000 (ft):	2.48	12.86	3.99
1000+ (ft):	4.70	19.68	4.57

Table 5. Minimum and maximum absolute errors of the On-Road, Off-Road, and Curved Path measurements.

Subset	Minimum and Maximum Error (ABS!%)					
	On-Road		Off-Road		Curved Path	
	Min	Max	Min	Max	Min	Max
0 – <12 (ft):	0.00	16.10	0.52	17.21	0.10	28.40
12 – <25 (ft):	0.10	24.35	0.34	5.84	0.06	18.01
25 – <50 (ft):	0.00	50.33	0.06	4.52	0.00	11.05
50 – <100 (ft):	0.00	13.28	0.10	14.65	0.02	6.31
100 – <250 (ft):	0.01	8.75	0.00	4.12	0.00	10.58
250 – <500 (ft):	0.00	2.44	0.02	1.42	0.02	8.54
500 – <1000 (ft):	0.05	0.68	0.04	3.46	0.07	1.73
1000+ (ft):	0.00	0.76	0.04	2.75	0.10	0.52

The maximum and minimum absolute percentage errors for each distance-based subset were determined.

The 95th-percentile confidence levels for each of the measurements in their respective distance-based subsets were calculated. The confidence intervals for each distance-based subset were calculated using the formula:

$$\text{Confidence Interval} = \bar{x} \pm z^* \frac{\sigma}{\sqrt{n}}$$

where $\bar{x}$ was defined as the mean of the differences between the conventional measurements and their respective Google Earth Pro measurements in each subset, z^* was defined as the 95th-percentile confidence level (z^* -value = 1.96), σ was defined as the standard deviation of the conventional measurements and their respective Google Earth Pro measurements in each subset:

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n ((GEP_i - CONV_i) - \bar{x})^2}$$

and n was defined as the number of measurements in the subset.

Table 6. Mean ($\bar{x}$) and 95th-percentile confidence levels ($\pm z^* \frac{\sigma}{\sqrt{n}}$) for each distance-based subset.

Subset	On-Road		Off-Road		Curved Path	
	Mean	+/-	Mean	+/-	Mean	+/-
0 – <12 (ft):	0.00	0.08	0.01	0.20	-0.16	0.17
12 – <25 (ft):	-0.13	0.15	0.03	0.21	-0.09	0.19
25 – <50 (ft):	0.02	0.16	-0.26	0.27	-0.24	0.32
50 – <100 (ft):	0.03	0.18	0.11	0.56	0.32	0.44
100 – <250 (ft):	0.16	0.29	0.37	0.34	1.43	1.30
250 – <500 (ft):	-0.18	0.40	0.59	0.64	-0.62	1.78
500 – <1000 (ft):	-0.58	0.72	-4.12	5.37	1.08	1.65
1000+ (ft):	-1.98	1.59	-13.24	10.27	-4.20	1.04

DISCUSSION

The results of this research had a strong correlation with the hypothesis that measurements obtained from Google Earth Pro were consistent with the measurements obtained from conventional instruments over short- and long-distances over multiple surfaces. Based on the number of measurements obtained, the geographical breadth of the measurements, the balance of the measurements over- or under-estimation about zero, the lack of negative or positive bias by individual researchers, the lack of negative or positive bias of the entire dataset, the low error rates of the measurements obtained from Google Earth Pro compared to the conventional measurements, the mean of the differences between measurements obtained from Google Earth Pro and the conventional measurements in the distance-based subsets near zero, and the narrow ranges for the 95th-percentile confidence intervals, the dataset in this research was deemed to be statistically significant to establish error rates for measurements from Google Earth Pro. Furthermore, the results of

this research validate the use of Google Earth Pro as a scientific utility and a measurement tool for short- and long-distance measurements within the software.

The mean of the differences between measurements obtained from Google Earth Pro and the conventional measurements in the distance-based subsets was near zero (<1) for most of the dataset below 500 feet. Furthermore, the confidence intervals were less than one for this same range. For example, with 95% confidence, the average difference between On-Road measurements obtained from Google Earth Pro and the On-Road measurements obtained using conventional instruments in the 100 - <250 foot distance-based subset was 0.16 ± 0.29 feet. Likewise, with 95% confidence, the average difference between Curved Path measurements obtained from Google Earth Pro and the Curved Path measurements obtained using conventional instruments in the 50 - <100 foot distance-based subset was 0.32 ± 0.44 feet. Generally, as the measurement distance increased, the magnitude of the mean and the range of the 95th-percentile confidence levels increased.

The percentage average error rates of the On-Road, Off-Road, and Curved Path measurements from Google Earth Pro generally decreased as the magnitude of the distance measured increased. For example, 69 On-Road measurements were taken between 0 - 12 feet with an average error of 3.35%, the 27 On-Road measurements taken over 1000 feet yielded an average error of over an order of magnitude smaller, only 0.26%. Variability in the image quality was one contributing factor that increased the relative error rate between the distance-based subsets; larger measurements with easier to define starting and ending reference points were easier to select than their relatively smaller (25 foot or less) counterparts.

The proper selection of the appropriate starting and ending point on a measurements error was magnified at the smaller distance-based subsets. While attempting to measure the width of a crosswalk, for instance, moving the starting or ending point a small distance relative to a pixelated and zoomed-in Google Earth Pro image can alter the measurement by half of a foot. A half foot variation over a ten foot distance due to the relative image quality is the largest contributor of error to the smaller measurement.

On-Road and Off-Road measurements were generally equally accurate for the same distance-based subset. One notable exception (more than 2% delta in the average error) was for the 0 - 12 foot distance-based subset. This result is likely due to the compounding error of the measuring wheel slipping more over the Off-Road surface and the selection of more ambiguous starting and ending points (i.e. the center of a tree or large embedded rock) in a pixelated and zoomed-in Google Earth Pro image of an Off-Road measurement. The other notable exception was for the 500 - 1000 and 1000+ foot On-Road and Off-Road distance-based subsets. The average error of Off-Road measurements was four to five times higher than the On-Road measurements over the same distance-based subset. This is likely due to the compounding error of the measuring wheel slipping more over the Off-Road's uneven surface over a larger distance compared to the On-Road measurement obtained on a smoother, more even surface. In addition, a smaller diameter measuring wheel was utilized for the majority of these Off-Road distance-based

subsets, larger diameter measuring wheels are less prone to error over uneven surfaces. Therefore, field measurements of 500+ foot Off-Road distances with measuring wheels must be taken with care and alternate measurement techniques should be considered.

Curved Path measurements were generally equally as accurate as both On- and Off-Road measurements between 0 - 50 feet. The relative accuracy of the Curved Path measurements and On- and Off-Road measurements began to diverge between 50 - 500 feet. Curved Path measurements require more user input for their selection in the Google Earth Pro software, the addition of more points along the curved path by the user can compound an error compared to the two-step (beginning and end selection) process for the On-Road Measurement.

The use of historical imagery within Google Earth Pro allowed the researchers to take accurate measurements of locations that had either changed from the current image displayed in Google Earth Pro or when a historical image provided a clearer perspective of the measurement of interest. This utility allowed the researchers to compare multiple historical images of an incident location that were taken over a multiple-year period, and to choose the most relevant image for the analysis of the measurement.

Often, there are over a dozen available historical images that pre- and post-date the accident being investigated. As demonstrated through its use in this study, the technique of verifying a site's substantial similarity in the most resolute Google Earth Pro image to the Google Earth Pro image that was taken in the closest proximity to the incident date yields accurate results. For example, if shadows in one historical image of the incident site being studied obscure the area of interest, another historical image of either better quality or without the shadows can be obtained. Even though the images may have been taken in different years, the substantial similarity of the images can be established through similar measurements in each image of relevant roadway features like lane widths, measurements between utility poles, crosswalks, etc. The substantial similarity of measurements within these respective images is also supported by the use of this methodology within this research and the accurate results obtained.

Table 7. Comparison of SAE 2015-01-1435 data to the On-Road data collected in this research, SAE 2017-01-9750.

Subset (ft)	2015-01-1435			2017-01-9750		
	n	RMSE (ft)	Avg. % Difference	n	RMSE (ft)	Avg. % Difference
5 to 25	54	0.227	1.23%	162	0.67	2.94%
25 to 50	19	0.580	1.39%	181	1.12	1.75%
50 to 75	17	0.405	0.48%	85	1.08	1.10%
75 to 100	8	0.530	0.50%	46	1.09	0.90%
Over 100	16	1.192	0.70%	296	1.96	0.56%

The results of this research were compared to the 2015 SAE paper that assessed Google Earth Pro's accuracy as a tool for accident reconstruction. The dataset from this research was organized to match the subsets the authors studied in their prior research using a Total

Station. As the previous authors only measured On-Road surfaces, only On-Road measurements from this research were compared. Off-Road and Curved Path measurements were ignored.

As expected, the use of a Total Station at distances under 100 feet yielded more accurate measurements when compared to the measurements obtained using conventional instruments. The smaller sample size of measurements over 100 feet in the 2015 SAE paper, however, prevented the authors for this research from directly comparing the results of this research against a larger sample size of Total Station measurements at distances between 500 - <1000 feet or 1000+ feet. However, the more accurate average percent difference for all measurements over 100 feet in this research compared to the 2015 SAE paper indicates that conventional instruments can be as accurate as Total Station data or laser scanners over long distances. The authors recognize the need for more research comparing laser scan data to measurements obtained from Google Earth Pro for distances over 100 feet.

SUMMARY/CONCLUSIONS

1. For most uses within accident reconstruction, relatively flat ground-length measurements from aerial views of Google Earth Pro presented sufficient accuracy to allow a substitution of actual on-site measurements. This study confirmed such measurement accuracy to distances over 2000 feet.
2. On-road, off-road, and curved path measurements from Google Earth Pro presented an average error rate of 1.45%, 1.61%, and 1.73%, respectively, to those obtained by manually rolled measurements for more than 1300 worldwide measurements.
3. The error rate of the measurements generally decreased with the length of the measurement.
4. This study utilized measurements obtained by conventional instruments over the subject terrain. The authors theorize that measurements taken by more accurate means, i.e., laser scanning, or total stations, will present lower error rates for equivalent measurements. This was confirmed for measurements less than 100 feet with the prior SAE 2015-01-1425 paper that focused on Total Station data.
5. The sample used in this study was statistically significant to establish an error rate for measurements from Google Earth Pro aerial views.
6. The use of historical imagery within Google Earth Pro was included in this study; error rates associated with the use of historical images were consistent with the most recent images provided in Google Earth Pro.
7. As the most recent Google Earth Pro image may not always provide the most resolute perspective, image quality in Google Earth Pro must be considered when identifying measurement points. The use of historical imagery within Google Earth Pro

is an appropriate methodology for obtaining measurements in these conditions.

8. More study is required to validate measurements with severe, off-road elevation changes, which may occur only rarely in accident reconstruction, such as large ditches, onto or across underpasses, or steep slopes on road edges.

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APPENDIX

APPENDIX A. MASTER TABLE OF RESULTS

		0-12 (ft)	12-25 (ft)	25-50 (ft)	50-100 (ft)	100-250 (ft)	250-500 (ft)	500-1000 (ft)	1000+ (ft)	Total
		Average Error:	3.35%	2.99%	1.75%	1.03%	0.70%	0.35%	0.31%	0.26%
Google Earth Pro v. Conventional - On-Road (Ruler Function)	Root Mean Square Error (ft):	0.34	0.81	1.12	1.08	1.96	1.92	2.48	4.70	
	Mean (ft):	0.00	-0.13	0.02	0.03	0.16	-0.18	-0.58	-1.98	
	95 th % confidence ($\pm$ ft):	0.08	0.15	0.16	0.18	0.29	0.40	0.72	1.59	
	Data Points (n):	72	100	181	131	182	74	35	27	802
Google Earth Pro v. Conventional - Off-Road (Ruler Function)	Average Error:	5.47%	2.47%	1.72%	1.42%	0.60%	0.37%	1.55%	1.05%	
	Root Mean Square Error (ft):	0.50	0.55	0.75	1.67	1.51	1.70	12.86	19.68	
	Mean (ft):	0.01	0.03	-0.26	0.11	0.37	0.59	-4.12	-13.24	
	95 th % confidence ($\pm$ ft):	0.20	0.21	0.27	0.56	0.34	0.64	5.37	10.27	
Google Earth Pro v. Conventional - Curved Path (Path Function)	Data Points (n):	23	24	26	33	70	23	19	8	226
	Average Error:	4.14%	2.07%	1.95%	1.22%	1.69%	0.98%	0.49%	0.30%	
	Root Mean Square Error (ft):	0.52	0.62	1.12	1.26	4.86	6.32	3.99	4.57	
	Mean (ft):	-0.16	-0.09	-0.24	0.32	1.43	-0.62	1.08	-4.20	
	95 th % confidence ($\pm$ ft):	0.17	0.19	0.32	0.44	1.30	1.78	1.65	1.04	
	Data Points (n):	32	40	44	29	48	47	20	17	277
Data Points (total):										1305

APPENDIX B. MASTER DATA SET

Date Obtained	Zip Postal Code Postcode	Measurement		Delta (ft)	Error (%)	Conventional Information			Meas. Type
		GEP	Conv.	GEP v. Conv	GEP v. Conv	Method	Instrument	ID	
06/07/16	32827	2.24	2.67	-0.43	16.10%	Roll-a-wheel	5505E	JMT	OnR
08/16/16	44130	2.55	3.08	-0.53	17.21%	Roll-a-wheel	PSMW48	SH	OffR
06/14/16	19952	3.00	3.04	-0.04	1.32%	Roll-a-wheel	PSMW48	JMT	OnR
06/07/16	32827	3.21	3.42	-0.21	6.14%	Roll-a-wheel	5505E	JMT	OnR
07/12/16	18943	3.63	3.83	-0.20	5.22%	Roll-a-wheel	WMP12	ETR	OnR
08/16/16	44130	3.73	4.04	-0.31	7.67%	Roll-a-wheel	PSMW48	SH	OffR
08/16/16	44130	4.05	4.00	0.05	1.25%	Roll-a-wheel	PSMW48	SH	OffR
06/07/16	32827	4.06	4.25	-0.19	4.47%	Roll-a-wheel	5505E	JMT	OnR
06/07/16	32822	4.08	4.67	-0.59	12.63%	Roll-a-wheel	5505E	JMT	OnR
08/16/16	44130	4.09	3.83	0.26	6.79%	Roll-a-wheel	PSMW48	SH	OffR
08/16/16	44130	4.11	4.08	0.03	0.74%	Roll-a-wheel	PSMW48	SH	OffR
08/16/16	45839	4.29	4.17	0.12	2.88%	Roll-a-wheel	PSMW48	SH	OffR
06/07/16	32827	4.41	4.75	-0.34	7.16%	Roll-a-wheel	5505E	JMT	OnR
08/31/16	98107	4.41	5	-0.59	11.80%	Roll-a-wheel	PSMW18	BJM	CP
08/16/16	44130	4.48	4.42	0.06	1.36%	Roll-a-wheel	PSMW48	SH	OffR
08/16/16	44130	4.63	4.17	0.46	11.03%	Roll-a-wheel	PSMW48	SH	OffR
06/13/16	01862	4.80	5.08	-0.28	5.51%	Roll-a-wheel	PSMW48	JMT	OnR
06/02/16	33126	4.97	4.92	0.05	1.02%	Roll-a-wheel	PSMW48	JMT	OnR
06/08/16	32821	5.20	4.75	0.45	9.47%	Roll-a-wheel	5505E	JMT	OnR
06/14/16	19952	5.20	5.50	-0.30	5.45%	Roll-a-wheel	PSMW48	JMT	OnR
10/20/15	04090	5.27	5.5	-0.23	4.18%	Roll-a-wheel	PSMW28	PC	OnR
08/28/16	06042	5.37	7.50	-2.13	28.40%	Roll-a-wheel	PSMW28	PC	CP
08/09/12	18966	5.51	5.68	-0.17	2.99%	Roll-a-wheel	WMP12	AI/BS	CP
09/12/16	3000 (VIC)	5.55	5.41	0.14	2.59%	Tape Measure	TM	KPH	OnR
09/12/16	3000 (VIC)	5.57	5.58	-0.01	0.18%	Tape Measure	TM	KPH	OnR
06/07/16	32827	5.87	5.42	0.45	8.30%	Roll-a-wheel	5505E	JMT	OnR
06/07/16	32827	5.90	6.92	-1.02	14.74%	Roll-a-wheel	5505E	JMT	OnR
08/16/16	44130	6.04	6.08	-0.04	0.66%	Roll-a-wheel	PSMW48	SH	OffR
08/31/16	98107	6.25	6	0.25	4.17%	Roll-a-wheel	PSMW18	BJM	CP
08/09/12	18966	6.28	6.96	-0.68	9.77%	Roll-a-wheel	WMP12	AI/BS	CP
08/31/16	98107	6.33	6.25	0.08	1.28%	Roll-a-wheel	PSMW18	BJM	CP
08/09/12	18966	6.36	6.83	-0.47	6.88%	Roll-a-wheel	WMP12	AI/BS	CP
06/07/16	32827	6.49	6.92	-0.43	6.21%	Roll-a-wheel	5505E	JMT	OnR
06/14/16	19952	6.68	6.83	-0.15	2.20%	Roll-a-wheel	PSMW48	JMT	OnR
06/14/16	19952	6.73	8.00	-1.27	15.88%	Roll-a-wheel	PSMW48	JMT	OnR
08/16/16	45839	6.73	6.92	-0.19	2.75%	Roll-a-wheel	PSMW48	SH	OffR
08/16/16	44130	6.74	7.42	-0.68	9.16%	Roll-a-wheel	PSMW48	SH	OffR
07/12/16	18943	6.90	6.88	0.02	0.29%	Roll-a-wheel	WMP12	ETR	OnR
08/09/12	18966	6.93	6.92	0.01	0.14%	Roll-a-wheel	WMP12	AI/BS	CP
06/26/13	12831	6.93	6	0.93	15.50%	Tape Measure		PC	OffR
06/07/16	32827	7.00	7.83	-0.83	10.60%	Roll-a-wheel	5505E	JMT	OnR
08/16/16	44130	7.05	7.00	0.05	0.71%	Roll-a-wheel	PSMW48	SH	OffR
08/16/16	44130	7.12	7.08	0.04	0.56%	Roll-a-wheel	PSMW48	SH	OffR
07/12/16	18943	7.17	7.04	0.13	1.85%	Roll-a-wheel	WMP12	ETR	OnR
06/13/16	03060	7.24	7.08	0.16	2.26%	Roll-a-wheel	PSMW48	JMT	OnR
10/30/15	10993	7.25	7.00	0.25	3.57%	Roll-a-wheel	PSMW28	PC	OnR
06/14/16	19952	7.46	8.00	-0.54	6.75%	Roll-a-wheel	PSMW48	JMT	OnR
06/02/16	33407	7.50	7.50	0.00	0.00%	Roll-a-wheel	PSMW48	JMT	OnR
08/31/16	98107	7.58	7.92	-0.34	4.29%	Roll-a-wheel	PSMW18	BJM	CP
05/29/16	08402	7.63	7.50	0.13	1.73%	Roll-a-wheel	PSMW48	JMT	OnR