8-2007

Photogrammetry in Traffic Accident Reconstruction

Lara Lynn O'Shields
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Lara Lynn O'Shields entitled "Photogrammetry in Traffic Accident Reconstruction." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Industrial Engineering.

John C. Hungerford, Major Professor

We have read this dissertation and recommend its acceptance:

Tyler Kress, Kenneth E. Kirby, Lee D. Han, Stephen H. Richards

Accepted for the Council:
<u>Dixie L. Thompson</u>

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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Accepted for the Council:

Carolyn R. Hodges
Vice Provost and Dean of the
Graduate School

PHOTOGRAMMETRY IN TRAFFIC ACCIDENT RECONSTRUCTION

A Dissertation
Presented for the
Doctor of Philosophy Degree
The University of Tennessee, Knoxville

Lara Lynn O'Shields
August 2007

DEDICATION

There are several to whom I wish to dedicate this dissertation. Firstly, this dedication goes to my paternal grandmother, Blanche O'Shields, who passed away in January 2004. Words can't express how my life was so richly blessed with you in it. I'll never forget your love, your words of encouragement, and your unique sense of humor. You had such a prevalent presence in my life; I was at your house more than my own at times. For this reason, you are partly responsible for whom I am today, and I thank you immensely for that. You were certainly a fine lady, Mamaw, and I'll never forget you.

Blanche and Lara O'Shields circa 1974

This dissertation is also dedicated to my maternal grandparents, Ann and Furman Smoak formerly of Canadys, South Carolina. They passed away in February and April 2005, respectively. As a child, I remember how I would get so excited when visiting their house. Papaw Smoak was such a sweet and kind soul; he instilled in me a love for nature and the outdoors. Mamaw Smoak was the best cook in the South and always had a gift waiting for me when I would visit. They remembered every single one of my birthdays with a card and a piece of money. I miss you two so much. Even though I reside in Tennessee, South Carolina will always be my other home.

Furman & Ann Smoak in SC in the late 1940's

I love you and miss you all so terribly.

Life won't be the same without you.

Finally, I dedicate this dissertation to *all* my family and friends (some who are begrudgingly unidentified), who have helped me emotionally, financially, and otherwise over the years. I couldn't have done this at all without your help.

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I would like to thank many people for their efforts in helping this dissertation materialize. Firstly, I would like to thank Dr. John Hungerford for introducing me to the profession of traffic accident reconstruction and to PhotoModeler, the basis for this dissertation. He and his wife Ruthie are such great people. I always receive a warm welcome (with the help of the critters) when I visit their home.

Next, I would like to thank Dr. Tyler Kress. Tyler will never know how much he has helped me. This guy is so brilliant—if I had just a small fraction of his intelligence, then I would be awesome. Tyler has opened my eyes to so much in the profession; I have learned a great deal from him. Both Tyler and Dr. Hungerford have selflessly given their time, money, and efforts in order to help me succeed. Thank you both so much.

Dr. Lee Han and Dr. Steven Richards deserve recognition also. These two introduced a new “twist” to my way of thinking—the Civil Engineering perspective. Your refreshing insight and your support is greatly appreciated. Many thanks go out to Dr. Ken Kirby as well. Dr. Kirby is an inspiration and a super kind of guy.

Next, I would like to thank the management at the Gatlinburg-Pigeon Forge Airport located in Sevierville, TN. These folks were gracious enough to let me carry out the experiments for Parts Two and Three of this dissertation on their property.

Sonya Lee Roberts, my dear friend since kindergarten (1977), warrants recognition and praise as well. Sonya is one of the most kind and thoughtful people in the world—I am certainly privileged to have her as a friend.

My brother, Seth L. O’Shields, is worthy of acknowledgment also. Seth’s help with some preliminary Part Two experiments (for CE 551) really helped a lot. Thanks Bud!

Teresa Kerr Hall and Robin Kerr (my stepmom's sisters) deserve special appreciation as well. They graciously helped me with the food for the defense of this dissertation. They've also been a source of tremendous support throughout this dissertation process. Thanks for all the fun times at the beauty shop!

Additionally, I would like express my thanks to each and every salesman that I bugged at every car lot that I visited across East Tennessee. God knows how many sets of pictures were taken for Part One's work (all of which were not utilized). Nearly all of you were very gracious and accommodating in helping me with my "project for school."

Lastly, I would like to thank my parents, Susan Gourley (& Stepdad Wayne) and David O'Shields (& Stepmom Alesia). Mom has provided me with tremendous amounts of encouragement and support throughout this dissertation process. She is the best mom in every way. Her frequent phone calls helped to keep me level-headed and sane at times. My dad has helped me immensely as

well, especially with Part Two (and portions of Part Three) of this dissertation. Dad, there is absolutely <u>no way</u> I could have completed this without your help. And thanks for listening to my "wacky" ideas and helping them come to life.

David O'Shields helping with Part II experiments

ABSTRACT

The aim of this research is to utilize PhotoModeler, a close-range photogrammetry software package, in various traffic accident reconstruction applications. More specifically, three distinct studies were conducted: 1.) vehicle crush measurement, 2.) road curve measurement, and 3.) an evaluation of common traffic accident reconstruction measurement methodologies.

The first study applied the photogrammetric process to controlled crash information generated by the National Highway Traffic Safety Administration (NHTSA). A statistical procedure known as bootstrapping was utilized to generate distributions from which the variability was examined. The "within" subject analysis showed that 44.8% of the variability is due to the technique itself and the "between" subjects analysis demonstrated that 55.2% of the variability is attributable to vehicle type—roughly half and half. Additionally, a 95% CI for the "within" analysis revealed that the mean difference (between this study and NHTSA) fell between -

2.52 mph and +2.74 mph; the "between" analysis showed a mean difference between -3.26 and +2.41 mph.

The second study focused on photogrammetry in road curve measurement. More particularly, this study applied photogrammetry to (simulated) road curves in lieu of traditional measurement methods, such as measuring tapes and measuring wheels. In this work, thirty (30) different radii of curvature of various known sizes were deliberately constructed. Then photogrammetry was used to measure each of the constructed curves. A comparison of the known "R's" (control group) and photogrammetry's value of "R" (treatment group) was then made. Matched Pairs or Paired Comparisons were then used to examine these two populations. The difference between the photogrammetry "R" and the known "R" range is between 0.001% and 0.874%. Additionally, we are 95% confident that the mean difference of the two techniques is between -0.33 and 0.51 feet. Since this interval contains zero, we can conclude that the two techniques do not differ.

The third study's aim was to learn what causes variation in three common traffic accident reconstruction measurement techniques: measuring tape, measuring wheels and photogrammetry. These three techniques were evaluated against a known benchmark distance measured by a total station. A full factorial 2^3 Design of Experiments study with four replicates was applied to each technique. The following results were found: <u>Measuring tape experiment</u>: None of the main effects or cross-effects were significant. <u>Measuring wheel experiment</u>: Two main effects ($p<0.0001$ and $p<0.0060$) and all of the cross-effects ($p<0.0079$ to 0.0345) were significant. <u>Photogrammetry experiment</u>: One main effect ($p<0.0063$) and one cross effect ($p<0.0325$) were significant. The measuring wheel is most sensitive to surface type (smooth or rough surface) and photogrammetry is most sensitive to digital resolution (low or high resolution).

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INTRODUCTION

General Introduction

This dissertation is a collection of three (3) experimental studies that focuses on PhotoModeler, a close-range photogrammetric software package, and its role in traffic accident reconstruction. Photogrammetry is the science and art of obtaining measurements from photographs, hence; photogrammetric measurements useful to Accident Reconstructionists are at the core of this dissertation. In the first two studies, the extracted photogrammetric measurements + engineering equations = information that is useful to the accident reconstructionist, such as speed prior to impact and the critical speed of a curve. (The third study is simply an evaluation of various measurement techniques available to accident reconstructionists, including photogrammetry.)

Part One of this work involves vehicle crush measurement using photogrammetry. If one can measure the amount of crush in a vehicle, the speed prior to impact may be determined either from crush alone or crush plus other engineering analyses; this, of course, is dependent on the particulars of the accident. The relationship of crush and speed is approximately linear in nature or proportional to one another; the more the vehicle is crushed, the faster it was going prior to impact and vice versa. The crush analysis process essentially involves the collection of the following: 1.) Six (6) evenly-spaced crush measurements from the affected crush area 2.) Crush coefficients specific to the subject vehicle; they can be computed, estimated, or purchased 3.) Other information such as vehicle weight and width of crush. The above information is then used in the crush equation developed by Campbell [1] and later revised by McHenry [2], which will yield the energy dissipated by crush. Speed due to this energy (hence, the speed of the vehicle) can subsequently be computed.

Photogrammetric crush measurement involves creating a 3-D model of the superimposed crushed and exemplar vehicles with the photogrammetry software. The pre- and post-impact crush positions are known precisely, which makes it superior to other crush-measurement methodologies like measuring poles, measuring tapes, and tarp and plumb bob. Moreover, this study makes use of controlled crash data (in the form of photographs and other vehicle information) generated by NHTSA. NHTSA conducts its frontal barrier crash testing at around 35 mph. So if this study's results are close to thirty-five (35) mph, all the better. For all intents and purposes, Part One is comprised of the following: photographs from the NHTSA frontal crash test reports are examined for photogrammetric feasibility; from "approved" reports/photographs, a 3-D model is generated and crush measurements are extracted; speed is computed using the aforementioned crush equations in a spreadsheet-type format; and finally an analysis using bootstrapping of this study's speed estimate versus the actual speed stated in the report was performed.

Part Two of this research concerns photogrammetric road curve measurement. Instead of using traditional measurement techniques such as measuring tapes or wheels, photogrammetry was used to measure curves. Thirty (30) known radii of curvature were deliberately constructed at a local airport using a pre-measured cable. Six (6) specifically made targeted traffic cones were used in this analysis; five (5) were placed along the arc of the curve and one (1) was placed directly across from the others. Various photographs from various angles were then taken of the cones. The curves were ultimately measured by extracting an "l" or chord and an "h" or middle ordinate from the photogrammetry software. $r = \frac{l^2}{8h} + \frac{h}{2}$ was then used to generate an estimate for each of the photogrammetrically-induced radii. These radii (treatment group) were compared to the known radii (control group) and a statistical procedure called Matched Pairs or Paired Comparisons was used to investigate the two groups.

Part Three examines the inherent variation in three common accident reconstruction measurement methodologies: the measuring tape, the measuring wheel, and photogrammetry. A 2^3 full-factorial Design of Experiments study was performed to study these variations. A pre-measured distance of forty-eight (48) feet, established by a total station, was used as a benchmark measurement in this experiment. This benchmark distance was measured a grand total of one hundred and twenty (120) times in Part Three; each of the above techniques measured the benchmark forty (40) times (each technique utilized a 2^3 full factorial with four

(4) replicates, which equals forty observations total). The factors selected for this study are as follows: Measuring Tape—tape type (cloth or steel), amount of masking tape used (low or high), and exposure to the road (low or high). Measuring Wheel—surface type (smooth or rough), wheel diameter (small or large) and road exposure (low or high). Photogrammetry—Number of pictures (low (4) or high (8)), digital resolution of the camera (low or high), and road exposure (low or high). The statistical software program JMP randomly determined the sequence of each of the treatment combinations via the embedded DOE tool. Each of the treatment combinations were recorded and input into the DOE tool and were subsequently analyzed for statistical significance.

Background

Photogrammetry In General

History

"Photogrammetry", as defined by the American Society for Photogrammetry and Remote Sensing (ASPRS), "is the art, science, and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting (photographic) images and patterns of electromagnetic radiant energy and other phenomena"; this is the definition from the ASPRS website [11]. It is interesting to note that this website definition and the Manual of Photogrammetry Fifth Edition [3] are nearly word-for-word except for the word "photographic". The Manual (current as of 2004, but quoting the 1980 4th edition definition) includes the words "photographic images". Perhaps the website definition is acknowledging the emergence and use of digital technologies; "photographs" can be construed by some as strictly coming from a film camera. Remote Sensing came a part of the American Society for Photogrammetry in 1975 [3] in name and in definition. The abovementioned definition which states "interpreting (photographic) images and patterns of electromagnetic radiant energy and other phenomena" obviously reflects the inclustion of remote sensing into ASPRS. For the purposes of this work, the American Society for Photogrammetry's 1934 defintion [3] will be rightfully appropriate: "The science and art of obtaining reliable measurements by means of photographs", with the understanding that "photograph" can mean either "digital photograph" or "film photograph" in the work of this research.

Since photogrammetry's beginnings in the mid 19th century, its main objective was for map-making purposes [3] and in fact, still is [6]. Topographic photogrammetry has object to camera distances of up to many miles, for example; an airplane performing an aerial survey at 10,000 feet would fit into this category. Non-topographic photogrammetry or close-range photogrammetry has object to camera distances of inches to hundreds of feet; accident reconstruction applications like crush measurement and accident scene documentation belong here. The Handbook of Non-Topographic Photogrammetry [3] defines this distance to be not more that three hundred (300) meters or nine hundred eighty-four (984) feet.

Photogrammetry's inception, from a practical or serviceable standpoint, began with the invention of photography in the mid 19th century; photogrammetry's primary media, of course, are photographs. However, the optical principles that lay the foundation for photogrammetry actually came earlier—around two thousand years earlier with Aristotole in 350 B.C. and later in 1492 with Leonardo da Vinci.

Photogrammetry, thus far, has evolved in four (4) different phases or cycles, with each reflecting the up-and-coming technologies of the day: The First Generation: Early Developments in Photogrammetry (1850 to 1900), The Second Generation: The Analog Phase (1900 to 1960), The Third Generation: The Analytical Phase (1960 to 1990), and The Fourth Generation: The Digital Phase (1990 to Present) [3, 4, 6, 12].

Before a discussion of the Four Generations is developed, there is a phase or cycle that is notable to mention which lays the foundation for all of photogrammetry, which will be called here the "Precursors to Photogrammetry" [4]. This particular phase includes all the developments leading up to the invention of photogrammetry, such as Durer's outlined Law's of Perspective (1525), Lambert's "Free Perpective", which combined mathematics with perspective and utilized them for map-making purposes (1759), and Daguerre's first practical photograph on metal plates, called Daguerreotypes (1837).

The emergence of photographs heralded a new era: The First Generation of Photogrammetry.

Generation One began when Colonel Aime Laussedat made maps from photographs in 1849. His efforts earned him the name "The Father of Photogrammetry". People using photogrammetry in this era would mount cameras onto balloons or kites to gain a higher viewpoint, however; these experiments usually yielded disappointing results for map-making purposes. Therefore, mapping operations (such as those carried out by Deville in Canada) largely utilized ground photography for their surveying functions.

The Second Generation of photogrammetry was dubbed the Analog Era. It was "flung" into existence by the invention of the airplane. Airplanes were mounted with large format cameras and photos would be taken of various terrains for map-making purposes. 3-D models could be subsequently generated from hardcopy 2-D images using optical or mechanical means. This was usually accomplished by large machines specifically designed for this purpose; The Autocartograph, Stereoplanigraph, and the Aerocartograph are some examples [4]. "When transparencies of overlapping photos were properly oriented in their projectors, corresponding light rays from the two photos were projected through objective lenses to create an accurate model of the overlapping terrain, and a map of the model could be drawn" [14]. The map generated in this process is an analog of the images themselves, hence the name.

The computer was the impetus for the Third Generation, the Analytical Era. In this cycle, 3-D models were created mathematically from photographs (as opposed to being physically fashioned by machine in the previous era). The photogrammetric equations, highly mathematical, iterative, and analytical in nature, were now made useful with the advent of the computer. Previously, analytical solutions ran the risk of being riddled with errors and took enormous amounts of time to solve. The computer made analytical solutions practical [4, 7]. The analytical equations themselves have inclusions for object space coordinates, image space coordinates, and camera parameters, and will be discussed in a following section. Analytical photogrammetry was used primarily for topographical purposes, however; non-topographic photogrammetry (aka close-range photogrammetry) got its start during this era.

The Fourth Generation, called the Digital Era, became apparent upon the creation of the charged-coupled-device (CCD), the primary component in digital cameras. Digital photogrammetry develops analytical solutions via digital images. Fraser [13] says "in the arena of non-topographic applications, digital photogrammetry has rendered film-based systems largely obsolescent." Additionally, Wolf [14] states that "Digital photogrammetry can be performed at a savings in labor and in cost," thereby circumventing the charge for the film itself and its processing, and time lost attributable to film processing and scanning. However, the use of digital photos is not without its critics. Unfortunately, digital photos have the ability to be "enhanced" with photographic software. This "enhancement" can range from the variation of the brightness and contrast values to a fraudulent manipulation of the components of the image itself, possibly revealing/removing elements that weren't there initially. So in some situations, using film over digital images is not a failure of the application of technology, but simply a preference for a particular documentation medium which may or may not have later legal implications. Table 1, History of Photogrammetry, delineates significant developments throughout these four phases.

Theory

Analytical photogrammetry, as mentioned above, is where the coordinates of the objects of interest (and subsequently their measurements) are computed mathematically with algorithms. Essentially what is taking place in analytical photogrammetry is a conversion of one coordinate system to another coordinate system [4, 15-20], i.e., 3-D to 2-D or the reverse. The first coordinate system, called object space, is 3-dimensional in nature. It is the "real world" in which we live. For example, the left corner of a desk has components in three directions, X, Y, and Z (object space is designated by the uppercase coordinates), when associated with some arbitrary coordinate system. The second coordinate system, called image space, is 2-dimensional in nature. A photograph (or digital image printed on paper) in and of itself has 2-D characteristics. Using the above desk example, one could easily identify the left corner of a desk in a photograph, which would have

Table 1. History of Photogrammetry

HISTORY OF PHOTOGRAMMETRY			
Date	Contributor	Contribution	Source
350 BC	Aristotle	Referred to the process of projecting images optically	[5]
1492	Leonardo da Vinci	Developed the principles of perspective and optical projection which forms the basis of photogrammetric theory	[4], [6], [7], [8]
Early 16th Century	Desargues & Pascal	Mathematicians that had proven some of the laws of perspective	[4]
1525	Albrecht Durer	Outlined the laws of perspective and developed a mechanical device that produced a true perspective drawing	[4], [6], [7], [8]
1574	Aughtread	Constructed the first slide rule	[4]
Circa 1574	John Napier	Published tables of logarithms	[4]
Circa 1574	Blaise Pascal	Created a desk calculator	[4]
Circa 1600	Johannes Kepler	Gave a precise definition of stereoscopy	[4]
Circa 1600	Jacopo Chimenti	Produced the first hand-drawn stereo-picture pair	[4]
Circa 1630	Issac Newton and Gottfried von Leibnitz	Presented scholars with differential and integral calculus	[4]
1715	Brook Taylor	Published a book on linear perspective	[5], [9]
1726	F. Kapeller	Constructed a topographic map of Mt. Pilatus, near Lake Lucerne in Switzerland	[4]
1759	Schultz	Observed that silver nitrate blackens when exposed to sunlight	[4]
1783	Montgolfier	Made the first successful hot-air balloon flights near Paris	[4]
1837	Jacques Mande Daguerre	Created the first "practical" photographs on metal plates called daguerreotypes	[4], [5], [6], [8], [14]
1840	Dominique Francois Jean Arago	Advocated the use of photography by topographers to members of the French Arts and Science Academy	[4], [6]
1849	Aime Laussedat	First to use photographs for map making; "The Father of Photogrammetry"	[4], [6], [9]
1855	Tournachon (aka Nadar)	Obtained the first aerial photograph	[4], [6]
1858	Aime Laussedat	Suspended a camera with kites and balloons for map-making purposes	[4], [6]
1858	A. Meydenbauer	Performed surveys of historical monuments, churches, and buildings	[7]
1859	Aime Laussadat	Presented the use of the phototheodolite (a camera and theodolite) for map making to the Academy of Science in Paris	[4], [6]

Table 1. cont'd

HISTORY OF PHOTOGRAMMETRY			
Date	Contributor	Contribution	Source
1867	Aime Laussadat	Publicly exhibited the first known phototheodolite and a plan of Paris based on photographic surveys	[4], [6]
1868	Chevallier	Developed the photographic plane table	[4], [6]
1871	Ernst Abbe	Studied the design of optical elements and their combination with an intense mathematical basis	[4]
1885	George Eastman	Used nitrocellulose as a film base and later (1890) replaced the photographic dry plate for roll film	[5], [6]
1886	E. Deville	Used ground Photogrammetry for topographic mapping of the rugged mountains of Western Canada	[4], [5], [7], [9]
1893	A. Meydenbauer	Published a paper on photographic surveying in which the term "Photogrammetry" was first used	[4]
1896	E. Deville	Invented the first stereoscopic-plotting instrument	[4], [6]
1899	Sebastian Finsterwalder	Published "Fundamental Geometry of Photogrammetry" a seminal paper on analytical Photogrammetry	[4], [6]
1901	Carl Pulfrich	Designed the first stereocomperator, the first photogrammetric instrument manufactured by Zeiss	[5], [6]
Circa 1901	Henry George Fourcade	Independently developed a similar stereocomperator to Pulfrich's	[6]
1902	Wright Brothers	Invented the airplane	[5], [6], [14]
1907	Ritter von Orel	Developed the first stereoautograph	[6]
1910		The International Society for Photogrammetry was formed	[7]
1913		The airplane was first used for obtaining photographs for mapping	[5], [14]
1914	Arthur and Norman Brook	Physically mounted an aerial camera to an airplane instead of holding the camera over the side	[6]
1921	Reinhard Hugershoff	Created the first analog plotter called the autocartograph	[4], [6]
1923	Zeiss Works	Produced a plotting instrument known as the Zeiss Stereoplanigraph	[4]
1924	Otto von Gruber	Derived the projective equations and their differentials which are fundamental to analytical Photogrammetry	[6]
1926	Reinhard Hugershoff	Created the Aerocartograph, a lighter version of the Autocartograph	[4], [6]
1930's	TVA & USGS	Undertook the topographic mapping of the entire Tennesse river basin by aerial Photogrammetry (40,000 square miles)	[4], [14]
1930	Earl Church	Developed analytical solutions to space resection, orientation, intersection, rectification, and control extension using direction cosines	[4], [6]
1934		The American Society for Photogrammetry was formed	[4]
1941	Zure	Invented the computer in Germany	[6]

Table 1. cont'd

HISTORY OF PHOTOGRAMMETRY			
Date	Contributor	Contribution	Source
1942	Bausch & Lomb Optical Company	Engaged in a comprehensive manufacturing program for photogrammetric optics, photointerpretation equipment, and map-producing devices	[4]
1943	Aitken	Independently invented the computer in the US	[6]
1951	Everett Merritt	Extended Church's work by making it more complete and published a complete exposition of his work in analytical photogrammetry in 1958	[4], [6]
1953	Helmut Schmid	Developed the principles of modern multi-station analytical photogrammetry using matrix notation	[4], [6]
1955	Duane Brown	Developed new approaches to camera calibration on the utilization of the bundle adjustment	[4], [6]
1956	Paul Herget	Developed an approach to analytical control using vector notation	[4], [6]
1957	Uki Helava	Invented the analytical stereoplotter	[4], [6]
Late 1950's	G.M. Schut	Applied the coplaniarity concept to analytical triangulation	[4], [6]
1959	Hellmut Schmid	Applied the least-squares method to the simultaneous solution to any number of photographs and the first photogrammetrist to plan his solutions in the anticipation of high-speed computers	[4]
1951 to 1967	Gilbert Hobrough	Helped to develop Digital Photogrammetry through various inventions	[6]
1959 to 1972		The Corona program was the first major satellite photo intelligence gathering system during the cold war	[4]
1967 to 1992	Uki Helava	Helped to develop Digital Photogrammetry through various inventions	[6]
1971	Houssam Karara	Developed Direct Linear Transformation (DLT), a method that does not require camera calibration data	[6]
1980's to 1990's		Expanded development and utilization of the conversion of hard-copy photographs to digital form via scanners	[4]
1990's to Present		CCD (Charged Couple Devices) allow for non-photographic imaging and the direct digital storage to computers	[6]

associated 2-D coordinates (x & y, lowercase) with respect to an arbitrary 2-D coordinate system. The third coordinate system, which this author terms "model space", is 3-D in nature. This 3-D space is reconstructed from the 2-D photographs. Note that in order to perform this type of reconstruction, a minimum of two (2) photographs are required. Some accident reconstruction applications only require 2-D photogrammetry, such as documentation of a road scene—here only one (1) photo is needed. But 3-D applications, such as vehicle crush measurement, require a minimum of two (2) photos to get that third dimension. For clarification, think about the human eyes. With only one (1) eye, we can see only in 2-D. But with both eyes, we see in 3-D because each eyeball has a slightly different perspective of the subject and the brain fuses or combines the two scenes. A similar situation is the children's toy, the Viewmaster. Photos of the Viewmaster are taken with a stereocamera, which is a two-camera or a two-lens specialty camera which takes two (2) photos of a slightly different perspective simultaneously. The result when looking through the Viewmaster is a 3-D image that has depth, or a stereomodel.

In this work, the coordinate conversions are as follows: 3-D (object space) → 2-D (image space) →3-D (model space). This is illustrated with an example in Figure 1. On the far left in Figure 1, we have a 3-Dimensional car that exists in the "real world" or Object Space. If we want, we can give, say, the left corner of the hood, a 3-D coordinate (X, Y, and Z). In the center of Figure 1, we have several 2-D representations or photographs of the 3-D object. We could, if necessary, identify the same point (left corner of the hood) in at least three (3), probably four (4) of those photographs. The points on the photographs would be of the form (x, y) and would be considered to be in Image Space. The right-most portion of Figure 1 is a screenshot from Case #5 in Part One of this work. In the upper-left corner of the screenshot, one can see PhotoModeler's 3-D Viewer, which is a black-filled window with a wire-frame model of the car. After much manipulation of the PhotoModeler software, and through the magic of analytical photogrammetry, a 3-D model can be recovered or recaptured from the 2-Dimensional photographs.

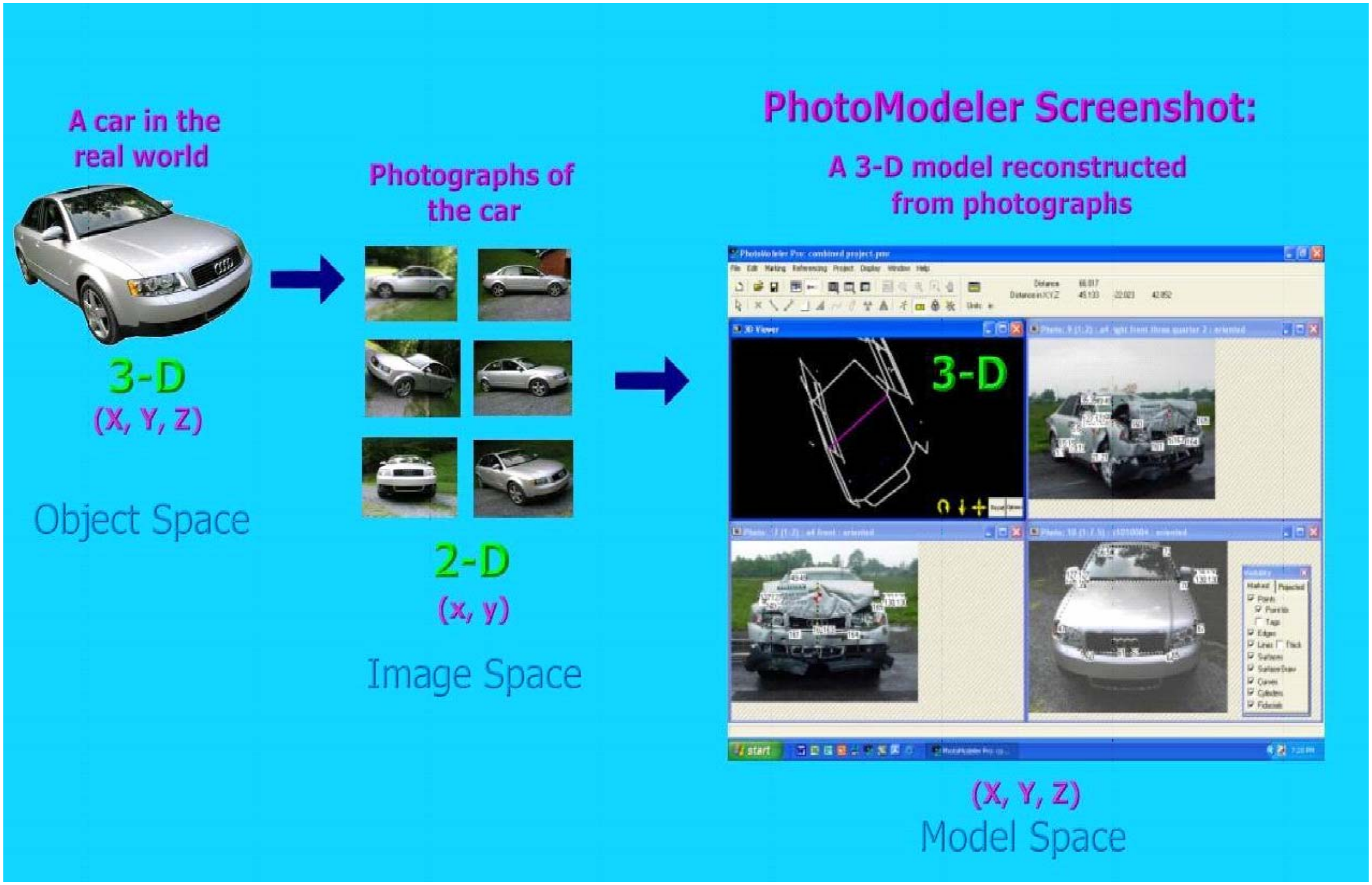

Figure 1. Coordinate Conversion Example

Objects in the 3-D Viewer have coordinates of the form (X, Y, Z) and exist in Model Space. Only after a 3-D model is created can measurements be extracted. When operating within PhotoModeler, coordinate systems are automatically assigned to the project, so the act of going from 3-D to 2-D to 3-D (object to image to model) is a seamless operation unknown to the user, however; seasoned PhotoModeler users can find indications of this process in various locations throughout the software.

The Collinearity Condition

The Collinearity Condition [4, 5, 16, 17], the basis behind the collinearity equations, is illustrated in Figure 2. The Collinearity Condition requires that the object point A, the perspective center C (at the camera lens) and the image point a, all lie in a straight line. This straight line requirement is exploited to develop the collinearity equations. In Figure 2, one can see the straight line requirement of A, a, and C. "A" possesses the three (3) coordinates X_A, Y_A, and Z_A (uppercase denoting object space) and "a" has its respective 2-D image space coordinates x_a and y_a. Note that "A" and "a" are homologous; they are the same point, but in different coordinate

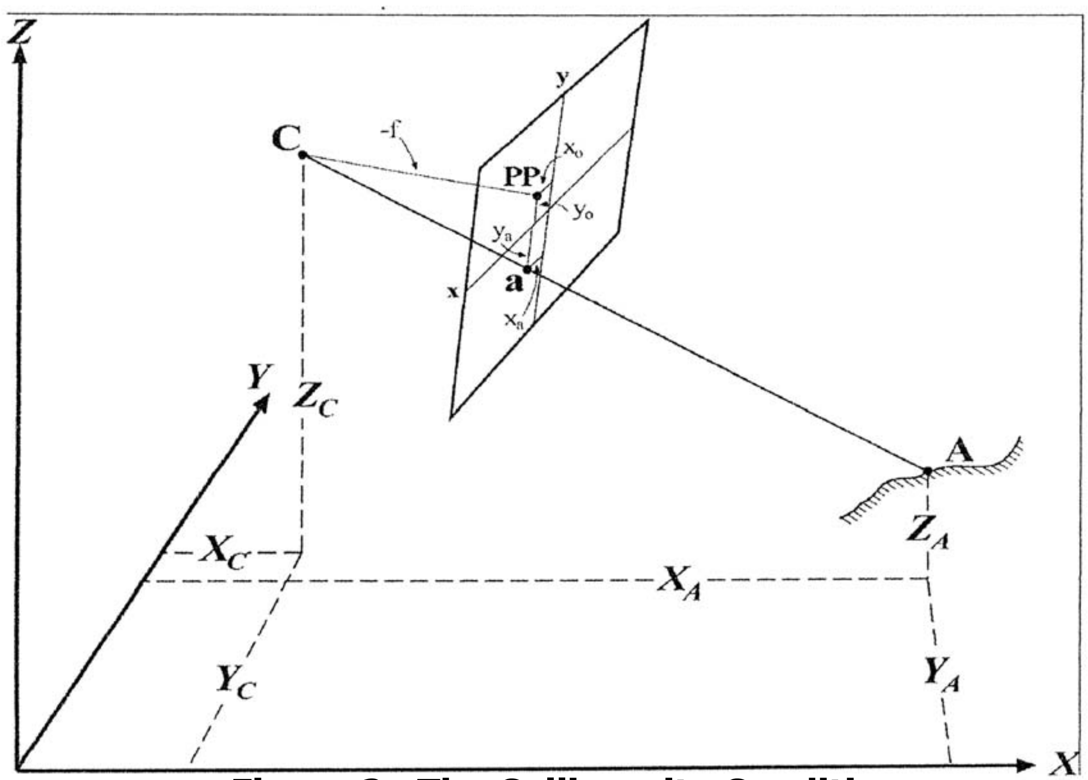

Figure 2. The Collinearity Condition

systems. In the collinearity equations, the image point "a" is put in terms of the principal point "PP" and its respective coordinates x_0 and y_0. The principal point is where the principal ray (the straight-line ray that travels from point "A" through the center of the lens to the center of the imaging plane unrefracted [4, 16, 21]) intersects the image plane, and is usually the center of the negative or CCD. In Figure 2, "PP" appears not to be in the center as it should be, but for illustration, it was (probably) offset to demonstrate that it also possesses its own respective image space coordinates. "-f" is the focal length of the camera (sometimes it is denoted with a "+f", depending on which convention is used) and "C" denotes the center of the camera lens with its respective object space coordinates X_C, Y_C, and Z_C. In reality, each camera has inherent lens distortion, making this straight-line assumption invalid, however; cameras that are calibrated (either via a calibration program or calibration certificate) have these lens distortion characteristics known, making it a much more accurate device for measuring (camera calibration is the process of taking photos of a special grid from a variety of angles to determine lens distortion, principal point location, focal length, and format size). The author has calibrated several cameras for this work and other works using PhotoModeler's embedded camera calibrator program; the results of the calibrations are located in the Appendix 1 and 13.

Collinearity Equations

As mentioned previously, the collinearity condition is used to develop the collinearity equations. The collinearity equations [4, 5, 16, 17] associate 3-D object space to 2-D image space in a mathematical fashion. They relate the 2-D image space coordinates in terms of principal point, focal length, camera location, camera rotation, and the 3-D coordinates of the object point. The derivation of the equations will not be done here. The reader is referred to the Manual of Photogrammetry [4] or one of the many other photogrammetry texts available [5, 17, 18, 20]. The equations are as follows:

$$x_A = x_0 - f\left[\frac{m_{11}(X_A - X_C) + m_{12}(Y_A - Y_C) + m_{13}(Z_A - Z_C)}{m_{31}(X_A - X_C) + m_{32}(Y_A - Y_C) + m_{33}(Z_A - Z_C)}\right]$$

$$y_A = y_0 - f\left[\frac{m_{21}(X_A - X_C) + m_{22}(Y_A - Y_C) + m_{23}(Z_A - Z_C)}{m_{31}(X_A - X_C) + m_{32}(Y_A - Y_C) + m_{33}(Z_A - Z_C)}\right]$$

where:

x_A and y_A	are A's image space coordinates
X_A, Y_A, and Z_A	are A's object space coordinates
X_C, Y_C, and Z_C	are the object space coordinates of the camera
m_{11} thru m_{33}	are the coefficients of the Rotation Matrix
x_0 and y_0	are the image space coordinates of the principal point
f	is the focal length of the camera lens

The Rotation Matrix, in terms of camera rotation angles ω, ϕ, and κ, is as follows:

$m_{11} = \cos\omega \cdot \cos\phi$
$m_{12} = \cos\omega \cdot \sin\phi$
$m_{13} = -\sin\omega$
$m_{21} = \sin\kappa \cdot \sin\omega \cdot \cos\phi - \cos\kappa \cdot \sin\phi$
$m_{22} = \cos\kappa \cdot \cos\phi + \sin\kappa \cdot \sin\omega \cdot \sin\phi$
$m_{23} = \sin\kappa \cdot \cos\omega$
$m_{31} = \cos\kappa \cdot \sin\omega \cdot \cos\phi + \sin\kappa \cdot \sin\phi$
$m_{32} = \cos\kappa \cdot \sin\omega \cdot \sin\phi - \sin\kappa \cdot \cos\phi$
$m_{33} = \cos\kappa \cdot \cos\omega$

PhotoModeler Software

It is not known precisely how analytical photogrammetry solutions are performed within the PhotoModeler Pro Software, however; it is assumed that the collinearity equations are used in some capacity. Many times in the PhotoModeler software help files [21] the collinearity condition is indirectly referenced particularly in the areas which explain how PhotoModeler works. The author is reluctant to contact PhotoModeler directly for information on their algorithm—most likely this is intellectual property and/or a proprietary secret. In fact, the PhotoModeler website states in a 2001 press release that their algorithm "is the result of more than 8 years of development and contains many of the known leading solution methods along with a number of proprietary improvements" [22]. But EOS Systems Inc. (PhotoModeler's parent company) does concede on the website and help files that a "bundle adjustment" is used and processing is executed in three stages (orientation, global optimization, and self-calibration) for the arrival of an optimal solution. The inclusion of a description of this process will not be done here; readers are referred to the sources above for more clarification.

Accuracy

Photogrammetric accuracy can range from low (1:5000) to high (1:50,000) and its cost is typically proportional to its accuracy ($1000 to $100,000, respectively) [46]. The notation of 1: N, with N being some number is a common technique to depict accuracy in photogrammetry. This methodology is a much better descriptor of accuracy than saying "It's ½ of an inch off." This statement tells the interested persons little to nothing about the scale of the project being measured, but 1: N incorporates the scale automatically into this expression. Being 0.5 of an inch off is rather good if the project is around 500 feet in length (1:12,000) but not so good if the project were about 1 ft in length (1:24). Conversely, a 1:10,000 accuracy could apply to a 50ft object (0.06 of an inch in error) or to a 1ft object (0.0012 of an inch in error) [47]. The following table is a summary of a sample of photogrammetric studies in which their accuracies are reported. It is interesting to note that PhotoModeler's accuracies range from 1:75 to 1:30,000. Alan Walford (president of

EOS Systems) states on the PhotoModeler website that 1:300,000 "could be the project accuracy" and "for most projects the accuracy would be lower than this" [28]. While researching the literature the author uncovered variety of software packages that were used in the studies such as PhotoModeler, Foto-G, OrthoMAX, self-developed software, and others. The majority of the studies provide a declaration of a benchmark measurement, with the preferred technique being the Total Station. A benchmark measurement is a reference measurement by which the study's measurements are compared. (The Total Station is well-regarded in terms of accuracy, but equipment cost and usability are common drawbacks.) One can see from a quick look of the table that a whole host of accuracies are realized. This author's previous accuracies with PhotoModeler are about 1:750 for crush measurement projects and up to 1:5400 for a bank robbery project (forensic photogrammetry). Potential users of photogrammetry will have to decide how much budgetary constraints will play when purchasing software; as said before, accuracy is proportional to cost in most cases. Overall, PhotoModeler is a very good buy in terms of accuracy and value. Table 2 is as follows:

Table 2. Reported Accuracies For Selected Photogrammetric Studies

TABLE OF ACCURACY SUMMARIES				
Author	**Application**	**Benchmark**	**Software/Method Used**	**Reported Accuracy**
Kullgren, et al. [23]	Vehicle Crush (TAR)	Not Given	Self-Developed Software	1:325
Rentschler & Uffenkamp [24]	Vehicle Crush (TAR)	CMM	Imetric	1:4250
Switzer & Candrlic [25]	An Accuracy Study for AR's	Total Station	PhotoModeler	1:75 to 1:5500
Pepe et al. [8]	An Accuracy Study for AR's	Total Station	FotoGram, Plantran, TRANS4, and Others	1:50 to 1:125
Zicarelli [26]	Industrial PG	Not Given	PM^3 Lite	1:3100
Aguilar et al. [27]	Agricultural PG	Laser Scanner	Shape Capture	1:2400
PhotoModeler Website [28]	Accuracy Table on Website	Not Given	PhotoModeler	1:350 to 1:300,000
Deng & Faig [29]	An Accuracy Study	Total Station	PhotoModeler	1:800 to 1:1700
Fraser and Riedel [30]	Industrial PG	Not Given	Austrailis	1:9000
Fenton et al. [10]	Vehicle Crush (TAR)	Not Given	PhotoModeler	1:1400
Jordan et al. [31]	PGM of Horse Hooves	CMM	PhotoModeler	1:2500 to 1:5000
Chandler et al. [32]	PG Accuracy Study	Total Station	Imagine's Ortho BASE Pro	1:1000 to 1:8000
Guarnieri et al. [33]	Architectural PG	Total Station	PhotoModeler	1:600 to 1:2700
Tumbas et al. [34]	An Accuracy Study for AR's	Total Station	Fotogram, Plantran, TRANS4, and Others	1:200
Hanke [35]	A PM Accuracy Study	Total Station	PhotoModeler	1:1700 to 1:8000
Jauregi et al. [36]	PGM of Bridge Deflection	Total Station	FotoG-FMS	1:1700 to 1: 8000
Pappa et al. [37]	PGM of Space Antennas	Not Given	PhotoModeler	1:5000 to 1:28000
Delorme et al. [38]	Medical PG	CT Scan	Self-Developed Software Using DLT	1:86 to1:1200
Fedak [39]	Industrial PG	Total Station	PhotoModeler	1:6700 to 1:23000
Townes & Williamson [40]	An Accuracy Study for AR's	Total Station	PhotoWin 35	1:2400
Brashington & Smart [41]	PG in Geomorphology	Total Station	Imagine's OrthoMAX	1:700 to 1:1750
Lane et al. [42]	PG in Geomorphology	Total Station	Imagine's OrthoMAX	1:800
Pottler et al. [43]	PGM of Solar Concentrators	Not Given	Vision Measurement System (VMS)	1:47000
Wallace et al. [44]	PG in Aerospace	Not Given	Self Developed Software	1:1350
Mills and Carty [45]	PM in Vehicle Crush (TAR)	Total Station	PhotoModeler	1:250
KEY: TAR=Traffic Accident Reconstruction; AR's=Accident Reconstructionists; PG=Photogrammetry; PGM Photogrammetric Measurement; DLT=Direct Linear Transformation				

Photogrammetry In Accident Reconstruction

The first use of photogrammetry for traffic accident reconstruction use, according to this Berling [32], was in 1932 by German police. Several sources maintain that photogrammetry was used for the first time in 1933 (or 1934, depending on which source one chooses) in Zurich Switzerland. Nonetheless, these first uses probably functioned with stereo-cameras and plotters; in other words, specialty machines would trace/draw maps sourced from two photographs of the accident scene. Graphical methods were prevalent in traffic accident reconstruction until the advent of the computer; as the PC became more available to the masses, analytical methods (using the mathematical/collinearity equations to make measurements) became practical and the norm. The fact is that the majority of the material is published after 1980—this directly corresponds to the increased use of computers. Table 3 outlines the history of photogrammetry in accident reconstruction. A sincere attempt was made to include all articles that could be acquired, but some articles were in different languages (prevalently in German & Chinese); obviously, those sources could not be embraced.

Table 3. History of Photogrammetry in Accident Reconstruction

HISTORY OF PHOTOGRAMMETRY IN ACCIDENT RECONSTRUCTION			
Date	Contributor	Contribution	Source
1932	Zeiss Works	German police suggested to the Zeiss firm to develop photogrammetric equipment for police use. The result was the DK 120.	[48]
Either 1933 or 1934	Zurich Switzerland Police	The first known instance where photogrammetry was used for accident reconstruction purposes; used stereo-cameras	[49], [50], [51], [52], [53], [84]
1935	German Police Agencies	Close-Range Photogrammetry was adopted for police use	[53]
1952	Doris L. Rock	Used analytical photogrammetry (computed by hand) to determine the length of skid marks	[49]
1954	Bertil Hallert	Used stereo-photogrammetry to measure deformation in a model airplane wing	[54]
1960	D.I. Burnett	A summary paper which mentions that photogrammetry is used for "road traffic accidents"	[55]
1963	Robert N. Colwell	Photography is unfortunately not always recognized by all "as an unbiased source of truth" and hence photogrammetry and photo interpretation	[56]
1964	John N. Schernhorst	Various types of photogrammetry (single photo, stereo-photogrammetry, and x-ray photogrammetry) are available for accident/crime investigation	[50]
1964	James R. Salley	Advocates the use of stereo-photogrammetry in liew of measuring tapes or pacing for traffic accident investigation	[51]
1967	Iruma City, Japan Police	Obtained a specialty vehicle outfitted with stereo-cameras for "accident disposal"	[53]
1970	Dietrich W. Berling and Karl Zeiss	Describes photogrammetric equipment instruments used in collision investigation by German police and the importance of a "true to scale" survey of the accident scene	[48]
1971	Thomas M. Lillesand and James L. Clapp	Evaluated stereometric camera systems in traffic accident reconstruction. The authors "concluded that stereometric methods can significantly improve the collection, accuracy, preservation, and presentation of metric accident data"	[52]
1974	Clifford G. Bryner	A final report from a NHTSA grant which covers the use of a fabricated stereo-camera system from consumer components in accident scene measurement, vehicle deformation measurement and anthropometric measurement	[57]
1976	Robert L. Bleyl	Employed a hand technique (rectification) to convert traffic accident scenes from a perspective view and converted it to a top-down view from which measurement could be made	[58]
1976	Joel Kobelin	Uses a truck outfitted with a stereometric camera system for the specific purpose of mapping traffic accident scenes in Florida	[59]
1978	William G. Hyzer	A quick manual photogrammetric method that employed perspective grids; limited use for flat surfaces only; buildings, streets, etc.	[60]
1979	A.O. Quinn	Advises the photogrammetrist on what to expect when testifying about his/her photogrammetric products in a court of law	[61]
1980	Robert M. Haralick	Informs the reader to the theory behind 2-D and 3-D perspective scene transformation and applies this transformation to an example	[62]
1980	A.W. Thebert	Utilizes a reverse-projection technique which consists of digitizing equipment and a computer algorithm that converts perspective pictures to a top-down map for making measurements of skid marks	[63]
1980	Sanjib K. Ghosh	Describes the use of close-range photogrammetry for traffic accident in Japan by police. Specialty vehicles with mounted stereo-cameras are used throughout Japan with much success	[53]
1980	Allan D. Howarth	A thesis that shows that a simple system consisting of non-metric cameras and perspective grid theory meets or exceeds conventional methods. This was accomplished through a review of literature, interviews of (police) personnel, and planned experimentation	[64]
1981	A. Lozzi & J. Chapman	Uses a single stereo-photogrammetric technique to determine the displacements and velocities of dummies in a car-to-pole side impact	[65]
1982	J.P. Verriest	Uses cinephotogrammetry to get the dynamic deformation of the torsos of cadaveric specimens or animals (pigs); the experiment itself simulates conditions similar to a vehicle crash	[66]

Table 3. cont'd

HISTORY OF PHOTOGRAMMETRY IN ACCIDENT RECONSTRUCTION			
Date	Contributor	Contribution	Source
1983	Francois Mesqui & Peter Niederer	Studied the head trajectories of pedestrian surrogates in a simulated vehicle-pedestrian collision via cinephotogrammetry	[67]
1984	Peter Niederer & Max Schlumpf	Cinephotogrammetry was used to study the impact of variable vehicle front geometry on the trajectories of pedestrian heads in a simulated accident	[68]
1984	P. Waldhausl & H. Kager	Used a self-developed photogrammetric package called ORIENT to examine traffic accident scenes in Austria	[69]
1985	Haim B. Papo	Developed a proposed method for the analysis of deformations of engineering objects and structures using close-range photogrammetry	[70]
1985	W. Hoechtl	Stereo-photogrammetry was used at VW to measure the crush deformation of vehicles engaged in crash tests	[71]
1985	John F. Kerkhoff	Extracted information (measurements) from photos using graphical techniques that follow the principals of perspective	[72]
1985	Peter Niederer et al.	Used a single-view photogrammetric technique for accident scene documentation with the assistance of computers that helped with image analysis	[73]
1985	Steven L. Birge	Developed a system that exploited the geometry of perspective and created a specialized adapted theory for their own use for real-time highway documentation	[74]
1986	Larry Gillen	A report on forensic photogrammetry at the ASPRS-ACSM meeting. Various photogrammetric and legal topics are discussed	[75]
1986	Wilfried Wester-Ebbinhaus & Ulrich E. Wezel	Used a metric photogrammetric system, the Rolleiflex SLX, in the deformation analysis in the Porsche car crash tests. Talked about the benefits over a traditional measuring technique.	[76]
1986	Larry Gillen	Utilized stereo-photogrammetry to map deformations. A stereo-camera, surveyor's range poles, and a stereo-plotter are used in this technique	[77]
1986	Kevin C. Breen & Carl E. Anderson	A paper that reports how photogrammetry was useful in a case study involving measurements of a windshield	[78]
1986	Wesley D. Grimes et. al.	A paper that shows that FOTOGRAM can be utilized for accident reconstruction purposes; illustrated with a single case.	[79]
1986	J. Rolly Kinney & Bill Magedanz	TRANS4 is a photogrammetric program that will transform 4 points 9hence the name0 from a real surface to a photograph surface; illustrated with a single example	[80]
1986	Janet Brelin et al.	Discussed FotoGram, a 2-D photogrammetric software package. FotoGram was developed by GM for accident reconstruction purposes	[81]
1986	J. Stannard Baker	A topic in a manual for traffic accident investigators. Tells readers how to utilize graphical techniques for accident map reconstruction; mentions stereocameras and their associated plotters	[132]
1988	Gregory C. Smith	A dissertation in which a mathematical model for dealing with single-photo situations is presented. Self-developed computer programs are created to assist in this work.	[82]
1988	Jack Whitnall et al.	The authors utilize reverse camera projection to extract measurements for a 2 year old case in which the intersection of interest was completely repaved and revamped.	[83]
1989	Taichi Oshima & Kiyoshi Oyamada	Summarized the current state of a country-wide implementation of specially outfitted photogrammetric vehicles for police use in Japan	[84]
1989	T.K. Koo	Developed a photogrammetric system that integrates a DLT analytical algorithm with a CAD program for accident mapping. The DLT algorithm is self-developed.	[85]
1989	Michael D. Pepe et al.	Discussed the history and theory of photogrammetry. Several case studies in which photogrammetry was employed were mentioned also.	[8]
1989	Terry D. Day and Randall L. Hargens	An article which warns about the misapplication of computer programs in accident reconstruction. Photogrammetry is mentioned; says of 4 control points, 3 must not be in a straight line	[86]
1989	Gregory C. Smith & Douglas Allsop	A review paper of single-image photogrammetric methods. A summary of dissertation; discusses his self-developed single-photo analytical method	[87]

Table 3. Cont'd

HISTORY OF PHOTOGRAMMETRY IN ACCIDENT RECONSTRUCTION			
Date	Contributor	Contribution	Source
1990	Robert Godding	VW used photogrammetry to evaluate a dummy's deformations and motion during crash tests	[88]
1990	Terry D. Day & Randall L. Hargens	A section in a topic of a manual for traffic accident reconstruction. Illustrates graphical photogrammetry with an example of how to measure skids using a single photo.	[133]
1991	T.K. Koo & Y. B. Aw	A refinement of a previous technique where this technique allows shaded renderings of accident scenes.	[89]
1991	Masary Yeyama, et. al.	The authors studied various deformation patterns of vehicles from various start positions. Photogrammetry was used to measure the deformations (used a stereo-camera system)	[90]
1991	Albert V. Karvelis, et. al	The authors developed a Photogrammetry Vision System (PVS) to analyze the deformations in high speed crash tests	[91]
1991	Ronald L. Woolley, et al.	Vehicle crush is determined using the "Two-Image Camera Reverse-Projection Method"; this technique was compared to the results of a Total Station	[92]
1992	Andrew C. Henry	Photogrammetry and traditional survey techniques were used to generate a 3-D model of a hill on which an accident occurred	[93]
1992	W. Faig et. al.	A technique was developed for vehicle-damage investigation; employed the use of a non-metric stereo-camera and a slide projector-tablet digitizer-microcomputer combination	[94]
1993	Annette L. Rizer et. al.	VROOM (Visual Reconstruction of Object Motion), a specialized cinephotogrammetry program, was used to reconstruct the vehicle's kinematics from film or video in a large environment	[95]
1993	A.T. Campbell and Richard L. Friedrich	A CAD program was used to model items first of a known nature, and next unknown items. These scenes are matched in the CAD program and measurements are subsequently extracted	[96]
1993	Pepe, Michael E. et. al.	Evaluation of the accuracy of 3-D photogrammetry by examining four situations: 1. planar 2. non-planar 3. non-planar compound 4. crush	[97]
1994	A. Kullgren, et. al.	Developed a photogrammetric system by which the exterior deformations of nearly 500 cases and 15 different car models have been examined. Time in the field and time to process photogrammetric measurements have been reduced greatly.	[98]
1994	A. Kullgren, et. al.	A more comprehensive version of the above study. Same study. Utilized non-technical and technical personnel. Used 2 models for each vehicle: an exemplar and a crushed and then made measurements separately (I use a superimposed method)	[23]
1994	Nicholas S. Tumbas et. al.	One 2-D and six 3-D experiments were evaluated for accuracy. Non-metric and metric cameras were used as were different photogrammetric programs (FotoGram, Trans4, Plantran)	[34]
1995	Ron Rohde	Used Adobe Photoshop to transform images without the use of photogrammetry software. Once the images were transformed, they are suitable for measurement extraction	[99]
1995	A. Kullgren et al.	An entire fleet of one particular make and model of car was outfitted with low-cost accelerometers. The interiors of the cares were evaluated and linked to the injuries of the occupants. Photogrammetry helped them to "judge the interior contacts."	[100]
1995	Donald F. Rudny & David W. Sallmann	An experiment not performed. An instruction-type paper that informs accident reconstructionists about the procedures on how to survey a scene with electronic survey equipment. Talks about how electronic survey can be important to photogrammetry in accident reconstruction situations	[101]
1995	Bruce W. Main and Eric A Knopf	A report on a new technique developed by the authors; an extension of the camera reverse projection technique (using model cars) was used to get the measurements needed	[102]
1996	Paul Duignan et. al.	A photogrammetric system at the Roads and Traffic Authority in N.S.Wales Australia examined 500 vehicles to date. A modification of the Lie [23] system was used	[103]
1996	Michael D. Pepe et. al.	Instead of rectifying a number of points (or line drawings) the authors rectified the entire image using DIREC, thereby supplying a great deal of more information as opposed to traditional methods	[104]

Table 3. Cont'd

HISTORY OF PHOTOGRAMMETRY IN ACCIDENT RECONSTRUCTION			
Date	Contributor	Contribution	Source
1996	Yih-Ping Huang et. al.	Two photos were used by the authors—one was supplied and one was "synthetic"—so that measurements could be extracted from the scene. A mathematical relationship relates the dimensions of the 2 photos.	[105]
1996	Fay & Gardner	The authors use a pseudo-camera-reverse-projection technique to verify actual photos of a scene to the animation for accuracy.	[106]
1997	William E. Cliff et. al.	Compared to PC-Rect's (2-D) results to survey results. Only good for flat scenes. Typical scenes are rectified with in a 1% accuracy.	[107]
1997	Stephen Fenton & Richard Kerr	A report of a newly developed technique. The authors generated an accident scene diagram using one "ole" and many "new" photographs. (The new photographs have features in common with the old photo.)	[108]
1998	A. E. Peterson et. al.	Developed a photogrammetric program called TRIPLET based on the collinearity equations to study velocity and acceleration at 2 particular intersections in Canada using video-taped footage.	[109]
1998	Harry W. Townes & James R. Williamson	Completed an accuracy study using an accident scene. Used ICE (Iteration of the Collinearity Equations) in this study. Uses single and multiple photos and two different focal lengths.	[110]
1998	David J. Massa & Roger W. Barrette	The authors state that 3DD can assist in a computer-reverse projection photogrammetry analysis when mapping a vehicle	[111]
1999	Mohammed Obaidat	Used a system that integrated stereo-photogrammetry and GIS to collect and process traffic accident data. Outputs are 3-D coordinates and time.	[112]
1999	David A. Switzer & Trevor M. Candrlic	The authors conducted a study to understand the specific variables affecting the accuracy of PhotoModeler, such as camera info known/unknown, fiducials present/not present, digitizing technique, image cropping, and number of control points	[25]
1999	Stephen Fenton et. al.	PhotoModeler was used by the authors to analyze a single vehicle's crush and to determine its EBS. PhotoModeler did the photogrammetry and EDCRASH determined the EBS.	[10]
1999	David J. Massa	A report of a technique in which accident scene information was located not from photographs (as in photogrammetry) but from animations or computer-generated images	[113]
1999	Walter Rentschler & Volker Uffenkamp	The authors use photogrammetry to measure the deformation during Phorche crash tests. Claims there is a reduction of 50% in measuring costs verses traditional measuring techniques	[24]
1999	Bruno Esteve et. al.	Discussed the use of photogrammetry in the measurement of drivers' visibility fields using a fish-eye lens	[114]
1999	Ruldolf Limpert	A section in a traffic accident reconstruction manual. Informs readers to a couple of graphical photogrammetric methods: the linear method and the grid field method	[134]
2000	**Lara L. O'Shields**	**A Master's Thesis that concerned the use of PhotoModeler in accident reconstruction; more specifically the measurement of a single vehicle deformation case compared against NHTSA crash test results and a single pre-measured accident scene.**	**[115]**
2000	Stephen Fenton, et. al.	PhotoModeler was used to determine crash severity and assist in the study of occupant kinematics. Very close to their 1999 SAE paper.	[116]
2000	Scott A. Cooner & Kevin N. Balke	A study that involved the determination of the feasibility of integrating photogrammetry into how Texas DOT and police agencies document crash scenes. Includes a survey of police agencies currently using photogrammetry.	[117]
2000	Zonghe Guo et. al.	Developed a video camera/self-developed software system to document traffic accidents in China. Presents the theory used & calibration data, but results from a traffic accident are not presented	[118]
2000	Samuel R. Rod	An article in a magazine aimed at those who use imaging equipment. Contains basic information on photogrammetry used in crime scenes and accident reconstruction	[119]
2001	William G. Hyzer	A chapter out of an online forensic reference book. Would bemore aptly entitled "Forensic Photography" rather than "Forensic Photogrammetry." Lightly uses graphical and analytical photogrammetric methods.	[120]

Table 3. Cont'd

HISTORY OF PHOTOGRAMMETRY IN ACCIDENT RECONSTRUCTION			
Date	Contributor	Contribution	Source
2001	H. Becker et. al.	Created a new photogrammetric vehicle documentation system at VW. Vehicles' deformations are later examined for directional force estimation and for assistance in the accident reconstruction	[121]
2001	Stephen Fenton et. al.	In lieu of using a transparency to match the accident scene (the traditional camera-matching method), the computer software is used to match the scene. A case study was utilized where the results of the camera matching technique was compared against a surveyed scene with known dimensions	[122]
2001	Bryan C. Randles et. al.	PhotoModeler was used to aid in the verification/'validation of pedestrian throw equations at a particular intersection in Helsinki, Finland equipped with a video camera	[123]
2001	Carol H. Waters & Scott A. Cooner	Suggested the use of photogrammetry to alleviate traffic jam situations due to traffic accidents. This alleviation might help in the prevention of road rage	[124]
2001	J. Stannar Baker et. al.	A chapter in a traffic investigation manual. Covers graphical techniques such as grids. Reverse camera projection and computer reverse projection are included. Discusses mathematical methods and computer programs	[135]
2003	Dirk Behring et. al.	Researchers at VW examine vehicle crash test deformation using photogrammetric software called TRITOP. Can measure up to 5000 points in less than two hours	[125]
2004	**Lara L. O'Shields et. al.**	**Used PhotoModeler to examine NHTSA crash tests and verified the computed EBS value to the actual test speed. The variations were examined with bootstrapping. 45% of the variability is due to technique, 55% of variability is due to vehicle type**	**[126]**
2004	William T.C. Neale, et. al.	The authors documented three different scenes/items with video, as opposed to using still photographs for photogrammetric purposes. Used a software program called Boujou 2.0.	[127]
2005	Robert V. McClenathan et. al.	Applied "real-time" photogrammetry in crash tests to study dummy occupant motion and vehicle deformation. FalCon eXtra 4.05 was the software used in this study.	[128]
2005	Fiona Coyle et. al.	The authors compared PhotoModeler's results to tape measure and measuring jig/pipes in a single crush measurement experiment	[129]
2005	Angelo Toglia et. al.	Four types of projects were completed in this work: 1. single-photo calibrated/2. inverse camera and 3. multi-photo calibrated/4. inverse camera. Three accident scenes were analyzed under different conditions. Claimed to have presented new tools/methodologies in the application of PhotoModeler	[130]
2005	Raymond M. Brach & R. Matthew Brach	Included a photogrammetry chapter in a traffic accident reconstruction text. Discusses reverse projection, planar (2-D) photogrammetry, and 3-D photogrammetry. Also photogrammetry in vehicle crush is mentioned	[15]
2006	Clifford C. Chou	Photogrammetry was used in a dynamic setting in a roll-over crash test using camera matching. Vehicle roll angle and rate were measured with photogrammetry and compared with vehicle sensors. Roll angles were in close agreement with the sensors; rate data was not.	[131]

Photogrammetry in Other Areas

It would be a great injustice to discuss photogrammetry by not discussing the other areas beneficially affected by this great art and science. There is a wide variety of the application of photogrammetry. Table 4, Application of Photogrammetry in Other Areas is by no means a comprehensive, all-inclusive list of possibilities; it is simply a mere sampling of uses.

Table 4. Photogrammetry in Other Areas

PHOTOGRAMMETRY IN OTHER AREAS			
Application	Description	Software	Source
Forensic	Compared bank video to actual suspect and found similarities in gait and other measures	PhotoModeler	[136]
Forensic	Introduced a preliminary study that attempts to make identification of persons from surveillance cameras using photogrammetry	PhotoModeler	[137]
Forensic	Photogrammetry assisted in the matching of a muzzle of a gun to wounds on a person's face	RolleiMetric	[138]
Forensic	A soft-tissue injury to the face was matched to tire tracks using photogrammetry	RolleiMetric	[139]
Architectural	Used PhotoModeler to help document and conserve Brazil's historic towns and urban areas	PhotoModeler	[140]
Architectural	Mounted a camera on a RC helicopter; took video of various national treasures; extracted stills from video; used PhotoModeler to create 3-D of national treasure	PhotoModeler	[141]
Architectural	A tutorial on the theory, procedures, and tools for architectural documentation via photogrammetry	PhotoModeler	[142]
Engineering	Photogrammetry was used to measure the amount of deformation of the wings of wind-tunnel models to help compute aerodynamic force	Self-developed	[143]
Engineering	PhotoModeler was used to model an automotive exhaust system and body.	PhotoModeler	[144]
Engineering	Iowa DOT used photogrammetry with low-flight helicopter photography for mapping in highway engineering.	SoftPlotter	[145]
Engineering	PhotoModeler helped to study acoustical phenomena of bells. A bell sounds differently while it is being struck and shortly after being struck.	PhotoModeler	[146]
Engineering	Used PhotoModeler, video cameras, lasers, and filters to study the dynamic properties in solar sails which are clear or aluminum	PhotoModeler	[147]
Engineering Education	Outlines a lab exercise for undergraduate mechanical engineering students. Used PhotoModeler Lite to model and measure some arbitrary part	PhotoModeler Lite	[148]
Biological	PhotoModeler was used to measure the surface area of corals and other irregular objects utilizing underwater photography	PhotoModeler	[149]

Relevance of This Work

There are a host of advantages for using photogrammetry in traffic accident reconstruction. The preceding sections maintain that photogrammetry is accurate and widely used in accident reconstruction (AR), but why? The following is a list of reasons (in no particular order) which make photogrammetry beneficial for the AR field:

- **Cost:** PhotoModeler, in comparison with other photogrammetry packages, is very affordable. PhotoModeler 6.0 sells for around $1000 USD. Some photogrammetry packages mentioned previously costs $100,000 +. PhotoModeler requires no specialized equipment—just a computer and a consumer-grade camera of your choice.
- **Efficiency:** Using photogrammetry results in less time in the field. The photos can be taken of the object of interest (a car, or an accident scene) and the much needed measurements can be obtained at a later time at the office. Also it has been written that photogrammetry may help alleviate traffic jam

situations which could help prevent further delays (and further accidents, see below) since it is quicker than total stations [117, 124].

- **Safety:** Photogrammetry is a safer alternative to using conventional measurement techniques because it is generally quicker. This is because personnel are not placed in harm's way (in the path of traffic) for as long when documenting accident scenes using photogrammetry [117, 124].
- **Accuracy:** The previous section attests to photogrammetry's accuracy. Its accuracy is in excess of what is required for most accident reconstruction applications. Speed estimates from skids and the CRASH3 algorithm require much less that what photogrammetry is capable of doing.
- **Timeless application:** Photogrammetry can be used at the time of the accident or even years later. Sometimes the accident reconstructionist is given photos of a vehicle that was crushed many years earlier. Perhaps that vehicle, in its crushed state, is not available for inspection because it was scraped, repaired, or even destroyed. Photogrammetry can determine

the amount of crush (and hence, a proper delta-v) for that vehicle even if it doesn't exist anymore. In this sense, photogrammetry is timeless; it doesn't care if the car was crushed two years ago even two days ago—it still can do the job. The same can go for accident scenes. Many times the scene has been "revamped" either by repaving or reconfiguration. It is possible for photogrammetry to extract needed measurements from the scene photos just as long as some components remain the same—like road signs, guard rails, manhole covers, and other prominent landmarks.

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PART ONE

VEHICLE CRUSH MEASUREMENT

Part One is lightly revised version of a paper published at the 2004 SAE World Congress in Detroit by Lara L. O'Shields, Tyler A. Kress, John C. Hungerford, and C.H. Aikens:

O'Shields, Lara L. et. al. "Determination and Verification of Equivalent Barrier Speeds (EBS) Using PhotoModeler as a Measurement Tool" SAE Paper 2004-01-1208, SAE International, Warrendale, PA, 2004. (126)

The content of this publication was an extension of O'Shields' Master of Science Thesis work. The Master's work and the PhD's work are similar in that they both used NHTSA's controlled crash data, however; they are dissimilar in the fact that this work analyzed twenty-one (21) different NHTSA vehicles as opposed to only one (1) vehicle in the Master's work. Kress gave O'Shields the idea of using NHTSA crash data back in 1998. Kress also helped with document edits. Hungerford provided the use of the PhotoModeler software and Aikens assisted with the statistical analysis portion of this work. Photogrammetry, spreadsheet development, bootstrapping, and document development were all done by O'Shields.

Abstract

This study focused on the role of PhotoModeler, a close-range photogrammetry software package, in an important facet of traffic accident reconstruction—vehicle crush measurement. More specifically, this study applied the PhotoModeler process to controlled crash information generated by the National Highway Traffic Safety Administration (NHTSA). A statistical technique known as

bootstrapping was utilized to generate distributions from which the variability was examined. The “within” subject analysis showed that 44.8% of the variability is due to the technique itself and the “between” subjects analysis demonstrated that 55.2% of the variability is attributable to vehicle type—roughly half and half. Additionally, a 95% CI for the “within” analysis revealed that the mean difference (between this study and NHTSA) fell between -2.52 mph and +2.73 mph; the “between” analysis showed a mean difference between -3.26 mph and +2.41 mph.

Introduction

In the accident reconstruction community, it has been known for thirty years or more that vehicle crush can be used to determine the equivalent barrier speed (EBS). Emori [150] and Campbell [1] each showed that the relationship between crush and speed is linear in nature. Additionally, Campbell [1] related vehicle crush and the vehicle’s stiffness characteristics to the amount of energy absorbed; this energy can be subsequently used to compute the EBS. Campbell’s work is the foundation for the equations and software used by accident reconstructionists to determine crush energy and, consequently, the EBS.

In order to get the energy from crush, the crush must first be measured. There are a variety of techniques available: tape measures, measuring poles, grids, and photogrammetry. The major problem with the first three techniques is that one is measuring against a "phantom" pre-impact boundary. The post-impact vehicle position/shape is located easily enough, but not the pre-impact vehicle boundary position/shape. With these two techniques, locating the front of the vehicle prior to frontal impact could be described as an educated guess at best. But with photogrammetry, the locations of the pre- and post-impact components are both known. The technique is one where 3-D models are created of both the crushed and the exemplar vehicles. The models of the two vehicles are "superimposed" on top of one another. Crush measurements can then be established from the pre- and post-impact points of the 3-D model. An energy calculation can then be made using vehicle stiffness data and the pre-impact speed can be determined via a correlation.

The main objective of this study was to show that PhotoModeler is a suitable measurement tool for vehicle crush measurement. This was accomplished by applying PhotoModeler plus crush equations to NHTSA controlled crash data. The consistency of the studies' results with the nominal 35 mph is the indicator of acceptability of the technique.

Two statistical analyses were performed: (1) the "within" subject design and (2) the "between" subject design. The first involved measuring the same vehicle twenty different times. This gave us a good idea of the repeatability of the experiment. The second involved measuring various types of vehicle categories (such as SUV's, Pickup Trucks, Luxury Cars, Mid-Size Cars) to examine the variability between vehicle classes.

The NHTSA photographs needed for this study's analysis are problematic to use for this work because of their poor quality and limited quantity. Therefore, this effort could not support a large sample size needed for most statistical analysis. As will be discussed later, a "bootstrapping" technique allowed statistical analyses to determine variance. In effect, there were two experiments (the "within" and the "between") and they each had their own associated bootstrapping analysis to determine each variance.

Selection of Samples

As mentioned previously, photographs from NHTSA reports were used. The specific sample that was used in the "within" subjects design was of a 1998 Ford Contour (NHTSA test # 2708). The specific samples that were used in the "between" subjects design are delineated in Table 1 below.

Table 1. Vehicles Used in the "Between" Subjects Design

Case	Category	Vehicle	NHTSA Test #:
1	Large Luxury Cars	2002 Cadillac DeVille	4238
2	Midsize Luxury Cars	2003 Mercedes E320	4483
3	Large Family Cars	2001 Buick LeSabre	3520
4	Midsize Moderately Priced	2003 Toyota Avalon	4486
5	Midsize Moderately Priced	2002 Audi A4	3566
6	Midsize Inexpensive	2003 Hyundai Accent	4473
7	Midsize Inexpensive	2001 Chevy Malibu	3666
8	Convertibles	2003 Honda S2000	4462
9	Small Cars	2002 Mini Cooper	4273
10	Small Cars	2003 Toyota Corolla	4266
11	Utility Vehicles	2002 Chrysler PT Cruiser	4230
12	Midsized Utility Vehicles	2002 Ford Explorer Sport	4223
13	Midsized Utility Vehicles	2002 Nissan Pathfinder	4263
14	Small Utility Vehicles	2002 Toyota Highlander	4265
15	Small Utility Vehicles	2003 Subaru Forrester	4479
16	Large Pickups	2002 Dodge Ram 1500	4240
17	Large Pickups	2001 Nissan Frontier	3574
18	Large Pickups	2003 Chevy Silverado	4472
19	Passenger Vans	2001 Dodge Wagon Van	3639
20	Passenger Vans	2001 Dodge Caravan	3659

Note that these samples were selected as having sufficient quality photographs.

PhotoModeler Procedure

Description of the Software

PhotoModeler is a photogrammetry software package presented by EOS Systems in Vancouver, British Columbia. The specific version of PhotoModeler used in this study was version 4.0g. PhotoModeler can be used for a multitude of different measuring applications, including plant engineering, forensics, anthropology, and of course, traffic accident reconstruction. Interested readers can visit http://www.photomodeler.com for purchasing and additional information. PhotoModeler is capable of handling 2-D AR projects like accident scene measurement, and 3-D projects such as vehicle crush measurement.

Description of a Generic PhotoModeler Procedure

The first step of a new PhotoModeler project involves taking pictures of the object or scene of interest. A new project is then created using the software's Project Setup Wizard; this is where the user enters fundamental information such as location of the digitized photos, approximate size of the object, and camera information. After that, the user marks features with a mouse on each photograph using the various tools available. Next the project is processed and PhotoModeler creates a 3-D model from the 2-D photographs. The user then gives the project dimension by scaling it. At this point, the user can extract the desired measurements from the marked features.

Camera Calibration

For use in this study, a digital Olympus C-5050 was calibrated using the embedded Camera Calibrator program in PhotoModeler. Camera calibration ensures an accurate measuring device. This particular camera was chosen because of its (relatively high at the time of the study) resolution (5.0 Mega pixels), its use of ordinary rechargeable AA batteries (the author has several sets of AA batteries on hand when performing photogrammetry work) and its ability to hold two (2) digital storage cards (an xD and a Compact Flash). The process involved taking eight (8) pictures of a special grid which was projected onto a wall. On the following page, this is illustrated with Figure 1, which is a screenshot (a depiction of what one might see on the computer screen) of the procedure. The calibration procedure is well documented in O'Shields [115] and in Appendix 1 and 13. After points were marked and processed with the Camera Calibrator software, camera information such as focal length, format size, and principal point was determined as a result. Figure 2 shows the C-5050's resultant camera information.

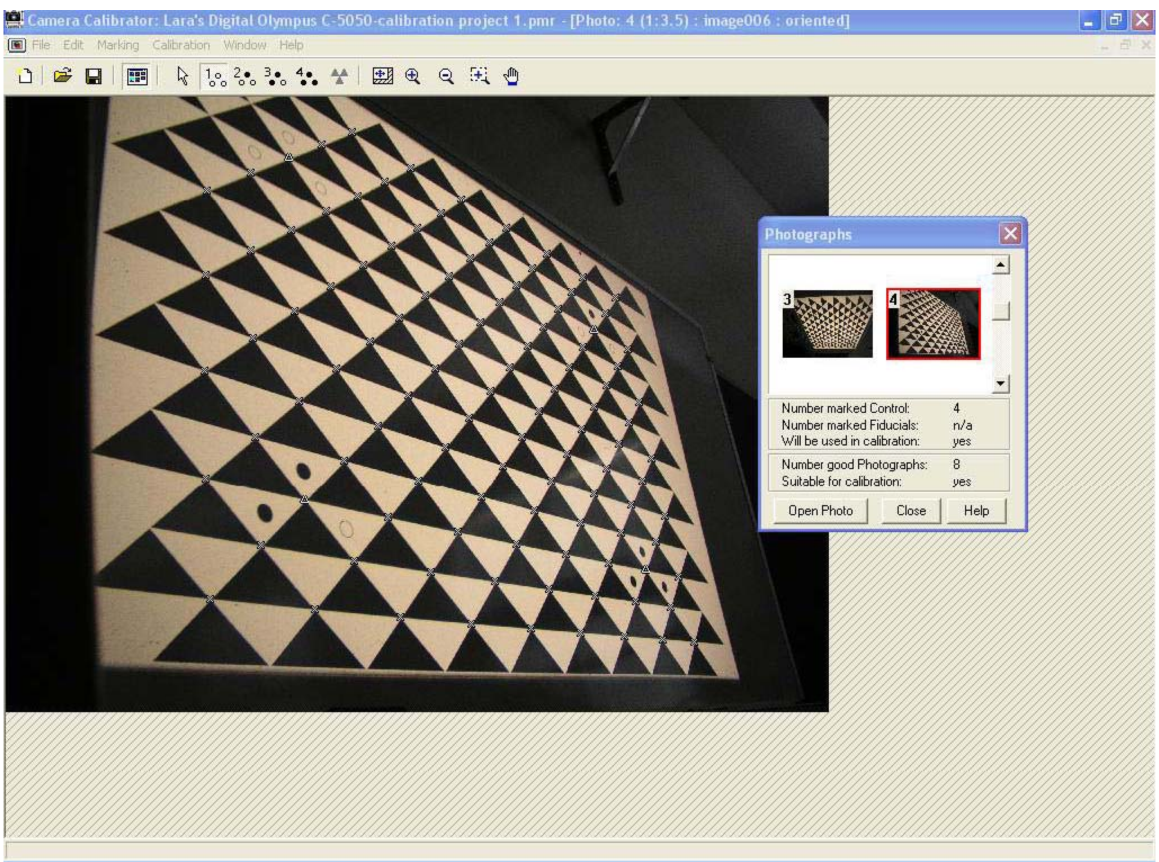

Figure 1. Camera Calibration Grid

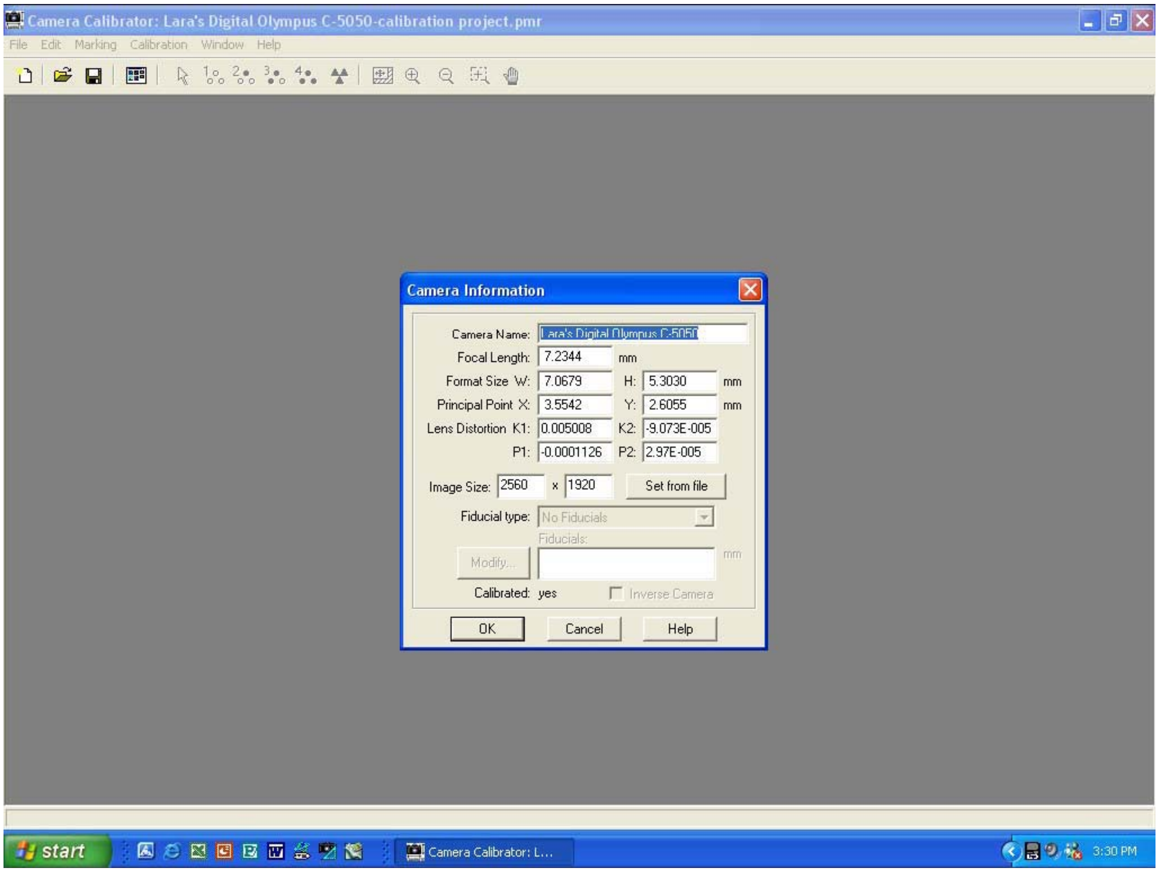

Figure 2. Result of the Olympus C-5050 Calibration Procedure

Exemplar Modeling

Note: A more involved and more detailed description of vehicle modeling can be found in O'Shields [115]; the following is a suitable but succinct version of the vehicle modeling process. The first step in the crush measurement project was to determine the year, make, and model of the subject or crushed vehicle and then locate an exemplar of that particular vehicle model at a local dealership.

Several pictures from a variety of angles were then taken of the exemplar with the calibrated camera. In order for PhotoModeler to create an accurate 3-D model, every point must reside in at least two (2) photographs, preferably three (3.) The user's picture taking technique needs to reflect this requirement, hence; the pictures must overlap. Figure 3 helps to demonstrate this point. For instance, a single point like Point # 8 (which is a point on the front badge of the vehicle) must reside in three (3) different photographs (Photo 1, Photo 2, Photo 3). The camera positions were typically at the four sides and at the four corners of the vehicle, which allowed for good overlap. For scaling purposes, at least one physical measurement must be made on the exemplar. This particular measurement can be between any two distinct points on the vehicle. Normally, the length along the bottom edge of a (front) door or the wheelbase was selected for the sake of simplicity. The photos themselves were downloaded from the camera to the computer via USB cable and stored in a folder marked "Exemplar Malibu" (or whatever the vehicle model may be) on the computer's desktop for easy retrieval.

Using PhotoModeler's "Project Setup Wizard", two or three photos at a time were opened up and distinct points on the vehicle were marked and referenced on all photos. "Marking a point" entails selecting the point tool which looks like a single "x" on the toolbar. The user would then mark a distinct point on the first photograph, such as point # 8 which is the edge of one of the stars on the Subaru badge. "Referencing a point" required the use of the referencing tool on the toolbar which resembles a double "x." Referencing "notifies" PhotoModeler of Point # 8's location on the other photos (Photos # 2 and # 3), i.e., this allows PhotoModeler to recognize that this is the same physical point in space. This procedure of marking and referencing continued until the entire exemplar was modeled. After processing and scaling, the exemplar model was exported into a .dxf format for the control point file. This step was completed in PhotoModeler under the File menu.

Crushed Vehicle Modeling

The first task in this portion of the study was to obtain pictures of the crushed vehicles. The user could download the pictures, print them out, and digitize them via flatbed scanner, or, download and save the pictures directly. This was the procedure utilized in this study, with the exception of the vehicle examined in the "within" subjects design (a 1998 Ford Contour). In this instance, the authors had the NHTSA report already in their possession and the photos were digitized with the scanner. The NHTSA website to visit to obtain the crash test photos is http://www-nrd.nhtsa.dot.gov/database/nrd-11/veh_db.html. The digitized photos were then opened into the exemplar project (saved under another name) and the .dxf control point file was opened. Control points were marked on undamaged portions of the crushed vehicle and referenced across the exemplar.

After processing, points on the damaged portion of the crushed vehicle were marked and referenced. The project was processed one final time. Reference lines were established and measurements were extracted. Figure 3, a screenshot of the 2003 Subaru Forester utilized in the study, shows exemplar and crushed photos, as well as a 3-D viewer. The 3-D viewer reveals the 3-D model created in the study; the exemplar is shown with white lines, while the crushed vehicle is indicated by blue points. One can easily see how much crush can be

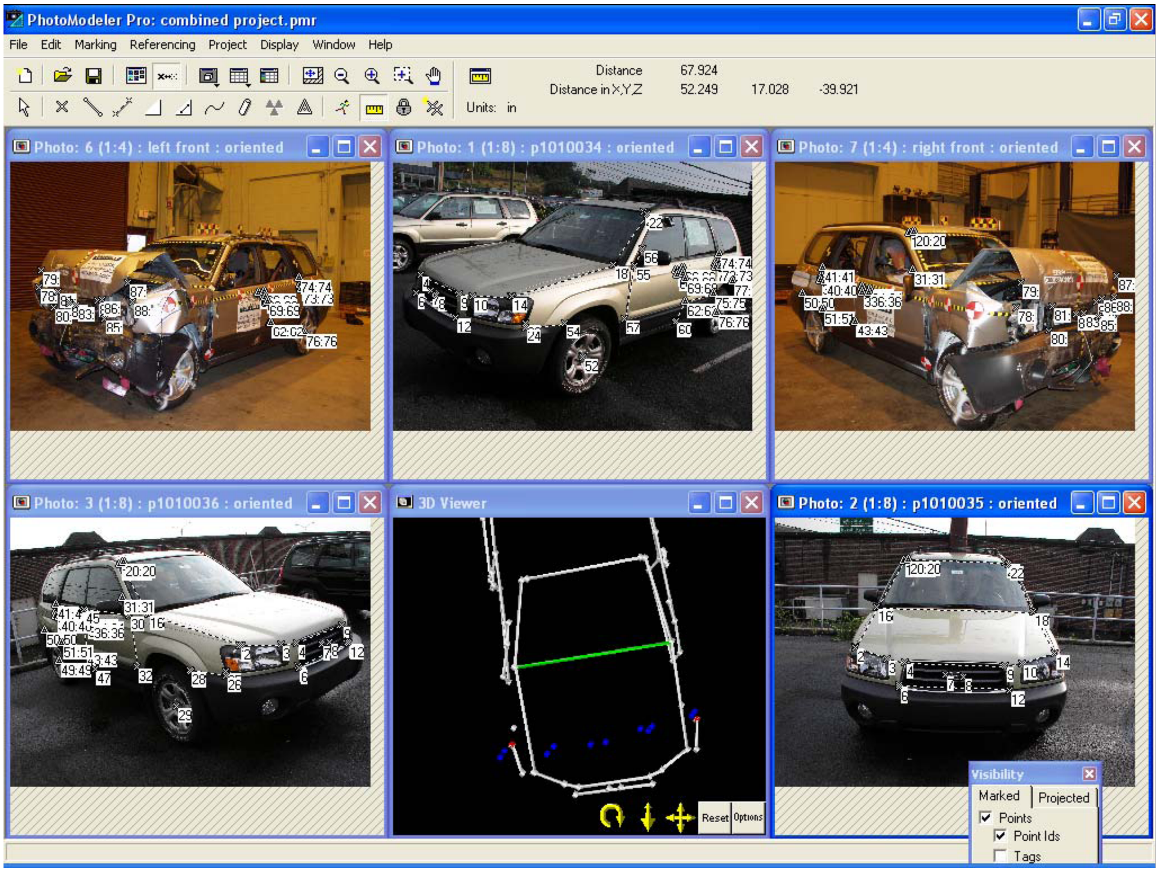

Figure 3. Screenshot of 2003 Subaru Forester

realized in each vehicle. Unfortunately, there were no screenshots generated from the "within" subjects study. Appendix 2 contains all 20 screenshots generated from the "between" subjects study.

EBS Determination

This study utilized equations put forth in Traffic Accident Reconstruction by Cooper [153]. The equations themselves are the

CRASH3 model equations which are based on Campbell's work; this is how this study determined EBS (Equivalent Barrier Speed) and is the authors' preferred method. In using this relationship, vehicle weight, width of crush, and crush coefficients are required input and must be known prior to the calculation of EBS. The first two can be determined easily; the last can be approximated or purchased.

Crush Coefficient Determination

This study made use of the CRASH3 equations for crush coefficients. They are:

$$A = \frac{wb_0 b_1}{gL}$$

$$B = \frac{wb_1^2}{gL}$$

$$b_1 = \frac{(v_i - b_0)}{c_{ave}}$$

where

w = weight of test vehicle (lbs.)
b_0 = maximum impact speed without damage (mph)
b_1 = slope (rate at which permanent deformation occurs)(mph/in)
v_i = velocity of crash test vehicle
g = gravitational constant (in/sec^2)
L = width of crush region on test vehicle (in)
c_{ave} = average crush depth of test vehicle

Figure 4 shows a typical spreadsheet used in crush coefficient determination. This particular example is of a 2003 Mercedes E320. The needed crash test data was taken directly from the NHTSA website which was given previously. Note that the crash test data is in metric units; this is specified on the right portion of the page. These dimensions were subsequently converted to English units, which are shown on the left portion of the page. Crush coefficients A

Crash Test Information				2003 Mercedes E320	case #2
Impact velocity of test:		35.20071	mph	56.65	kph
Maximum speed w/o permanent damage: (b0)		5	mph		
Crush measurements from crash test report:		15.31496	in (c1)	389	mm (c1)
		19.88189	in (c2)	505	mm (c2)
		22.83465	in (c3)	580	mm (c3)
		22.67717	in (c4)	576	mm (c4)
		19.76378	in (c5)	502	mm (c5)
		13.97638	in (c6)	355	mm (c6)
Average crush amount		19.0748	in		
Test vehicle weight		4265.945	lbs	1935	kg
Width of crush damage		71.34646	in	1990	mm
	b1	1.583277	mph/in		
	A	362.6139	lb/in		
	B	109.7281	lb/in^2		

Figure 4. Crush Coefficient Determination

and B were easily computed with the above formulas, information from the website, and the spreadsheet. The initial value of A and B in Figure 4 was determined with a b_0 = 5 mph. Appendix 3 contains all initial crush coefficient spreadsheet information. Additionally, a sensitivity analysis for the crush coefficients was established. This involved using various values of b_0, which in turn, generated different crush coefficients. This can be seen in Figure 5. The b_0 values were

2003 Mercedes E320		**case #2**																
A =	362.6139	lb/in		A =	347.3349	lb/in		A =	331.7556	lb/in		A =	315.8762	lb/in		A =	299.6966	lb/in
B =	109.7281	lb/in*2		B =	111.5523	lb/in*2		B =	113.3915	lb/in*2		B =	115.2457	lb/in*2		B =	117.115	lb/in*2
W (width of cr	0	in		W (width o	0	in		W (width o	0	in		W (width o	0	in		W (width o	0	in
c1 =	15.31496063	in		c1 =	15.31496063	in		c1 =	15.31496	in		c1 =	15.31496	in		c1 =	15.31496	in
c2 =	19.88188976	in		c2 =	19.88188976	in		c2 =	19.88189	in		c2 =	19.88189	in		c2 =	19.88189	in
c3 =	22.83464567	in		c3 =	22.83464567	in		c3 =	22.83465	in		c3 =	22.83465	in		c3 =	22.83465	in
c4 =	22.67716535	in		c4 =	22.67716535	in		c4 =	22.67717	in		c4 =	22.67717	in		c4 =	22.67717	in
c5 =	19.76377953	in		c5 =	19.76377953	in		c5 =	19.76378	in		c5 =	19.76378	in		c5 =	19.76378	in
c6 =	13.97637795	in		c6 =	13.97637795	in		c6 =	13.97638	in		c6 =	13.97638	in		c6 =	13.97638	in
θ =	0	degrees		θ =	0	degrees		θ =	0	degrees		θ =	0	degrees		θ =	0	degrees
G =	599.1575561	lbs		G =	540.739782	lbs		G =	485.3176	lbs		G =	432.8915	lbs		G =	383.4609	lbs
E =	0	in-lbs		E =	0	in-lbs		E =	0	in-lbs		E =	0	in-lbs		E =	0	in-lbs
E=	0	ft-lbs		E=	0	ft-lbs		E=	0	ft-lbs		E=	0	ft-lbs		E=	0	ft-lbs
w = (weight of	4265.944773	lbs		w = (weigh	4265.944773	lbs		w = (weigh	4265.945	lbs		w = (weigh	4265.945	lbs		w = (weigh	4265.945	lbs
v =	0	ft/sec		v =	0	ft/sec		v =	0	ft/sec		v =	0	ft/sec		v =	0	ft/sec
v =	0	mi/hr		v =	0	mi/hr		v =	0	mi/hr		v =	0	mi/hr		v =	0	mi/hr
bo= 5.0 mph				**bo= 4.75 mph**				**bo= 4.5 mph**				**bo= 4.25 mph**				**bo= 4.0 mph**		
56.65	km/h is equal to	**35.200706**	mph				**A average**	368.9027	lb/in		**B average**	108.8837	lb/in*2		**v average =**	0	mi/hr	
A =	377.5929	lb/in		A =	392.2716	lb/in		A =	406.6502	lb/in		A =	420.7286	lb/in		A =	434.5068	lb/in
B =	107.919	lb/in*2		B =	106.1249	lb/in*2		B =	104.3458	lb/in*2		B =	102.5818	lb/in*2		B =	100.8328	lb/in*2
W (width of cr	0	in		W (width o	0	in		W (width o	0	in		W (width o	0	in		W (width o	0	in
c1 =	15.31496063	in		c1 =	15.31496063	in		c1 =	15.31496	in		c1 =	15.31496	in		c1 =	15.31496	in
c2 =	19.88188976	in		c2 =	19.88188976	in		c2 =	19.88189	in		c2 =	19.88189	in		c2 =	19.88189	in
c3 =	22.83464567	in		c3 =	22.83464567	in		c3 =	22.83465	in		c3 =	22.83465	in		c3 =	22.83465	in
c4 =	22.67716535	in		c4 =	22.67716535	in		c4 =	22.67717	in		c4 =	22.67717	in		c4 =	22.67717	in
c5 =	19.76377953	in		c5 =	19.76377953	in		c5 =	19.76378	in		c5 =	19.76378	in		c5 =	19.76378	in
c6 =	13.97637795	in		c6 =	13.97637795	in		c6 =	13.97638	in		c6 =	13.97638	in		c6 =	13.97638	in
θ =	0	degrees		θ =	0	degrees		θ =	0	degrees		θ =	0	degrees		θ =	0	degrees
G =	660.5713458	lbs		G =	724.9806981	lbs		G =	792.3864	lbs		G =	862.7873	lbs		G =	936.1843	lbs
E =	0	in-lbs		E =	0	in-lbs		E =	0	in-lbs		E =	0	in-lbs		E =	0	in-lbs
E=	0	ft-lbs		E=	0	ft-lbs		E=	0	ft-lbs		E=	0	ft-lbs		E=	0	ft-lbs
w = (weight of	4265.944773	lbs		w = (weigh	4265.944773	lbs		w = (weigh	4265.945	lbs		w = (weigh	4265.945	lbs		w = (weigh	4265.945	lbs
v =	0	ft/sec		v =	0	ft/sec		v =	0	ft/sec		v =	0	ft/sec		v =	0	ft/sec
v =	0	mi/hr		v =	0	mi/hr		v =	0	mi/hr		v =	0	mi/hr		v =	0	mi/hr
	bo= 5.25 mph			**bo= 5.5 mph**				**bo= 5.75 mph**				**bo= 6.0 mph**				**bo= 6.25 mph**		

Figure 5. Crush Coefficient Sensitivity Analysis

approximately centered around 5 mph, ranging from 4 mph to 6.25 mph. Then the average A and B were computed, which is indicated by the center of the figure. These average crush coefficients were the final values used in EBS computations. Appx. 4 contains all spreadsheets for the sensitivity analysis performed. Appx. 9 contains the crush coefficients (purchased from Neptune Engineering) for the 1998 Ford Contour which was used in the “within” study. These coefficients were used in the Thesis work also [115].

Computing EBS

The EBS equations used in the study were:

$$E = \frac{W}{5}\left[\begin{array}{l} 5G + \\ \frac{A}{2}(C_1 + 2C_2 + 2C_3 + 2C_4 + 2C_5 + C_6) + \\ \frac{B}{6}(C_1^2 + 2C_2^2 + 2C_3^2 + 2C_4^2 + 2C_5^2 + C_6^2 + C_1C_2 + C_2C_3 + C_3C_4 + C_4C_4 + C_5C_6) \end{array}\right](1 + \tan^2\theta)$$

which computes the amount of energy dissipated by crush damage,

where E = the amount of energy dissipated (in-lbs)

W = the width of the crushed region (in)

G = the "energy" dissipated before permanent deformation occurs (lbs) $G = \frac{A^2}{2B}$

A = crush coeffiecient A; the maximum force per inch of damage which will not cause permanent damage (lb/in)

B = crush coeffiecient B; the spring stiffness per inch of damage width (lb/in^2)

$C_1 \rightarrow C_6$ = the crush measurements obtained by PhotoModeler (in)

θ = the angle of the force to the vehicle's surface (degrees)

and

$$EBS = v = \sqrt{\frac{2gE}{w}}$$

which computes the velocity (EBS) of the vehicle, where

v = the velocity of the vehicle (ft/sec)
g = the gravitational constant (ft/sec^2)
E = the amount of energy dissipated by the crush (ft-lbs)
w = the weight of the vehicle (lbs)

The EBS calculations for each case examined in this study were computed using spreadsheets and can be found in Appendices 5 & 6. Appendix 5 contains the “within” subject spreadsheets, and Appendix 6 the “between” spreadsheets. PhotoModeler provided the width of crush and c1 through c6 measurements for these spreadsheets.

Bootstrapping

As mentioned previously, the photographs needed for this study are limited in number due to their poor quality. The authors had quite a dilemma finding twenty (20) sets of photographs suitable for use with PhotoModeler. Since good photographs were limited in number, it was essential to find a statistical technique which focused on small samples. There are a variety of small sample techniques available to researchers. They include, but are not limited to, Bootstrapping, Jackknife, and Cross-Validation. These techniques, which are very computer intensive, fall under the umbrella of Resampling Techniques. Bootstrapping is the most popular of the three, and it is the preferred technique of this study.

The Bootstrapping procedure is quite simple. Figure 6 and these bullets will help illustrate:

- Part A: Start out with an original data set, of say 20 points.
- Part B: The computer algorithm will make a copy of each point, say a billion times
- Part C: All copies are placed in a "bin" and are thoroughly shuffled
- Part D: From this conglomerate, bootstrap samples are extracted.
- Statistical inferences (like variance) are made on the bootstrapped samples

The bootstrapping software utilized in this study was "Resampling Stats for Excel 2.0", which is an add-in module to Microsoft Excel [151]. For this portion of the work, each set of "seed" data for the

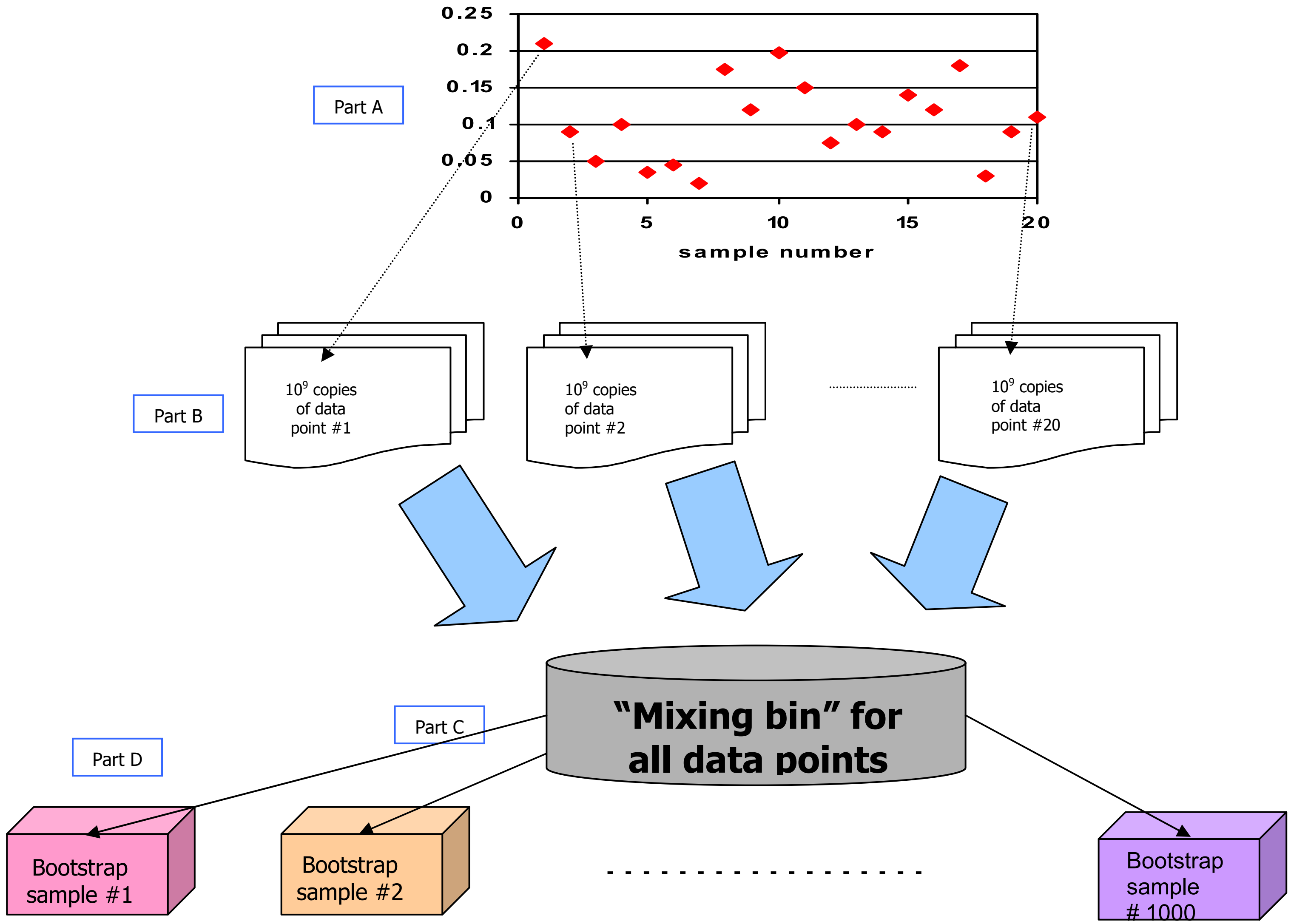

Figure 6. Explanation of Bootstrapping Procedure

"within" and "between" subjects design was entered in an Excel worksheet (these "seed" data sets are precisely the differences found in Tables 2 and 3.) Then resampling with replacement was selected (resampling with replacement is Bootstrapping; resampling without replacement is known as the Jackknife procedure.) 100 independent samples of the twenty data points were subsequently generated along with their associated mean and variances. Appendix 7 contains "within" bootstrap data; Appendix 8 contains the "between" bootstrap data. At the end of each of these appendices, a grand total mean and variance of the 100 samples were computed for both studies. These numbers gave rise to the statistical analysis from which the statistics of the complete study were examined.

Results

Within Subjects Design

The test vehicle's reported velocity for this segment was 34.98 mph (NHTSA test # 2708). Table 2 shows the twenty replications of the "within" subjects' estimated EBS values and their differences from the actual test velocity (units are in mph).

Between Subjects Design

Table 3 summarizes the study's between subjects EBS estimates, their actual test velocities, and differences (units are in mph).

Table 2. Results of the "Within" Subjects Design

Replication #:	EBS Using PhotoModeler's Results	Difference
1	33.75	-1.23
2	33.34	-1.64
3	34.63	-0.35
4	35.50	0.52
5	34.42	-0.56
6	35.17	0.19
7	33.95	-1.03
8	34.24	-0.74
9	33.74	-1.24
10	34.60	-0.38
11	34.79	-0.19
12	33.98	-1.00
13	35.46	0.48
14	34.82	-0.16
15	34.78	-0.20
16	38.55	3.57
17	36.55	1.57
18	37.43	2.45
19	35.21	0.23
20	36.86	1.88

Table 3. Results of the "Between" Subjects Design

Case #:	EBS Using PM's Results	Actual Test Velocity	Difference	NHTSA Test #:
1	33.55	35.30	-1.75	4238
2	32.70	35.20	-2.50	4483
3	35.20	35.10	0.01	3520
4	32.71	35.20	-2.49	4486
5	34.21	35.00	-0.79	3566
6	33.37	34.70	-1.33	4473
7	35.87	34.52	1.35	3666
8	34.20	35.40	-1.20	4462
9	36.46	34.90	1.56	4273
10	33.27	34.74	-1.47	4266
11	32.43	35.00	-2.57	4230
12	35.77	34.56	1.21	4223
13	35.97	34.90	1.07	4263
14	33.24	34.68	-1.44	4265
15	34.36	35.40	-1.04	4479
16	35.54	35.10	0.44	4240
17	34.14	34.89	-0.75	3574
18	36.66	34.73	1.93	4472
19	35.44	34.71	0.73	3639
20	34.95	34.55	0.40	3659

Bootstrapping

Complete bootstrapping results can be found in Appendix 7 & 8. The computed variances from the bootstrapped samples are given below:

$\sigma_W^2 = 1.64$ the "within" variance

$\sigma_B^2 = 2.02$ the "between" variance, and

$\sigma_T^2 = \sigma_W^2 + \sigma_B^2 = 3.66$ the total variance

Conclusion

To get an idea of the repeatability of PhotoModeler as a measurement tool, one needs to look at the proportion of the within variance to the total variance, or $\frac{\sigma_W^2}{\sigma_T^2}$. The other proportion, $\frac{\sigma_B^2}{\sigma_T^2}$, indicates the variability due to vehicle type. The actual computation of the proportions is as follows:

$$\frac{\sigma_W^2}{\sigma_T^2} = \frac{1.64}{3.66} = 44.8\% \qquad \text{and} \qquad \frac{\sigma_B^2}{\sigma_T^2} = \frac{2.02}{3.66} = 55.2\%.$$

The first proportion indicates the source of 44.8% of the variability is the technique itself, while the second proportion indicates that 55.2% of the variability is attributable to vehicle type—so the variation on the whole is split half and half.

Additionally, a 95% confidence interval for the within subjects design is given by:

$$\begin{aligned} &\overline{x} \pm 1.96 \bullet sd \\ &0.11 \pm 1.96 \bullet 1.34 \\ &(-2.52, 2.73) \end{aligned}$$

A 95% confidence interval for the between subjects design is given by:

$$\bar{x} \pm 1.96 \bullet sd$$
$$-0.43 \pm 1.96 \bullet 1.45$$
$$(-3.26,\ 2.41)$$

One could interpret the “within” CI with the following statement: “There is a .95 probability that the mean difference wil fall between -2.52 mph and 2.73 mph.” In other words a discrepancy of anywhere between 2.5 mph below the actual speed and 2.73 mph above the actual speed could be realized. This is a 5.25 mph range. Conversely, one could interpret the “between” CI with the following: “There is a .95 probability that the mean difference will fall between -3.26 mph and 2.41 mph.” In other words, a discrepancy of anywhere between 3.26 mph below and 2.4 mph above the actual speed could be realized. This is a 5.67 mph range.

Future Directions / Research

- An extension of this work could include utilizing NHTSA photos which show the location of CMM measurement points. Sometimes photos will have distinct “x” marks across the front bumper or some similar point indicators. That way PhotoModeler could be compared directly against the CMM measurement data. Figure 7 illustrates these marks. The significance of the "L" and "R" are unknown. This idea was taken from the reviewers' comments which are in Appendix 10.

- Since publication of 2004-01-1208 (126), more NHTSA controlled crash data has been conducted. A PhotoModeler analysis could be performed on these new cases as well, and possibly a larger sample could result and more traditional statistical techniques such as Paired Comparisons could be

Figure 7. CMM Measurement Marks

employed (in lieu of Bootstrapping).

- Also since the publication of 2004-01-1208, the author has run across a better method of crush coefficient estimation. The procedure is outlined in Chapter 8 of Brach and Brach's <u>Vehicle Accident Analysis and Reconstruction</u> [15]. Chapter 8 in this book is entitled "Crush Energy and ΔV" and the particular area of concern is based on Prasad [152]. The following equation is the basis for this method:

$$\sqrt{\frac{2E_C}{w} + d_o + d_1 C}$$

where

E_C is the crush energy

w is the width of crush

d_0 and d_1 are the stiffness coefficients

After one computes d_0 and d_1, the "traditional" crush coefficients A and B can be computed using the following relationship:

$$d_1 = \sqrt{B}$$

$$d_0 = \frac{A}{\sqrt{B}}$$

Figure 8 is one of the author's spreadsheets using this new method.

TEST VEHICLE INFORMATION								
NHTSA Test	**2784**							
1998 Dodge 1500 Club Cab								
test weight:	2502	**kg**	**5515.964**	**lbs**				
test speed:	57	**kph**	35.41815	**mph**	**51.94662**	**fps**		
crush width:	1860	**mm**	73.22835	**in**	**6.102362**	**ft**		
c1:	565	**mm**	22.24409	**in**	1.853675	**ft**		
c2:	652	**mm**	25.66929	**in**	2.139108	**ft**		
c3:	651	**mm**	25.62992	**in**	2.135827	**ft**		
c4:	641	**mm**	25.23622	**in**	2.103018	**ft**		
c5:	605	**mm**	23.8189	**in**	1.984908	**ft**		
c6:	395	**mm**	15.55118	**in**	1.295932	**ft**		
Cavg	**1.98753281**	**ft**						
assume KE--->Elastic Pot E					**A=**		**383.6043**	**lb/in**
Kinetic E of this test crash:	KE35=.5mv^2				**B=**		**98.36798**	**lb/in^2**
KE35=	**231126.76**	**ft-lbs**						
compute do using c-0in and v=5 mph or 7.3 fps								
KE5=	4564.37476							
do=	**38.677345**	**lb^.5**						
d1=	**119.016757**	**lb^.5/ft**						
CHECK								
K1=	3.0511811							
K2=	12.1286451							
K3=	12.1819373							
Ec=	232952.588	ft-lbs						
	0.78996852	**% difference from original KE**						

Figure 8. Spreadsheet of New Crush Coefficient Method

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PART TWO

PHOTOGRAMMETRIC CURVE MEASUREMENT

Abstract

This study focused on the role of PhotoModeler, a close-range photogrammetry software package, in an important facet of traffic accident reconstruction—road curve measurement. More specifically, this study applied photogrammetry to (simulated) road curves in lieu of traditional measurement methods, such as measuring tapes and measuring wheels. In this particular work, thirty (30) different radii of curvature of various known sizes were deliberately constructed. Then photogrammetry was used to measure each of the constructed curves. A comparison of the known "R's" (control group) and photogrammetry's value of "R" (treatment group) was then made. Matched Pairs or Paired Comparisons was then used to examine these two populations.

The difference between photogrammetry's "R" and the known "R" range is between 0.001% and 0.845%. Additionally, we are 99% confident that the mean difference of the two techniques is between -0.48 and 0.66 feet. Since this interval contains zero, we can conclude that the two techniques do not differ.

Introduction

For many years, accident reconstructionists have used the Critical Speed Formula to determine the speed at which vehicles begin to sideslip around a curve. This formula in one of its simplest forms, $v = \sqrt{gr\mu}$, requires a value for r, or the radius of the path of the vehicle's center of gravity. "R's" use in this equation can manifest in one of two ways: (1) in yaw mark applications and (2) in road curve applications. For the first case, the radii of yaw marks and the Critical Speed Formula have been studied extensively [154-164] and will not be discussed here. References 8, 9, and 10 make mention of case two, road curve applications, and provide an estimate for "r" through the following formulas:

$$r = \frac{l^2}{8h} + \frac{h}{2} \qquad or, \quad R = \frac{C^2}{8M} + \frac{M}{2}$$

where r (R)= radius, l (C)=chord, and h (M)=middle ordinate. These equations will be discussed in detail later. Additionally, the authors of these references (161, 162, and 163) make suggestions on how to measure l (or C) and h (or M) with tape measures.

The main goal of this study is to show that the measurement of l and h can be accomplished with photogrammetry. Photogrammetry is the science and art of making measurements with photographs, and to date, has not been used in this capacity.

A technique called Matched Pairs was used for the statistical analysis. As mentioned before, thirty (30) known radii were assembled. Each known "r" was "paired up" with photogrammetry's outcome for "r". The consistency of this study's results to the known results is an indicator of the acceptability of the technique.

Selection Of Samples

The sizes of the thirty (30) known radii were intentionally chosen to represent driving situations most anyone would encounter. It was decided that radii between 50 and 500 feet would be satisfactory in terms of approximating real-world situations and from a construction feasibility standpoint. The random number generator in Excel was used to create thirty random numbers between 50 and 500, which is shown in the first column of Table 1. The second column is an ordered version of column 1. This column was helpful in marking off the various distances on the cable that was used to construct the radii; this will be discussed later in the paper. Lastly, column three shows the Critical Speed for the sorted radii and using a coefficient of friction of 0.7. One can see that speeds between 23 and 72 run the gamut of driving situations.

Table 1. Radii Selected for Use in This Study

Random Radii between 75 and 500 feet	Random Radii Sorted	Critical Speed (using sorted radii and μ=0.7)
141	50	22.89
80	62	25.49
109	80	28.95
85	82	29.31
171	85	29.84
128	109	33.80
287	112	34.26
124	116	34.86
424	124	36.05
409	128	36.62
471	141	38.44
145	145	38.99
497	171	42.33
220	183	43.79
347	220	48.01
318	224	48.45
267	267	52.89
383	287	54.84
112	291	55.22
50	318	57.72
183	346	60.21
224	347	60.30
62	383	63.35
399	399	64.66
116	409	65.46
461	424	66.65
291	459	69.35
459	461	69.50
82	471	70.25
346	497	72.16

Radii Construction

The radii used in this study were constructed in June 2004 at the Gatlinburg-Pigeon Forge Airport in Sevierville, TN at the tie-down area north of the runway. The cable used in this study was 1/8" insulated steel cable purchased at a local hardware store. The cable itself was affixed to a steel pin which was driven into the ground for stability. Figure 1 shows the pin and the spool of cable.

Figure 1. Steel Pin and Cable Used in the Study

The cable itself was marked off according to the second column of Table 1, an ordered random set between 50 and 500 feet. A tape measure was used to mark these distances. This is illustrated in Figure 2. Marking the radii onto the pavement was accomplished by using a stick of soapstone, which leaves a bright white mark when applied. The radii were marked as according to the first column in Table 1, the original random set.

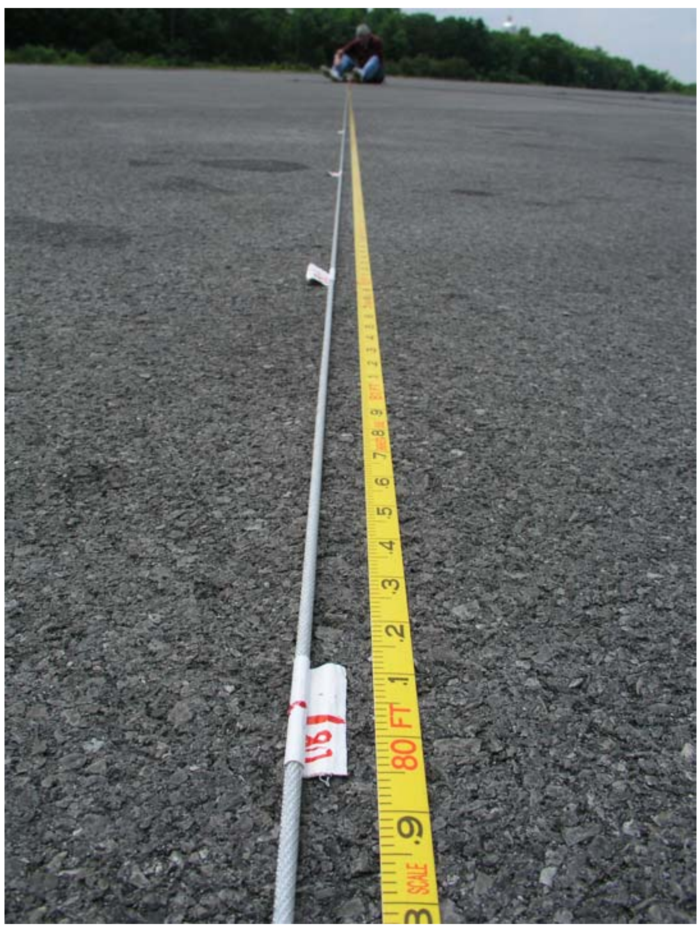

Figure 2. Marking the Cable

PhotoModeler Procedure

Description of the Software

PhotoModeler is a photogrammetry software package by EOS Systems in Vancouver, British Columbia. The version used for this study was version 4.0g. PhotoModeler can be used for a multitude of different measuring applications, including traffic accident reconstruction. PhotoModeler can handle 2-D accident reconstruction projects like accident scene measurement and 3-D projects such as vehicle crush measurement.   Interested readers can visit http://www.photomodeler.com for additional information.

Description of a Generic PhotoModeler Procedure

The first step of a new PhotoModeler project involves taking pictures of the object or scene of interest. A new project is then created using the software's Project Setup Wizard; this is where the user enters fundamental information such as location of the digitized photos, approximate size of the object being modeled, and camera information. After that, the user marks features with a mouse on each photograph using the various tools available. Next the project is processed and PhotoModeler creates a 2-D or 3-D model from the 2-D photographs. The user then gives the project dimension by scaling it. At this point, the user can extract the desired measurements from the marked features.

Camera Calibration

In this study, a digital Olympus C-5050 was calibrated using the embedded Camera Calibrator program in PhotoModeler. Camera calibration ensures an accurate measuring device. This camera was chosen for its (relatively high) resolution (5.0 Mega pixels), its use of ordinary AA batteries (which are easily rechargeable) and its ability to hold two (2) digital storage cards (xD and Compact Flash). The process itself (well documented in Appendix 1 & 13) involved taking eight (8) pictures of a special grid which was projected onto a wall. This is illustrated with Figure 3, which is a screenshot of the procedure. After points were marked and processed with the Camera Calibrator software, camera information such as focal length, format size, and

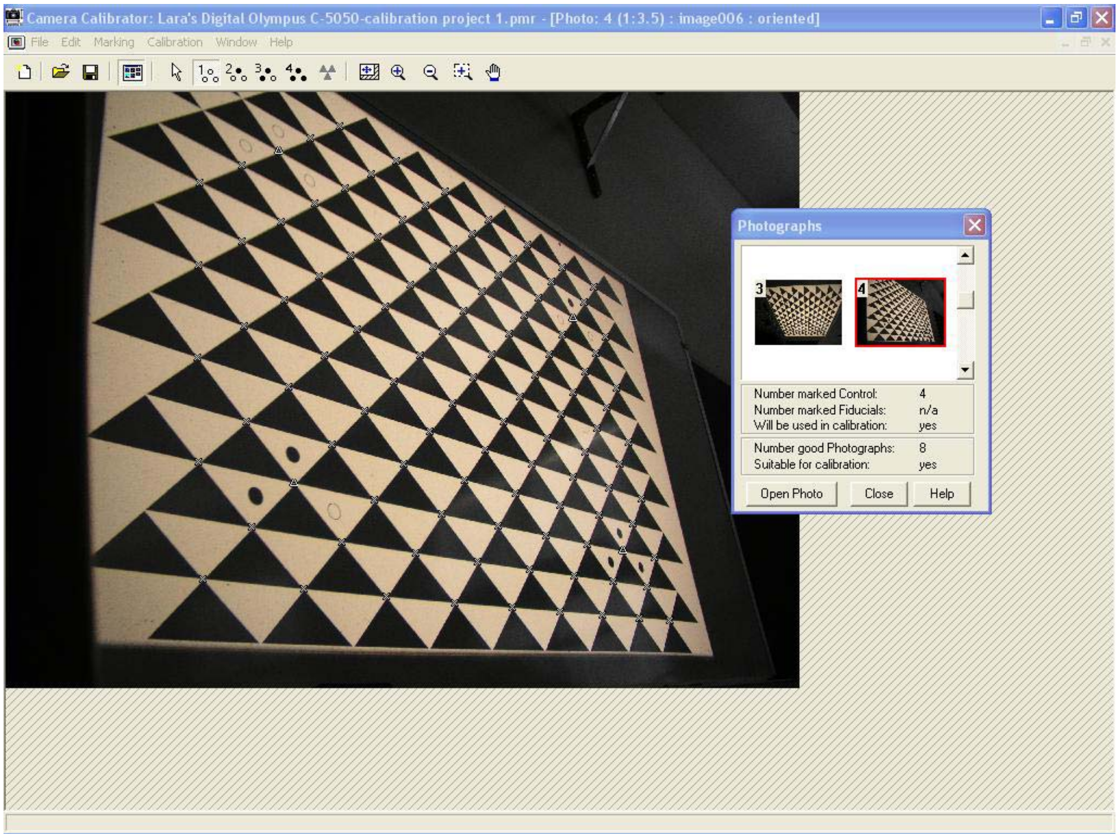

Figure 3. Camera Calibration Grid

principal point was determined as a result. Figure 4 shows the C-5050's resultant camera information.

Targeted Cone Placement

This study utilized a special form of the ordinary traffic cone—the targeted cone. Each targeted cone has a total of three (3) targets, two (2) placed on the exterior and one (1) placed on top. The minimum number of points PhotoModeler needs for a project to process is six (6) points; hence this study uses six (6) targeted cones.

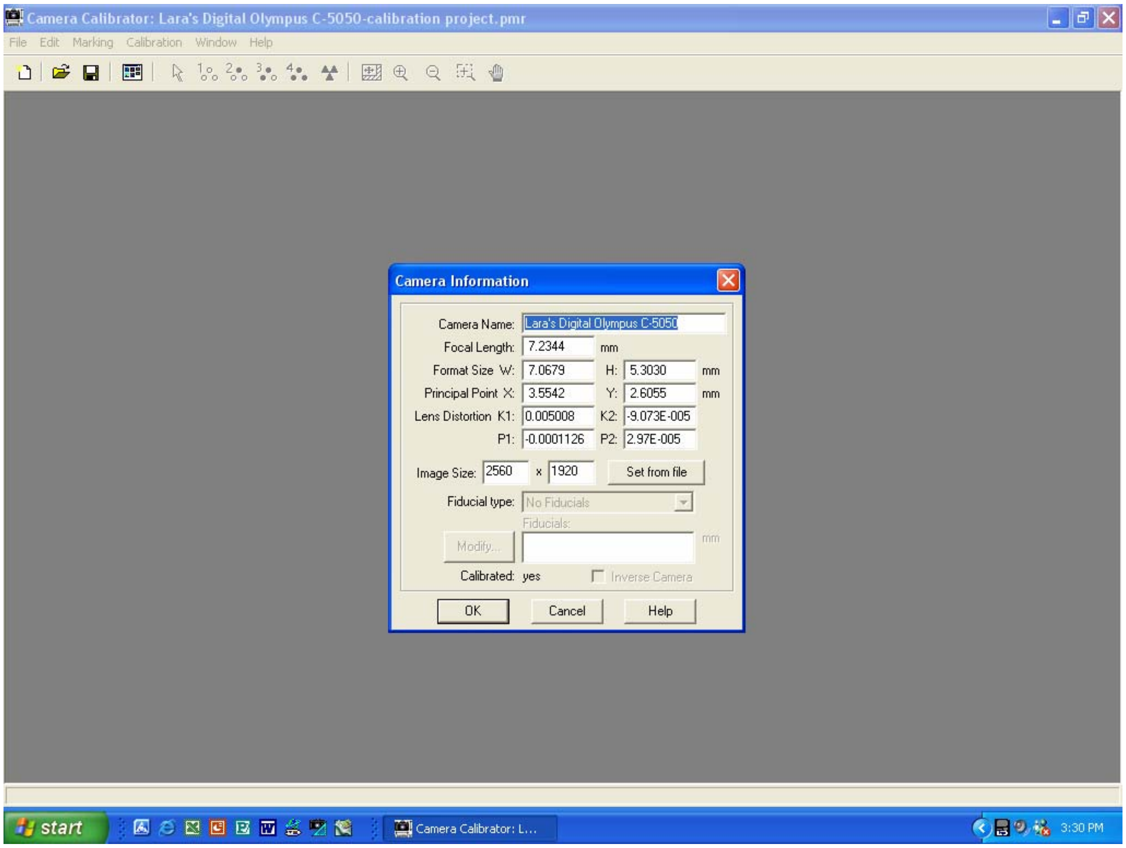

Figure 4. Result of the Olympus C-5050 Calibration Procedure

The top targets were precisely constructed at a local sign shop. Figure 5 shows the targets. What is important to note about these targets is that they are sufficiently thin enough that the point in the center, whether photographed from either side, occupies the same point in space. This is important when referencing the points in PhotoModeler. The targets for the exterior of the cone were printed out by an inkjet printer onto label paper, cut out, and placed on the outside of the cone. Figure 6 shows a targeted cone straddling a soapstone mark (sorry for the camera strap in photo).

Five (5) targeted cones are placed on the soapstone marks along the radius. The sixth cone is placed directly across from the third or middle cone. For ease in conspicuity, alternating square and round targets are utilized. Figure 7 shows this configuration.

Curve Modeling

The first step in curve modeling is to take pictures of the

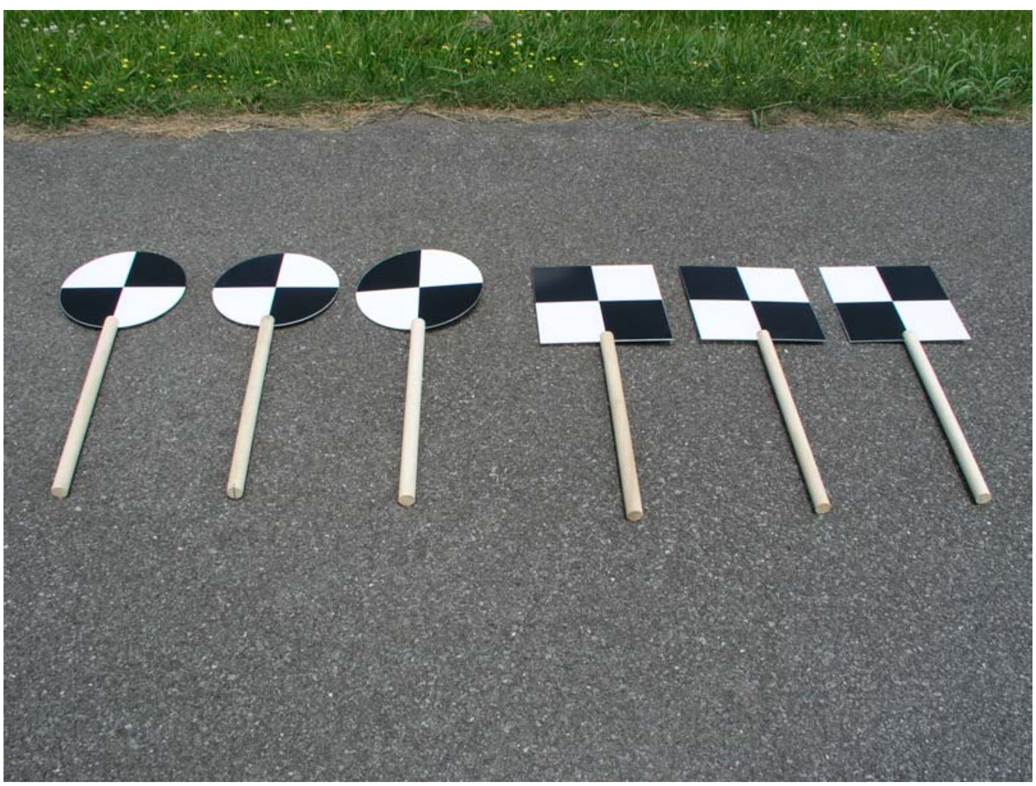

Figure 5. Targets for the Top of the Cones

Figure 6. Target Cone on a Mark

Figure 7. Arrangement of Cones Along Radius

targeted cones from both sides, i.e., from an upstream and a downstream location. In order for PhotoModeler to create an accurate model, each point must reside in at least two (2) photographs, preferably three (3). The user's picture taking technique needs to reflect this requirement, hence; about four or five pictures were taken on each side for this study. For scaling purposes, a physical measurement of the curve must be made. This measurement can be between any two cones; for this study the scaling measurement was made between cones #3 (the middle cone in the arc) and #6 (the cone across from all other cones) with a measuring wheel and recorded.

Using PhotoModeler's "Project Setup Wizard", four (4) or five (5) photos from a single side (upstream or downstream) were opened up and the centers of all targets were marked and referenced across all photos. "Marking a point" entailed selecting the point tool which looks like a single "x" on the toolbar. The user would then mark a target on the first photograph. "Referencing a point" required the use of the referencing tool on the toolbar which resembles a double "x". Referencing "notifies" PhotoModeler that that particular point is the same across all photos; it allows PhotoModeler to recognize that this is the same physical point in space. This procedure of marking and referencing points continued across all eight (8) or ten (10) photos until all points were marked and referenced. Then the project was processed and scaled. After that, two lines were drawn using the line tool on the PhotoModeler toolbar. The first line is drawn between cone #1 and cone #5. This measurement is our chord. The next line is drawn between cone#3 and cone #6. Where the first line intersects the second line to cone #3 is our middle ordinate. These two measurements can be extracted from PhotoModeler using the measuring tool on the toolbar. Figure 8 illustrates the chord and middle ordinate measurements which can be seen in the 3-D viewer. Note that a measurement of 5.869 ft is circled in blue. This is case 14's measurement for h. To get a radius measurement, use PhotoModeler's results for l and h, and plug into $r = \frac{l^2}{8h} + \frac{h}{2}$ for an estimate for the radius.

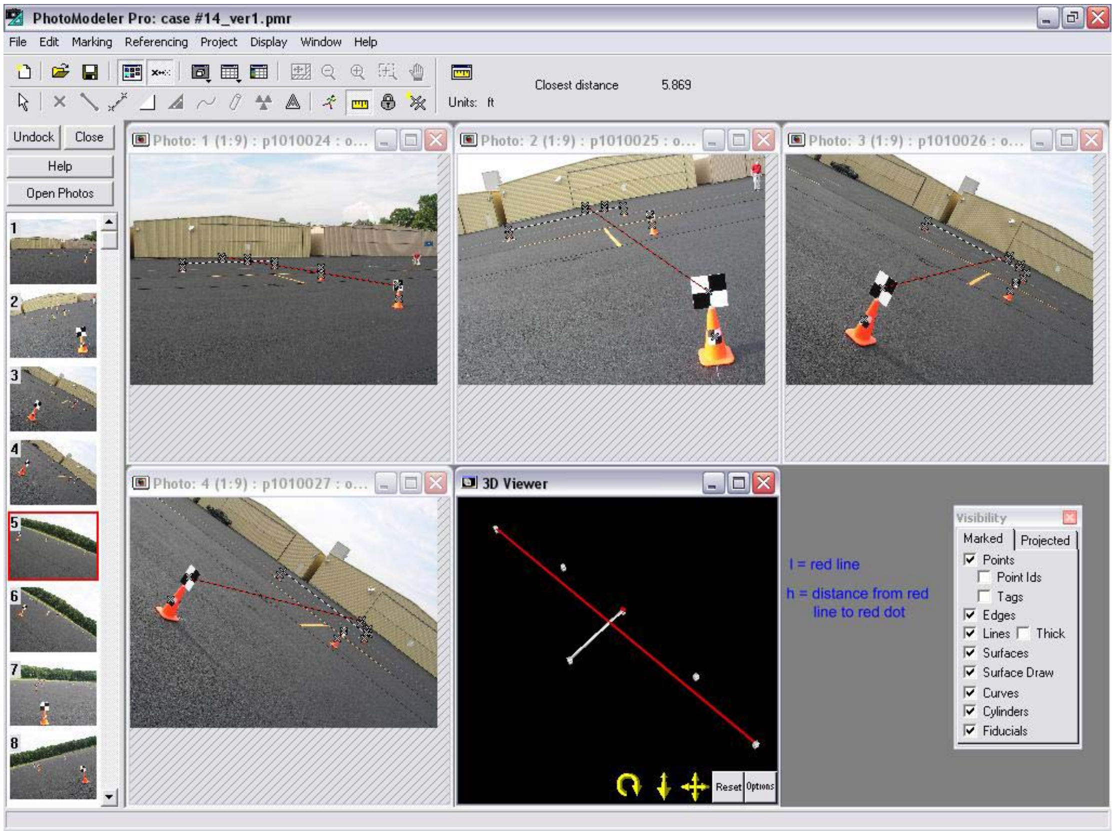

Figure 8. Chord and Middle Ordinate

Results

Table 2 shows the results for this study. Columns included in the table are the following: the known “r”, which is the random number set from Table 1; the scale factor, which is the distance used by PhotoModeler for scaling purposes; l and h, the chord and middle ordinate measurements extracted directly from PhotoModeler; the

Table 2. Results of the Study

#	known "r"	scale factor	l	h	computed "r"	diff (ft)	diff (inch)	%difference	speed (known "r")	speed (comp. "r")	diff (mph)
1	141	27.3333333	75.419	5.16	140.3713169	-0.6286831	-7.544197	0.44587455	38.43749612	38.35170898	-0.085787138
2	80	28	77.127	9.897	80.07952618	0.0795262	0.9543142	0.099407728	28.95279707	28.96718423	0.014387161
3	109	29	88.794	9.429	109.2374403	0.2374403	2.8492841	0.217835178	33.79549267	33.83228197	0.036789301
4	85	21.08333333	95.36	14.534	85.47610967	0.4761097	5.7133161	0.560129028	29.84386012	29.92732555	0.083465426
5	171	34.0833333	116.639	10.223	171.4601296	0.4601296	5.5215549	0.269081622	42.32954382	42.38645618	0.056912364
6	128	19.25	74.631	5.593	127.2776854	-0.7223146	-8.667775	0.564308256	36.62271335	36.51923476	-0.103478592
7	287	23.08333333	148.954	9.832	286.9961225	-0.0038775	-0.04653	0.001351042	54.83861545	54.83824515	-0.000370303
8	124	21.08333333	96.455	9.783	123.765657	-0.234343	-2.812116	0.188986274	36.04594166	36.01186471	-0.034076954
9	424	25.16666667	111.039	3.635	425.8085427	1.8085427	21.702512	0.426543084	66.65434441	66.79634807	0.142003659
10	409	21.95833333	108.472	3.593	411.1401816	2.1401816	25.682179	0.523271786	65.46470074	65.63575659	0.171055848
11	471	27.45833333	112.145	3.345	471.6463799	0.6463799	7.7565583	0.137235639	70.25156225	70.299751	0.048188748
12	145	17.16666667	84.254	6.233	145.4784548	0.4784548	5.741458	0.329968853	38.97889597	39.04315221	0.064256248
13	497	26.125	117.186	3.448	499.5690767	2.5690767	30.828921	0.516916843	72.16452	72.35079506	0.186275059
14	220	22.16666667	100.902	5.869	219.7775227	-0.2224773	-2.669727	0.101126024	48.01278226	47.98849954	-0.024282723
15	347	17.41666667	89.158	2.901	343.9681217	-3.0318783	-36.38254	0.873740149	60.29902228	60.03501611	-0.264006173
16	318	20.95833333	72.018	2.051	317.1269337	-0.8730663	-10.4768	0.274549154	57.72435553	57.64506036	-0.079295176
17	267	28.41666667	130.705	8.069	268.6862075	1.6862075	20.23449	0.631538404	52.89336092	53.06011914	0.166758213
18	383	17.20833333	91.422	2.75	381.2832765	-1.7167235	-20.60068	0.448230667	63.34975212	63.20761633	-0.142135794
19	112	15.41666667	76.294	6.637	112.9458624	0.9458624	11.350349	0.844520034	34.25741149	34.4017628	0.144351314
20	50	10.41666667	42.637	4.775	49.97686568	-0.0231343	-0.277612	0.046268639	22.88919585	22.88390003	-0.005295812
21	183	15.8333333	80.74	4.527	182.2653666	-0.7346334	-8.815601	0.401439028	43.78961005	43.70162749	-0.087982565
22	224	13.70833333	97.535	5.409	222.5481916	-1.4518084	-17.4217	0.648128728	48.44729593	48.29004042	-0.157255513
23	62	17.41666667	48.628	4.937	62.33993974	0.3399397	4.0792769	0.548289904	25.48832978	25.5581093	0.069779519
24	399	27.625	106.086	3.549	398.1621936	-0.8378064	-10.05368	0.209976547	64.65944622	64.59152588	-0.067920339
25	116	18.6666667	74.7222	6.153	116.5050546	0.5050546	6.0606555	0.435391918	34.86378443	34.93959914	0.075814709
26	461	30.8333333	123.069	4.123	461.2531918	0.2531918	3.0383011	0.054922291	69.50179092	69.52087447	0.019083551
27	291	21.75	101.913	4.49	291.3947653	0.3947653	4.7371834	0.135658173	55.21944374	55.25688604	0.037442296
28	459	28.875	119.449	3.901	459.143002	0.143002	1.7160235	0.03115511	69.35086394	69.36166645	0.010802511
29	82	17.41666667	49.833	3.869	82.1660808	0.1660808	1.9929696	0.202537564	29.31247294	29.34214239	0.029669446
30	346	21	118.378	5.102	345.8808433	-0.1191567	-1.42988	0.034438354	60.21207339	60.20170464	-0.010368757

	feet	inches
d-bar:	0.0910014	1.0920172
std dev:	1.1297617	13.55714

computed “r” which uses PhotoModeler’s results for l and h and $r = \frac{l^2}{8h} + \frac{h}{2}$ to compute the radius; diff (ft) and diff (inch) are the differences of the known “r” and PhotoModeler’s computed “r”; % difference is the % difference between the known “r” and the computed “r”; speed (known “r” and comp “r”) uses the Critical Speed Formula $v = \sqrt{gr\mu}$ with coefficient of friction = 0.7; diff (mph) is the difference between the two speeds. The results of the Matched Pairs analysis are shown in Figure 9, which is a JMP screenshot. Appx. 11 contains all screenshots for the thirty (30) cases.

Conclusion

When looking at Table 2, the “% differences” range from 0.001% to 0.874%. When examining the JMP screenshots, we can see that a 95% C.I. indicates that we are 95% confident that the difference lies between -0.33 and 0.51 feet. Additionally, by looking at the two-tailed t-test, the difference between the two techniques is not significant. Since the p-value is not small (>0.05), we accept the

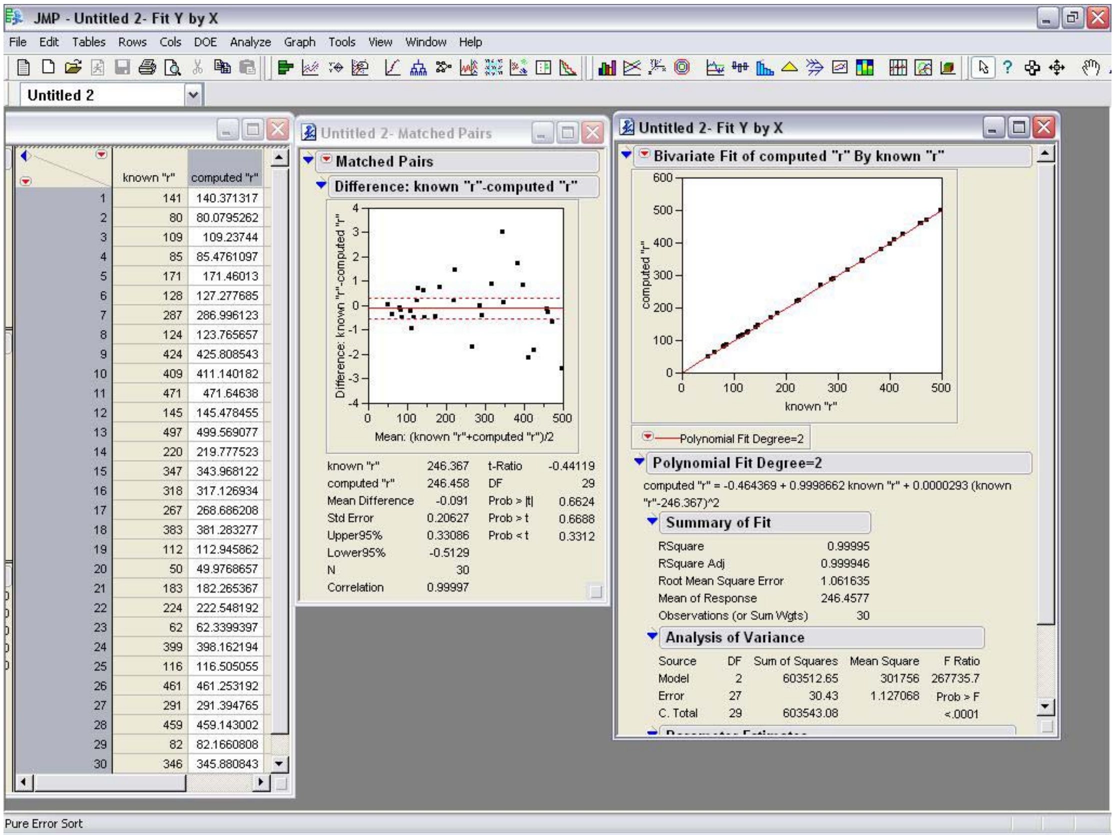

Figure 9. Matched Pairs Results

null hypothesis and say that the mean difference between the two techniques is zero. This is further evidenced by zero in the confidence interval. On average, the methods are the same. Also if one looks at R^2, one can see that it is very close to one, which indicates an almost perfect relationship. This suggests that the known “r’s” predict the computed “r’s” exactly.

Future Directions

- Measure photogrammetry's results against a number of real-world curves. Ideally, the curves to be measured would have their own blueprints, design plans, or total station documentation where values for radius (also grade and superelevation) are easily obtained, and photogrammetry could be measured against these benchmarks.

- Supplement this study with photogrammetry's results vs. the Tape Measure Method. Paired Comparisons could be utilized for the statistical portion. This idea was taken from a reviewer for this study. In 2005, this study was not accepted for publication for the SAE Congress, unless certain changes were made. As to date, the changes haven't been made and this study remains unpublished. Appendix 12 contains the reviewers' comments.

- Develop procedures to measure superelevation and grade with photogrammetry. The author was going to include these items in a separate paper, but a reviewer suggested it be included with this one.

- Perform a study on the scaling measurement itself. A reviewer recommended this, and at first, this author thought it was an unwise suggestion. After some thought, however, it's actually not a bad idea—perhaps not for a curve paper, but a paper affecting the accuracy of PhotoModeler. Digital resolution has a big impact on accuracy (as one will find out in Part Three) and somewhat, on the scaling measurement. It is this author's experience that a scaling measurement that encompasses a big chunk of the object being modeled makes for a better project in terms of accuracy. In other words, don't use a scaling measurement of 0.5 ft when the object being modeled is 30 ft long. Pick something on the object that is well defined and bigger. This suggestion certainly warrants some investigation.

- Examine the impact on accuracy due to the number of photos in a curve project. What is optimal? What is minimally required? Theoretically, only two photos are required. However, this author knows more pictures increase accuracy. (You can have too many pictures; the potential for error is great with a lot of pictures). PhotoModeler doesn't like two photo projects (as evidenced in the Process dialog), but it'll do them (reluctantly).

- Consider the effect of targets on error when grade or superelevation is present. As stated before, a prospective direction for the study is to include superelevation and grade in photogrammetric curve measurement. Part Two's experiments were conducted on (relatively) flat terrain where e and G were not an issue. A targeted cone takes on an interesting appearance when on a hill—the cone is in agreement with the alignment on the grade, but the target itself remains straight up and down. This is because the target dangles on top of the cone; it is not permanently affixed to it. Some trial experiments would quickly determine if this is an issue or not; if so, a cone could be constructed with a fixed, rigid target.

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PART THREE

AN EVALUATION OF COMMON ACCIDENT RECONSTRUCTION MEASUREMENT METHODOLOGIES

Abstract

This study's aim was to learn what causes variation in three common traffic accident reconstruction measurement techniques: measuring tape, measuring wheels and photogrammetry (PhotoModeler). These three techniques were evaluated against a known benchmark distance (48 feet) measured by a total station. A full factorial 2^3 Design of Experiments study with four replicates was applied to each technique. The following results were found: Measuring tape experiment: None of the main effects or cross-effects was significant. Measuring wheel experiment: Two main effects ($p<0.0001$ and $p<0.0060$) and all of the cross-effects ($p<0.0079$ to 0.0345) were significant. Photogrammetry experiment: One main effect ($p<0.0063$) and one cross effect ($p<0.0325$) were significant. The measuring wheel is most sensitive to surface type (smooth or rough surface) and photogrammetry is most sensitive to digital resolution (low or high resolution).

Introduction

It is often necessary for physical measurements to be taken from the highway. This can be done for a variety of reasons: making accident diagrams, identifying the locations of the resting positions of vehicles, or measuring skidmarks. The measurement process itself can manifest in one of several forms: pacing, total stations, lasers, measuring tapes, measuring wheels, or photogrammetry. This study will examine various factors that could affect the accuracy of the later three abovementioned measurement techniques. The tool utilized for this purpose is the Design of Experiments (DOE). Analysis of Variance (ANOVA) will determine which details of the experiment are significant or relevant.

Design of Experiments

History

According to Joan Fisher Box [165], Design of Experiments got its start in the agriculture industry. R.A. Fisher was a statistician working at the Rothamsted Experimental Station in England. It was at this location that Fisher developed DOE; here he planned different experiments on crops and fertilizers. In the abstract of her article, Box eloquently describes how analysis of variance brought about the need for DOE, factorial blocking designs, randomization, and replication. In 1935, Fisher wrote the book, Design of Experiments which contained few numerical examples and masses of theory [166]. Initially, Fisher's experiments received much opposition. His critics maintained that the experiments themselves were too complex but they eventually began to appreciate their merit to the agricultural world.

DOE Variable Definition

The main objective in experimental studies is to evaluate the set of *pre-selected variables* at *different intensities* to investigate their reaction to a variable of interest [167]. The pre-selected variables are identified as factors, different intensities as levels, and variable of interest as response variable. To improve the accuracy of your experiment the following is suggested [167]:

- Blocking (removes nuisance errors)

- Randomization (removes nuisance errors)
- Replication (removes random errors)
- Repeat measurements (removes measurement errors)

Experimental Designs

Tamhane [167] explains that the completely randomized design (CRD) is an experiment where the treatments are assigned in a random order, however; CRD designs can mask the effects of treatment effects, especially if one or more of the same treatment is in the same block. Randomized Block Designs (RBD) are random and unique within the blocks, reducing the effect of a nuisance variable (an additional treatment in a block.) Fig. 1 shows a CRD and RBD.

Completely Randomized Design

Block 1	Block 2	Block 3	Block 4	Block 5
A	**C**	D	D	B
B	A	A	C	D
C	D	B	A	C
B	**C**	D	B	A

2 B's **2 C's**

Nuisance factors could confound your results here

unbalanced

Randomized Block Design

Block 1	Block 2	Block 3	Block 4	Block 5
A	D	C	D	B
C	A	B	C	C
B	C	D	B	A
D	B	A	A	D

1 replicate of each treatment for each block—
nuisance factors are more controlled

balanced

Figure 1. Illustration of CRD and RBD Designs

Factorial Designs

2^2 Design

For this situation, we have 2 levels$^{(2\ \text{factors})}$ = $2^2 = 4$, hence we have 4 treatment combinations possible. Table 1 delineates this type of design.

2^3 Design

In a similar fashion, the 2^3 Design will have 3 factors, resulting in a possible 8 treatment combinations. Table 2 delineates this type of design.

Table 1. 2^2 Design

Factor A	Factor B	Treatment combination	Interpretation of experiment
-	-	(1)	Low level of A with low level of B
+	-	a	High level of A with low level of B
-	+	b	Low level of A with high level of B
+	+	ab	High level of A with High level of B

Table 2. 2^3 Design

Factor			Treatment Combination	Interpretation
A	B	C		
-	-	-	(1)	Low levels of A, B, and C
+	-	-	a	High A, Low B & C
-	+	-	b	Low A, High B, Low A
+	+	-	ab	High A, High B, Low C
-	-	+	c	Low A, Low B, High C
+	-	+	ac	High A, Low B, High C
-	+	+	bc	Low A, High B, High C
+	+	+	abc	High levels of A, B, and C

Analysis of Variance (ANOVA)

History

As mentioned earlier, Box [165] informed that ANOVA's beginnings were the results of DOE. Scheffe [168] claims that Fisher "coined" the terms variance and analysis of variance, but others before him were using ANOVA's components long before Fisher. Scheffe also conveys that many subsequent improvements have been made to Fisher's ANOVA tables since their inception—the table you see today is *roughly* the table Fisher created years ago.

The Delineated ANOVA Table

Below is a typical ANOVA table (Table 3) which can be used in conjunction with DOE. In lieu of hand calculations it is advisable to use software packages such as JMP or SAS to do the calculations.

Research Design

The objective of this project is to reveal the sources of variability in different measuring techniques. As mentioned previously, the total station, the common measuring device used by civil engineers for a variety of applications, will be used as a benchmark in this design.

Table 3. ANOVA Table

Variation	Degrees of Freedom	Mean Square	F
Between treatments, V_R	$a-1$	$\hat{S}_R^2 = \frac{V_R}{a-1}$	$\frac{\hat{S}_R^2}{\hat{S}_E^2}$
Between blocks, V_C	$b-1$	$\hat{S}_C^2 = \frac{V_C}{b-1}$	$\frac{\hat{S}_C^2}{\hat{S}_E^2}$
Interaction, V_I	$(a-1)(b-1)$	$\hat{S}_I^2 = \frac{V_I}{(a-1)(b-1)}$	$\frac{\hat{S}_I^2}{\hat{S}_E^2}$
Residual or random, V_E	$ab(c-1)$	$\hat{S}_E^2 = \frac{V_E}{ab(c-1)}$	
Total, V	$abc-1$		

In other words, the results photogrammetry, the measuring wheel, and the measuring tape will all be compared to the results of the total station. Following this reasoning, the execution of three (3) separate experiments, one for each measuring technique, will be required. After the completion of each experiment, the results of each will be analyzed.

Designing of the Experiment

- **Type of Design:** 2^3; 2 levels$^{3 \text{ factors}}$
- **Response Variable:** Error (or accuracy or measurement difference)
- **Factors:** When deciding what factors to include in the experiment, one must ask the following: What would influence the amount of error in each measuring device? Since each measuring device is unique and measures distances in a different way, they should each have their own set of factors, as indicated by Table 4.
- **Levels:** The levels for each methodology were selected mainly for convenience and ease of use. **PhotoModeler:** The low and

Table 4. Factors and Levels For Each Experiment

Photogrammetry	
Factor	**Levels**
Number of Pictures Taken	4 (low), 8 (high)
Digital Resolution of Camera	low, high
Exposure to Road While Taking Measurements	low exposure (rush to get job done), high exposure (take your time)
Measuring Wheel	
Factor	**Levels**
Roughness of Pavement	not rough, rough
Wheel Diameter	small, large
Exposure to Road While Taking Measurements	low exposure (rush to get job done), high exposure (take your time)
Measuring Tape	
Type of Tape	cloth, steel
Amount of Masking Tape Used	low, high
Exposure to Road While Taking Measurements	low exposure (rush to get job done), high exposure (take your time)

high levels of # of photos are 4 and 8 respectively. The digital resolution levels are 0.15 mega pixels (low) and 5 mega pixels (high). "Exposure to road" on average was 4 minutes for 4 photos and 5 minutes for 8 photos (low level or rush) and 8 minutes for 4 photos and 9 minutes for 8 photos (high level or take time). **Measuring Wheel:** The levels for roughness of pavement were not rough (on pavement) or rough (in the gravel). Wheel diameter levels were small (4 inches) and large (12 inches). "Exposure to road" levels were on average 30 seconds (low level or rush) and 1.5 minutes (high level or take time). **Measuring Tape:** **"**Type of tape" levels were cloth (low level) and steel (high level). The levels for amount of making tape used were 4 pieces (low) and 8 pieces (high). "Exposure to road" levels were on average 1.5 minutes (low) and 3 minutes (high).

- **Design Matrices:** Tables 5a, 5b, and 5c depicts an appropriate design matrix for each experiment.

Table 5a. Photogrammetry Design Matrix

PhotoModeler Experiment			Treatment Combo	Interpretation
A: # of Pix	**B:** Dig. Res.	**C:** Exp		
-	-	-	(1)	Low levels of A, B, and C
+	-	-	a	High A, Low B & C
-	+	-	b	Low A, High B, Low A
+	+	-	ab	High A, High B, Low C
-	-	+	c	Low A, Low B, High C
+	-	+	ac	High A, Low B, High C
-	+	+	bc	Low A, High B, High C
+	+	+	abc	Hi levels of A, B, and C

Table 5b. Measuring Wheel Design Matrix

Measuring Wheel Experiment			Treatment Combo	Interpretation
A: Rough	B: Diameter	**C:** Exp		
-	-	-	(1)	Low levels of A, B, and C
+	-	-	a	High A, Low B & C
-	+	-	b	Low A, High B, Low A
+	+	-	ab	High A, High B, Low C
-	-	+	c	Low A, Low B, High C
+	-	+	ac	High A, Low B, High C
-	+	+	bc	Low A, High B, High C
+	+	+	abc	Hi levels of A, B, and C

Table 5c. Measuring Tape Design Matrix

Measuring Tape Experiment			Treatment Combo	Interpretation
A:TapeType	**B:** Mask. tape	**C:** Exp		
-	-	-	(1)	Low levels of A, B, and C
+	-	-	a	High A, Low B & C
-	+	-	b	Low A, High B, Low A
+	+	-	ab	High A, High B, Low C
-	-	+	c	Low A, Low B, High C
+	-	+	ac	High A, Low B, High C
-	+	+	bc	Low A, High B, High C
+	+	+	abc	High levels of A, B, and C

- **Number of Replications:** It was determined that 5 replications of each experiment should be performed. Since there are 8 treatment combinations and 5 replications, there will be a total of 40 data points. To ensure that the within block confounding is reduced, a Randomized Block Design is utilized. The following table (Table 6) illustrates an order in which the experiments could be conducted. Recall that this table will apply to each experiment: PhotoModeler, measuring wheel and measuring tape.

Table 6. RBD with 5 Blocks

Block 1	Block 2	Block 3	Block 4	Block5
(1)	bc	ab	a	c
abc	c	bc	ac	ab
a	b	a	b	b
bc	(1)	c	bc	a
b	abc	(1)	ab	abc
ac	ac	b	abc	(1)
ab	a	ac	c	ac
c	ab	abc	(1)	bc

Selection of Sample

The sample that was measured in this study is a strip of asphalt and gravel located at the hangar area north of runway 28 at the Gatlinburg-Pigeon Forge airport in Sevierville, TN. This particular sample was selected because of its "lack of activity", minimum contact with airport traffic, and interruptions. All experiments for Part Three were conducted on this area. Figure 2 shows this sample. Note the asphalt area and the gravel area.

Figure 2. Part Three's Experiment Area

Instrument Used

Photogrammetry Experiment

The primary instrument used in this experiment is the photogrammetry software package called PhotoModeler (version 4g), from EOS Systems, Inc. The software is used in conjunction with a calibrated digital camera. Two levels of digital resolution were used in this experiment: high and low. High resolution calibration details are described in Appendix 1; low resolution calibration details are in Appendix 13. A digital camera was used in this experiment, primarily for time and money saving reasons; a film camera would require film processing and digitization via scanner.

Measuring Wheel Experiment

The primary instrument used in this experiment is a measuring wheel. One can make measurements with this device holding the handle in a standing position while allowing the wheel to roll along the pavement surface. Two types of wheels will be used, of different diameters. Measuring wheels are used quite frequently in accident reconstruction.

Measuring Tape Experiment

The primary instrument in this experiment is a measuring tape. Two types of measuring tapes will be used: cloth and steel. Measuring tapes are also used quite frequently in accident reconstruction.

Procedures

Total Station Measurement

The first step in this project is to obtain a total station and measure the road segment of interest. Recall that this must be done first, for the total station is considered the benchmark measuring device in this project. In October 2004, two (2) registered land surveyors from VISION Engineering in Sevierville, TN measured a 48 ft distance on the asphalt and in the gravel. Figure 2 shows the crew measuring the benchmark. Appendix 14 contains all photos of the total station benchmark measurement.

Photogrammetry Experiment

Utilizing JMP's embedded DOE Tool, the order of experiments were determined.

The photogrammetry experiment proceeded according to the following procedure:

- Place center of targeted cone at the endpoints of the line segment (on pins)
- Place 4 more cones between endpoints (PhotoModeler needs a minimum of 6 points for a project to process
- Take the predetermined amount of pictures (4 or 8) from an upstream and a downstream position
- Take one measurement (usually between 2 arbitrary cones) for scaling purposes
- Download images from camera onto computer
- Use PhotoModeler
    - Create a new project
    - Mark and reference points
    - Scale project
    - Process
    - Extract needed measurements
- Record results on data sheet.

Figure 3 shows equipment used for this experiment. Figure 4 shows a project with 8 photos. Figure 5 shows a project with 4 photos.

<u>Measuring Wheel Experiment</u>

Again utilizing JMP's DOE Tool, determine which experiment to perform first. The measuring wheel experiment will proceed as follows:

- Visually locate the two endpoints to be measured.
- Reset the counter, located at the base of the wheel.

Figure 3. Equipment Used For Photogrammetry Experiment

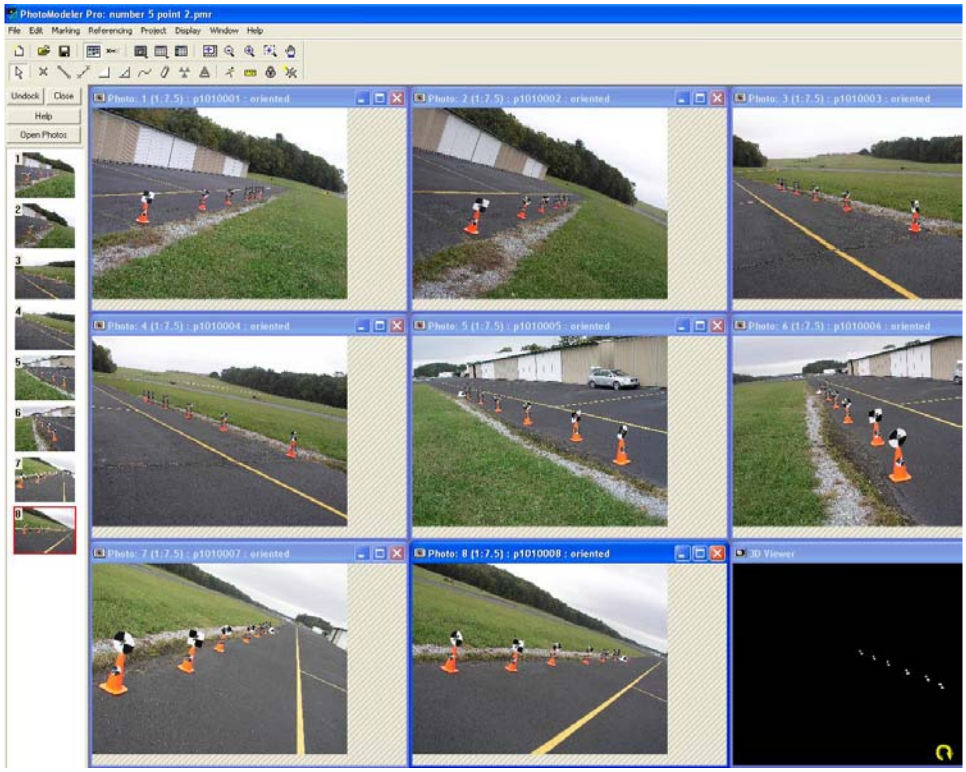


Figure 4. A PhotoModeler Project With 8 Photos

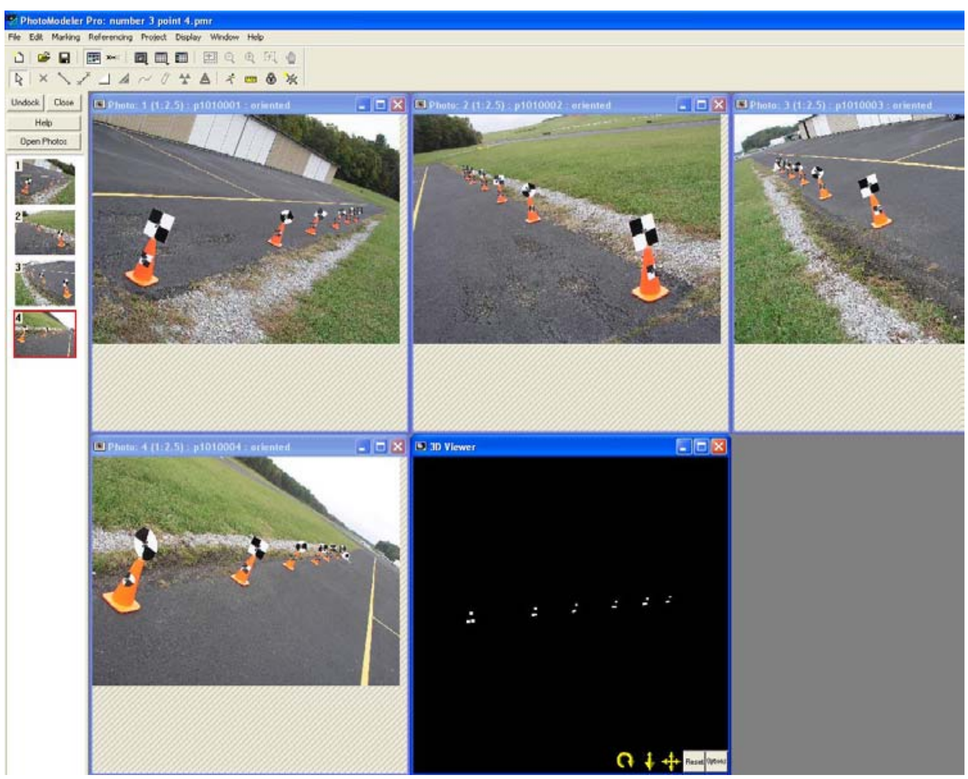


Figure 5. A PhotoModeler Project With 4 Photos

- Start at the first point, firmly holding wheel to pavement so there's good contact.
- Try to track in a straight line as best you can from point to point to increase accuracy.
- Record the results on the data sheet.

Measuring Tape Experiment

Use JMP's DOE to determine which experiment to perform. The measuring tape experiment will proceed as follows:

- Visually locate the two endpoints to be measured
- Stretch out tape, approximately the entire length of line segment
- Secure measuring tape with masking tape, applying the proper amount specified (4 or 8 pieces). Try to follow a straight line as best as possible to increase accuracy.
- Record the results on the data sheet.

Appendix 15 contains some photos of this experiment.

Results

Total Station Result

The RLS in charge on benchmark measurement day in October 2004 said on average, his measurements were "within a 1/16th of an inch." This author asked and wanted a data printout from his total station for documentation purposes, but he wasn't able to provide one.

The results of the three experiments are specified below in Figures 6-8:

Results From Photogrammetry Experiment

2x2x2 Factorial PhotoModeler

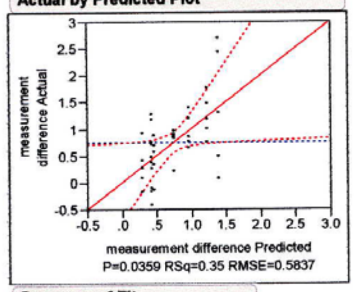
Rows	Pattern	# of pics	digital resolution	exposure	measurement difference
1	−++	-1	1	1	0.891
2	+++	1	1	1	0.37
3	+−+	1	-1	1	0.325
4	+−−	1	-1	-1	0.476
5	+−+	1	-1	1	0.867
6	−+−	-1	1	-1	-0.12
7	−++	-1	1	1	0.203
8	+++	1	1	1	0.46
9	−+−	-1	1	-1	-0.433
10	−+−	-1	1	-1	0.251
11	−−+	-1	-1	1	0.842
12	+++	1	1	1	0.706
13	−−−	-1	-1	-1	0.74
14	+++	1	1	1	0.741
15	−−−	-1	-1	-1	0.993
16	−−+	-1	-1	1	1.185
17	+−−	1	-1	-1	2.692
18	+−−	1	-1	-1	1.297
19	−+−	-1	1	-1	1.261
20	++−	1	1	-1	0.255
21	++−	1	1	-1	0.4
22	++−	1	1	-1	-0.188
23	+−+	1	-1	1	0.559
24	+−−	1	-1	-1	2.428
25	−−−	-1	-1	-1	1.754
26	+−+	1	-1	1	0.679
27	−++	-1	1	1	0.954
28	−−+	-1	-1	1	0.759
29	−−−	-1	-1	-1	1.47
30	++−	1	1	-1	0.07
31	−−+	-1	-1	1	0.639
32	−−+	-1	-1	1	1.384
33	−+−	-1	1	-1	1.159
34	++−	1	1	-1	0.913
35	−−−	-1	-1	-1	1.174
36	+++	1	1	1	-0.178
37	+−+	1	-1	1	-0.142
38	+−−	1	-1	-1	0.064
39	−++	-1	1	1	0.818
40	−++	-1	1	1	0.862

2x2x2 Factorial PhotoModeler- Fit Least Squares

Response measurement difference

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.353999
RSquare Adj	0.212686
Root Mean Square Error	0.583684
Mean of Response	0.7395
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	5.974119	0.853446	2.5051
Error	32	10.901993	0.340687	Prob > F
C. Total	39	16.876112		0.0359*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.7395	0.092289	8.01	<.0001*
# of pics	-0.0998	0.092289	-1.08	0.2876
digital resolution	-0.26975	0.092289	-2.92	0.0063*
exposure	-0.0933	0.092289	-1.01	0.3196
# of pics*digital resolution	-0.01505	0.092289	-0.16	0.8715
# of pics*exposure	-0.1077	0.092289	-1.17	0.2518
digital resolution*exposure	0.20625	0.092289	2.23	0.0325*
# of pics*digital resolution*exposure	0.05965	0.092289	0.65	0.5227

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
# of pics	1	1	0.3984016	1.1694	0.2876
digital resolution	1	1	2.9106025	8.5433	0.0063*
exposure	1	1	0.3481956	1.0220	0.3196
# of pics*digital resolution	1	1	0.0090601	0.0266	0.8715
# of pics*exposure	1	1	0.4639716	1.3619	0.2518
digital resolution*exposure	1	1	1.7015625	4.9945	0.0325*
# of pics*digital resolution*exposure	1	1	0.1423249	0.4178	0.5227

Figure 6. JMP Printouts for Photogrammetry Experiment

Results From Measuring Wheel Experiment

2x2x2 Factorial measuring wheel

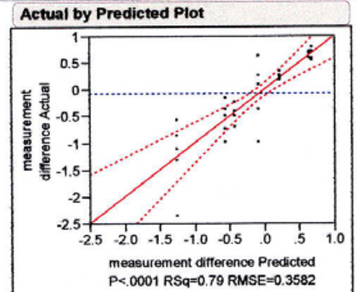
Rows	Pattern	surface	wheel diameter	exposure	measurement difference
1	+--	1	-1	-1	-2.375
2	---	-1	-1	-1	0.7083
3	+-+	1	-1	1	-1
4	+--	1	-1	-1	-1.334
5	-+-	-1	1	-1	0.33
6	+++	1	1	1	-0.7084
7	+-+	1	-1	1	0.083
8	++-	1	1	-1	-0.375
9	++-	1	1	-1	-0.75
10	--+	-1	-1	1	0.5416
11	+++	1	1	1	-0.5
12	-++	-1	1	1	0.25
13	++-	1	1	-1	-0.5
14	---	-1	-1	-1	0.666
15	--+	-1	-1	1	0.583
16	+++	1	1	1	-0.417
17	--+	-1	-1	1	0.7916
18	+++	1	1	1	-0.25
19	+-+	1	-1	1	-0.375
20	++-	1	1	-1	-1
21	---	-1	-1	-1	0.7083
22	+-+	1	-1	1	0.625
23	+-+	1	-1	1	0.25
24	---	-1	-1	-1	0.583
25	+--	1	-1	-1	-1.125
26	+--	1	-1	-1	-0.584
27	-+-	-1	1	-1	0.166
28	-++	-1	1	1	0.25
29	--+	-1	-1	1	0.7083
30	++-	1	1	-1	-0.167
31	---	-1	-1	-1	0.583
32	+--	1	-1	-1	-0.875
33	-++	-1	1	1	0.166
34	+++	1	1	1	-0.25
35	-+-	-1	1	-1	0.166
36	-+-	-1	1	-1	0.2083
37	-++	-1	1	1	0.25
38	--+	-1	-1	1	0.7916
39	-+-	-1	1	-1	0.25
40	-++	-1	1	1	0.166

2x2x2 Factorial measuring wheel- Fit Least Squares

Response measurement difference

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.786894
RSquare Adj	0.740277
Root Mean Square Error	0.358155
Mean of Response	-0.06901
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	15.156958	2.16528	16.8800
Error	32	4.104801	0.12828	Prob > F
C. Total	39	19.261759		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.06901	0.056629	-1.22	0.2319
surface	-0.51236	0.056629	-9.05	<.0001*
wheel diameter	-0.066745	0.056629	-1.18	0.2472
exposure	0.166795	0.056629	2.95	0.0060*
surface*wheel diameter	0.156375	0.056629	2.76	0.0095*
surface*exposure	0.160335	0.056629	2.83	0.0079*
wheel diameter*exposure	-0.13538	0.056629	-2.39	0.0229*
surface*wheel diameter*exposure	-0.12509	0.056629	-2.21	0.0345*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
surface	1	1	10.500511	81.8594	<.0001*
wheel diameter	1	1	0.178196	1.3892	0.2472
exposure	1	1	1.112823	8.6753	0.0060*
surface*wheel diameter	1	1	0.978126	7.6252	0.0095*
surface*exposure	1	1	1.028292	8.0163	0.0079*
wheel diameter*exposure	1	1	0.733110	5.7151	0.0229*
surface*wheel diameter*exposure	1	1	0.625900	4.8794	0.0345*

Figure 7. JMP Printouts for Measuring Wheel Experiment

Results From Measuring Tape Experiment

2x2x2 Factorial measuring tape

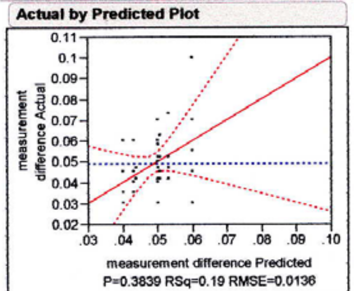
Rows	Pattern	tape type	amt of tape	exposure	measurement difference
1	-++	-1	1	1	0.04
2	+++	1	1	1	0.058
3	+--	1	-1	-1	0.0416
4	-+-	-1	1	-1	0.04
5	+--	1	-1	-1	0.0416
6	+++	1	1	1	0.0416
7	-+-	-1	1	-1	0.07
8	++-	1	1	-1	0.0416
9	-+-	-1	1	-1	0.03
10	+-+	1	-1	1	0.052
11	-++	-1	1	1	0.06
12	-+-	-1	1	-1	0.05
13	+--	1	-1	-1	0.0416
14	---	-1	-1	-1	0.07
15	--+	-1	-1	1	0.03
16	---	-1	-1	-1	0.055
17	---	-1	-1	-1	0.03
18	--+	-1	-1	1	0.06
19	-++	-1	1	1	0.035
20	+++	1	1	1	0.052
21	-++	-1	1	1	0.035
22	-++	-1	1	1	0.045
23	++-	1	1	-1	0.052
24	---	-1	-1	-1	0.1
25	+-+	1	-1	1	0.052
26	-+-	-1	1	-1	0.06
27	++-	1	1	-1	0.052
28	--+	-1	-1	1	0.03
29	+--	1	-1	-1	0.0469
30	---	-1	-1	-1	0.045
31	+-+	1	-1	1	0.0625
32	++-	1	1	-1	0.0469
33	+--	1	-1	-1	0.0469
34	--+	-1	-1	1	0.035
35	--+	-1	-1	1	0.045
36	+++	1	1	1	0.0469
37	+-+	1	-1	1	0.0416
38	+++	1	1	1	0.052
39	++-	1	1	-1	0.073
40	+-+	1	-1	1	0.045

2x2x2 Factorial measuring tape- Fit Least Squares

Response measurement difference

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.194641
RSquare Adj	0.018469
Root Mean Square Error	0.013628
Mean of Response	0.048818
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.00143628	0.000205	1.1048
Error	32	0.00594284	0.000186	Prob > F
C. Total	39	0.00737912		0.3839

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0488175	0.002155	22.66	<.0001*
tape type	0.0005675	0.002155	0.26	0.7940
amt of tape	0.0002325	0.002155	0.11	0.9147
exposure	-0.002887	0.002155	-1.34	0.1897
tape type*amt of tape	0.0019825	0.002155	0.92	0.3644
tape type*exposure	0.0038625	0.002155	1.79	0.0825
amt of tape*exposure	0.0003875	0.002155	0.18	0.8584
tape type*amt of tape*exposure	-0.002862	0.002155	-1.33	0.1934

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
tape type	1	1	0.00001288	0.0694	0.7940
amt of tape	1	1	0.00000216	0.0116	0.9147
exposure	1	1	0.00033351	1.7958	0.1897
tape type*amt of tape	1	1	0.00015721	0.8465	0.3644
tape type*exposure	1	1	0.00059676	3.2133	0.0825
amt of tape*exposure	1	1	0.00000601	0.0323	0.8584
tape type*amt of tape*exposure	1	1	0.00032776	1.7648	0.1934

Figure 8. JMP Printouts for Measuring Tape Experiment

Conclusions

Even though this experiment truly has categorical (or discrete) factors (smooth/rough; small/large; rush/take time), the experiment was executed as continuous as per the suggestion of the Statistical Consulting Center at UT (the experiment was actually carried out both ways and the results were practically identical). The SCC suggested this because JMP computes more accurately in a continuous setting than in categorical. JMP simply assigns a -1 or +1 to each level; the experimenter has to keep each setting straight as to avoid confusion. Appendix 15 contains all JMP printouts with handwritten notes included.

Measuring Wheel

The main effects that were significant in this experiment were surface and exposure to the road. Using the prediction profiler in JMP's embedded DOE tool will show that smooth is better for being on target; a smooth surface gives you results that are <u>long</u> of the target (this is possibly due to wavy behavior or bad tracking) and a rough surface give you results short of target (possibly due to lack of rotation of the wheel); rushing gives a short of target result (wheel possibly skips) and taking your time gives a long of target result (wheel possibly waves about).

The following cross effects will yield the lowest errors: surface and wheel diameter—a smooth surface plus a large wheel diameter will yield a lower error; surface and exposure—if you have a rough surface it is best to take your time; wheel diameter and exposure—if you have a large diameter wheel, it is best to take your time; surface and wheel diameter and exposure—if you have a rough surface plus a small diameter wheel, it is best to take your time.

Measuring tape

The factors that were thought to have an impact on the response turned out to have no impact at all—this is very clear by looking at the printout—no main nor cross effects were significant. In retrospect, the experiment could have been done differently. A possible factor that was not included in this experiment was length of measurement; shorter measurements would be more accurate than longer measurements because in longer measurements, the tape measure itself could become more twisted than with shorter measurements.

Photogrammetry

One main effect and one cross effect were significant at the α=5% level: digital resolution=0.0063 and digital resolution* exposure=0.0325. If one looks at the mean of response (response being measurement error), measuring tape did the best (0.045518 ft or 0.586 inches), followed by measuring wheel (-0.06901 ft or -0.82812 inches), and then photogrammetry (0.7395 ft or 8.874 inches). 8.874 inches translates to a 1.5% error over 48 feet; this is a reasonable and acceptable measurement error for accident reconstruction applications such as speed estimates from skid marks. Future photogrammetry experiments should utilize the pins themselves; the pins would have to be incorporated into the measurement process, perhaps by highlighting the pins with neon paint to facilitate conspicuity in the digital photos.

Future Directions and Research

- Incorporate length of measurement into the experiment, at two levels (short/long). Measure a distance at say, 48 feet, and then a distance longer than 48 feet. 48 feet was very manageable by all the techniques, perhaps a bit *too manageable*. Maybe something like 108 feet could work; this is roughly the distance across a two 4-lane highway with a median. In hindsight, the impact of measurement length could not only affect the results of measuring tape experiments, but the measuring wheel experiments as well, due to more opportunities for skips and wavy motion. The author's initial feeling is that the photogrammetry experiment probably wouldn't be affected by length of measurement, provided that the targets are still clearly seen in all the photos while working within the photogrammetry software, however; there is a point where targets are not easily seen when placed far from the camera, which in case, the target size would have to be increased or the distances measured decreased; a clear, crisp target placed at a long distance can look a blurry blob when enlarged (zoomed in) within PhotoModeler.

- Study the effect of digital resolution on photogrammetry more closely. To date, no one has published on this topic in the accident reconstruction community. It is especially important since these days, most accident scenes and vehicles are documented with digital cameras. Each day brings new digital cameras to the market. This study utilized the same digital camera (at 5 mega pixels) at two levels of resolution (at 5 MP and 0.15 MP). Perhaps a new experiment could make use of say, a 12 MP camera and the 5 MP in the study.

- Use the benchmark measurement markers more precisely in the photogrammetry experiment. As mentioned before, enhancing the pins with paint, or even develop a new technique, maybe something like a small flag with a magnetic bottom to place on the pin. There are a host of similar possibilities that could be employed. The author had planned to revamp this part of the experiment before this document was prepared but the airport was the lucky recipient of a grant for new paving projects; the experiment site used in this study was completely repaved. The precisely placed pins are currently under a substantial amount of asphalt. Even the gravel area adjacent to the old asphalt surface (used for the wheel experiment) is now under asphalt. Permission to reuse the site would most likely be granted, but the site would now have to be considerably prepared for future experiments, or a totally new site would have to be located.

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APPENDIX 1

CAMERA CALIBRATION OF OLYMPUS C-5050 HIGH RESOLUTION

APPENDIX 1

CAMERA CALIBRATION OF OLYMPUS C-5050 HIGH RESOLUTION

This Appendix contains details for the camera calibration procedure, however; early in January 2007, the author was the unlucky victim of a hard disk crash. Photos of the Olympus C-5050 calibration project were lost forever (as were other parts of this dissertation), but the PhotoModeler project itself still exists (go figure). So post-calibration camera parameters are still available, but the eight (8) or so images of the calibration grid no longer exist. This is a good situation if you want to process a project, but not so good if you want to communicate the fine aspects of camera calibration. The author feels that camera calibration can be best explained using photos from her Thesis [115]. The difference between the Thesis and the Dissertation calibration is that the Thesis work utilized a film camera and the Dissertation utilized a digital. While the two calibration procedures are very similar, they do have their differences. Firstly, the film camera calibration requires a film insert, either EOS's two-point fiducial or the nine-point fiducial. A fiducial is a device that is installed between the lens and the film. So any pictures taken with a fiducial camera will have particular marks in the image. These fiducial marks help PhotoModeler determine the orientation of the camera (i.e., how the camera is positioned at the time of exposure---up, down, sideways, etc.) which is a significant part of the photogrammetric processing. Figure 1 illustrates the two-point while Figure 2 shows the nine-point fiducial. Fiducials are indicated in red. Note that the two-point fiducial covers the extreme

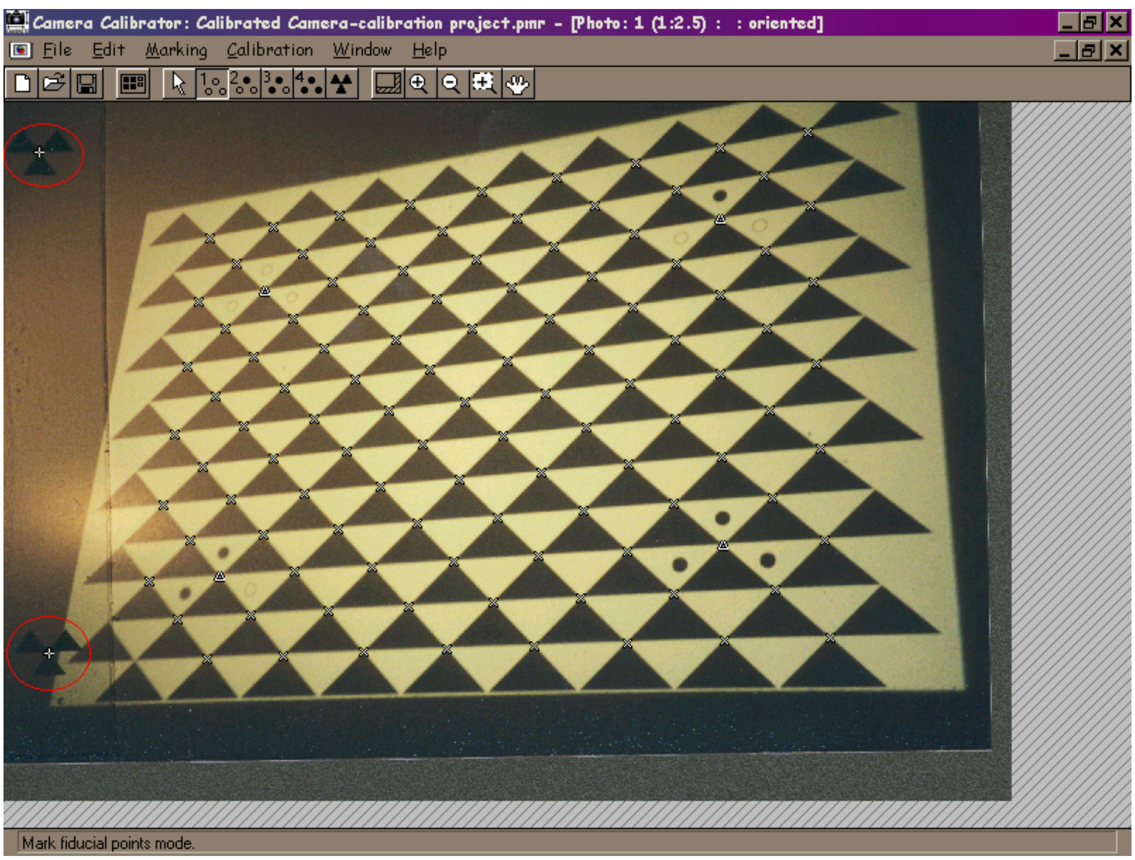


Figure 1. Two-point fiducial image

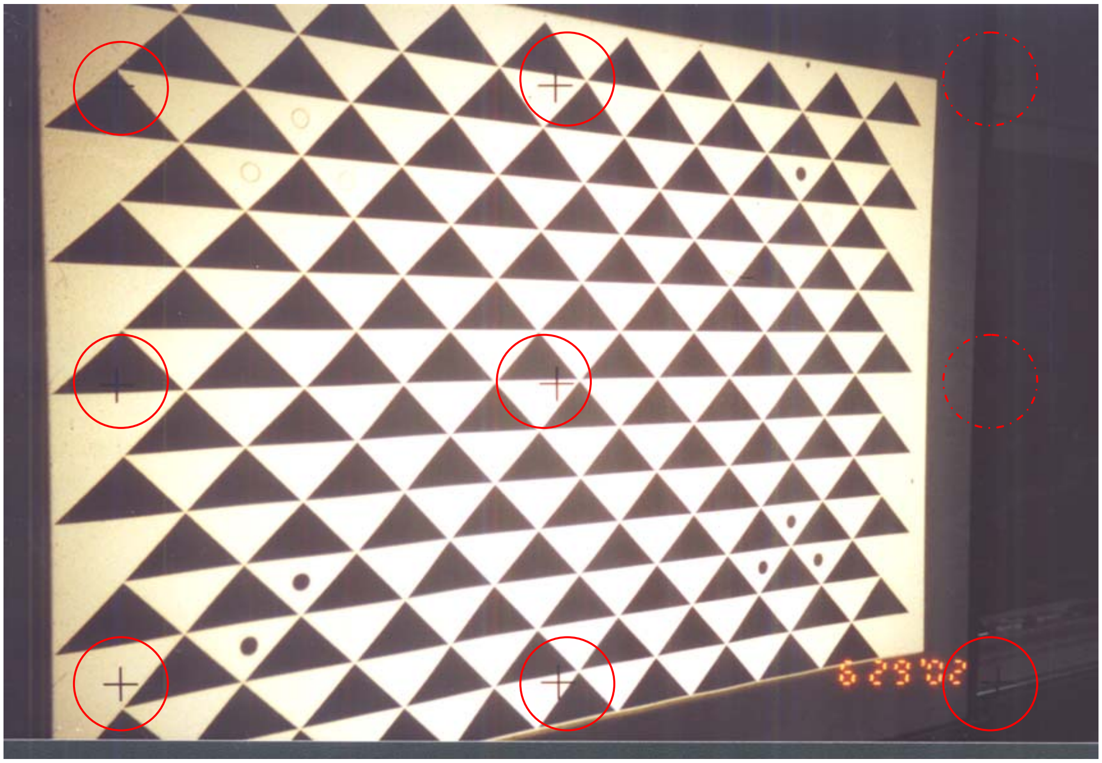
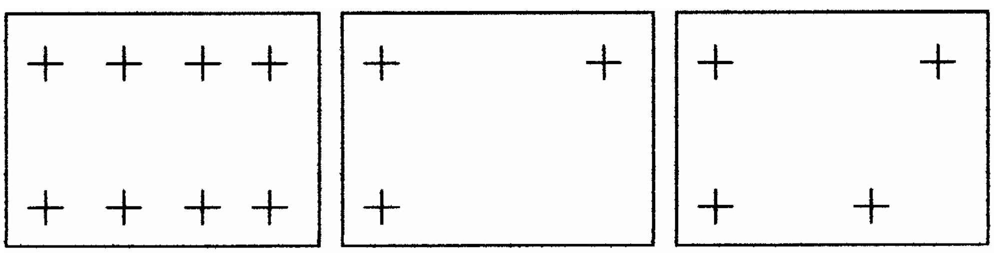


Figure 2. Nine-point fiducial image

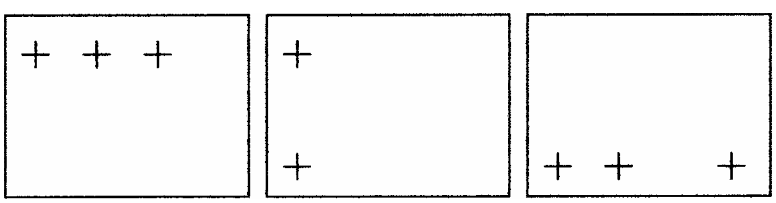
left side of the photo, while the nine-point fiducial covers the entire film plane. Figure 2's right-most fiducials are not well seen; this is indicated with the red dashes. A situation like this is no cause for alarm; all nine are not required to be visible in the photograph when using the nine-point insert (when using a two-point fiducial insert, both fiducials must be visible—if only one is marked, then that photo won't be processed by PhotoModeler). In fact, it is quite commonplace to have one or more fiducials covered by dark areas. PhotoModeler requires a minimum of three (3) fiducials, however;

the placement of the fiducials, whether it be three (3) or more, requires some precision [21]. Figure 3 illustrates these requirements.

This particular Appendix is entitled “Camera Calibration of Olympus C-5050, High Resolution”. The distinction “High Resolution” was identified as such to differentiate this particular Appendix from Appendix 13, which is associated with Part 3’s work. Appendix 1 involves images taken at a 2560 x 1920 resolution, which ends up



These are good fiducial configurations, however;



these are not. More than one-third of the image must be covered, i.e., more than a single row or column must be visible.

Figure 3. Good/Bad Fiducial Configurations
Source: PhotoModeler Help Files

being a 1.02 MB file. Appendix 13's images are taken at a 1024 x 768 resolution, which ends up being a 0.148 MB file. The resolution used in this appendix is the default setting on the Olympus C-5050, which is the second highest resolution the camera can generate.

It is notable to mention that the Thesis work calibration was performed with PhotoModeler's Camera Calibrator 3.1; the version used in this work is Camera Calibrator 4.0g. When working with digital cameras, the process of scanning photos has been completely circumvented and there is no need for the film plane insert. The calibration procedures are essentially the same; the calibrator procedural differences in working with film vs. digital makes them a little dissimilar; though, the buttons and drop down menus on Calibrator 3.1 and 4.0g are <u>exactly</u> the same.

Overview

Camera calibration involves the projection of a special grid pattern onto a flat wall, which is free of textures. This is generally done by a slide projector. PhotoModeler's software package includes this calibration slide. Pictures are then taken of the slide from eight

(8) different positions: upper, middle, lower and middle vertical on both the left and right sides. Next is the transmission of the digital photos from the camera to the computer. After that, points are marked and the calibration process begins. If the processing is successful, then the camera is calibrated and can be used as a measurement device with PhotoModeler.

Prepare for Picture Day

Several preparations were made prior to taking photographs of the calibration slide. First, a uniform, flat wall (free of wallpaper) was located. The wall also needs to be as large as possible; 12 ft by 15 ft were the dimensions of the wall used in this calibration project. Also obtained was a slide projector which projected the image onto the wall. The projector used had an adjustment that allowed the image to become as square as possible; this is very important in the calibration process. Figure 4 and Table 1 shoes the values required and obtained, respectively, for squareness verification of the calibration image. A check of Figure 4 reveals that the squareness requirements were indeed fulfilled.

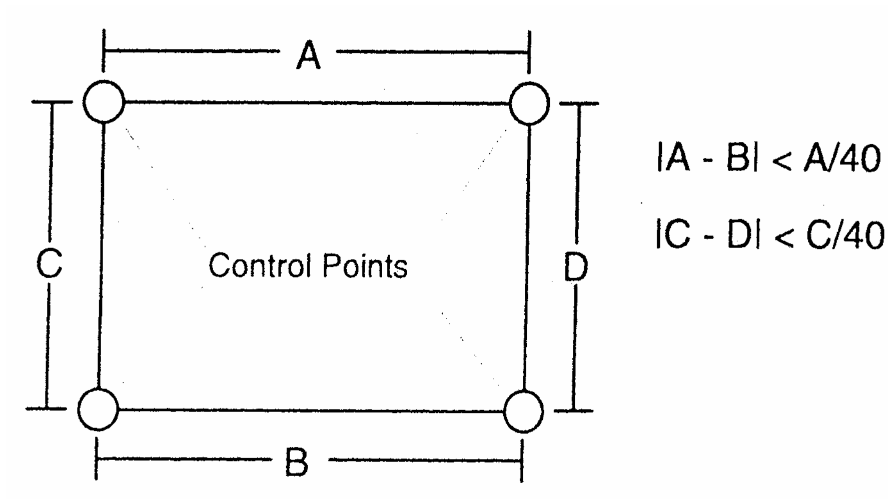


Figure 4. Squareness Verification Equations
Source: EOS Systems, Inc.

Squareness Verification Data	
A=69 inches	C= 45.625 inches
B= 68.5 inches	D= 45.375 inches
|A-B| < A/40	|C-D| < C/40
|.5| < 69/40	|.25| < 45.625/40
|.5| < 1.725 ✓	|.25| < 1.14 ✓

Table 1. Squareness Verification Data

Next, a ladder was collected. The ladder was used to allow the user to take pictures of the upper corners of the calibration slide. The ladder used in this project was 4 ft tall. To successfully project the calibration image onto the wall, the room itself needed to be dark; overhead lights ruin the effectiveness or crispness of the image.

Finally, the author found it useful to counteract the harshness of the flash by turning the flash down by navigating through a series of menus on the Olympus C-5050. If this step were not competed, the flash would cause vital parts of the photo of the calibration slide to become washed out, and hence, unusable.

Take Pictures

As mentioned previously, eight (8) pictures need to be taken of the calibration image on the wall. First, the pictures of the left side were taken, upper left, middle left, middle left vertical, and bottom left. Then the pictures on the right side were taken in a similar manner. To be safe, more than eight (8) pictures were taken, and the best ones were selected at a later time. Figure 5 shows some of the various photograph positions used in this calibration project.

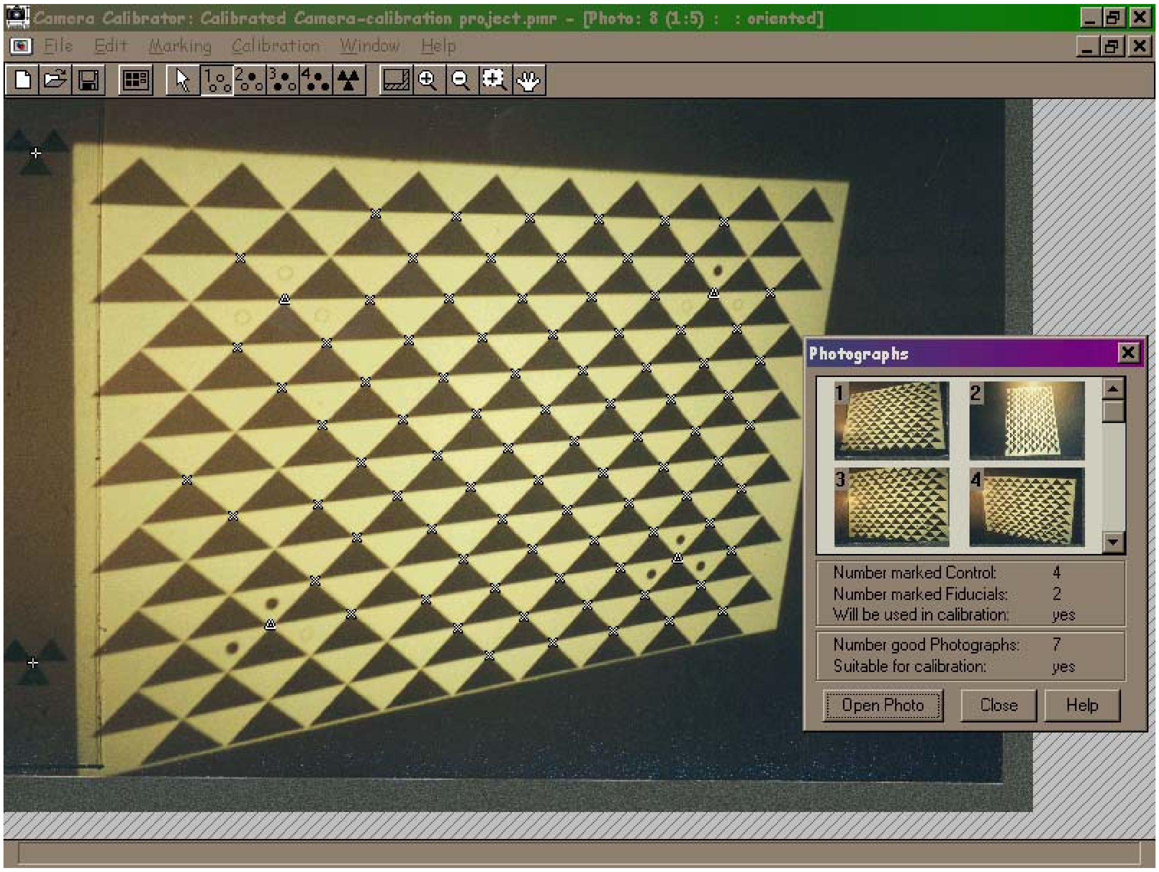


Figure 5. Various Calibration Photos

Select Pictures

After the pictures were taken, the photos were downloaded onto the computer. The best pictures were selected for the calibration project. Pictures selected had the entire calibration slide in the photograph and were of the needed orientation (upper left, lower right, etc.) The images were given a name, saved, and put into a directory which could be easily found by the user, usually on the desktop.

Start the Calibration Project

For a Windows operated PC, go to Start, Programs, PhotoModeler, and then Camera Calibrator 4.0. Once the Camera Calibrator is open, go to File and New Camera Calibration. A Wizard appears on the screen. The Wizard outlines the steps needed in the camera calibration project; refer to Figure 6 for this information.

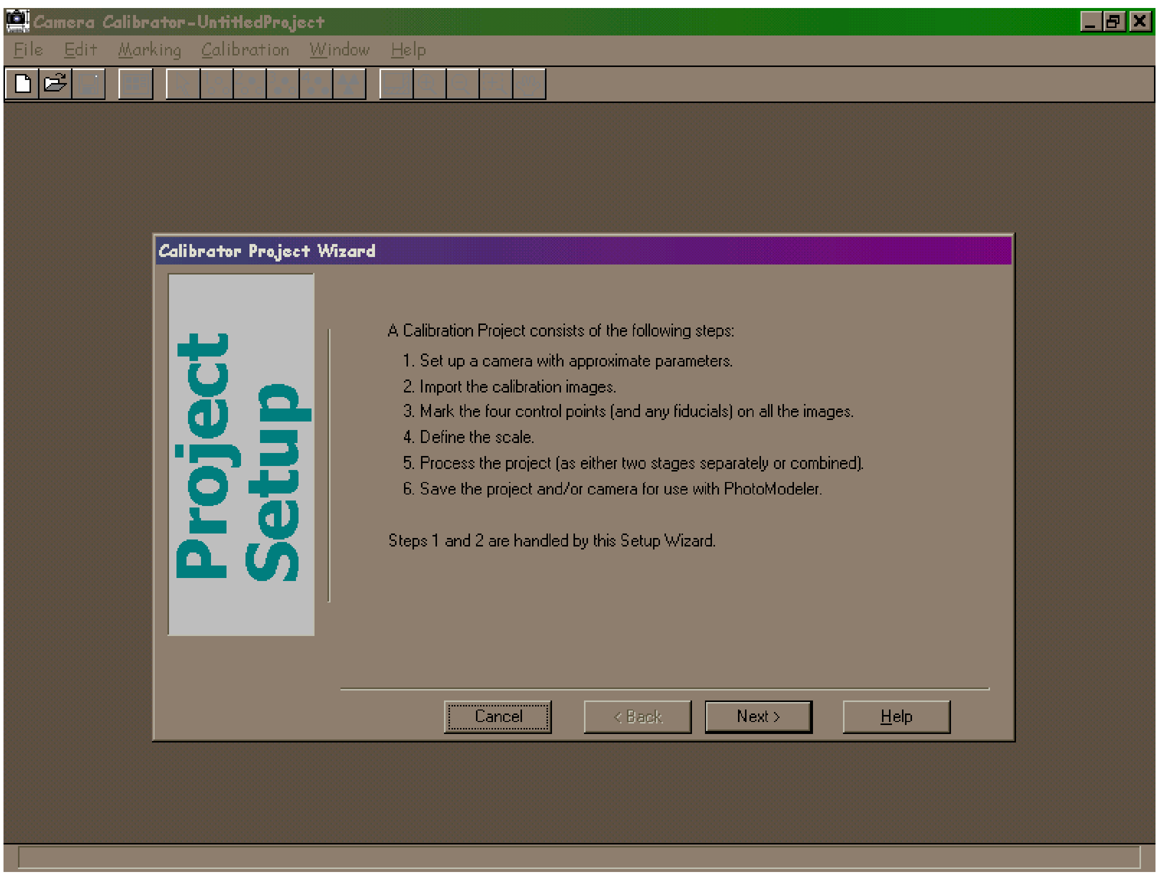


Figure 6. Camera Calibrator Wizard

Next the camera information, such as camera name (Olympus C-5050), type of camera (digital), focal length, and image resolution size that was used was entered into the Wizard. Then the images were loaded into the program by finding the correct directory.

Mark Points

First, the four (4) control points were marked on all photos. Notice that each control point (1, 2, 3, and 4) has its own button on the tool bar at the top of the screen which corresponds to a unique control point on each image. Figure 7 shows marked control points.

Scale the Calibration Project

The Camera Calibrator requires that a distance on the projected image be known. This required distance is the diagonal between control points #1 and #4. A flexible tape measure was physically taped on the wall between control points #1 and #4 and the distance was determined. The Set Scale Dialog (retrieved under the Calibration menu) was brought up and the appropriate distance was entered. Note that control points #1 and #4 are highlighted in green. See figure 8 for this information.

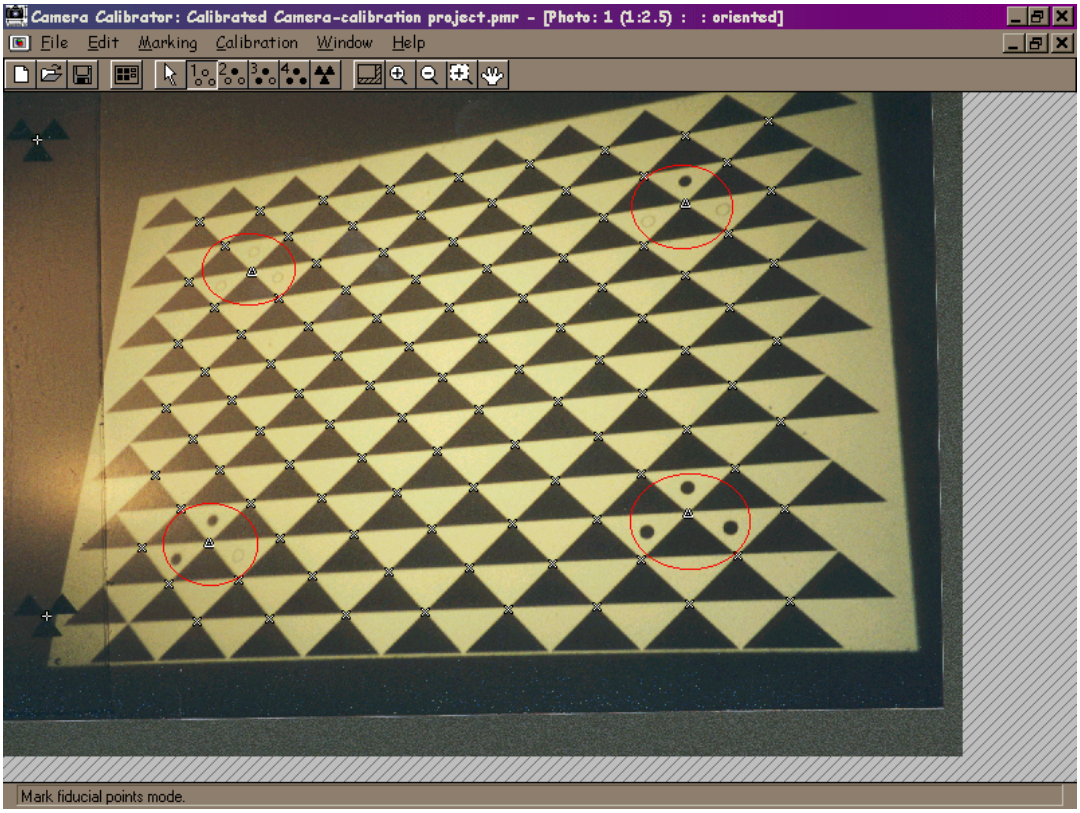


Figure 7. Marked Control Points

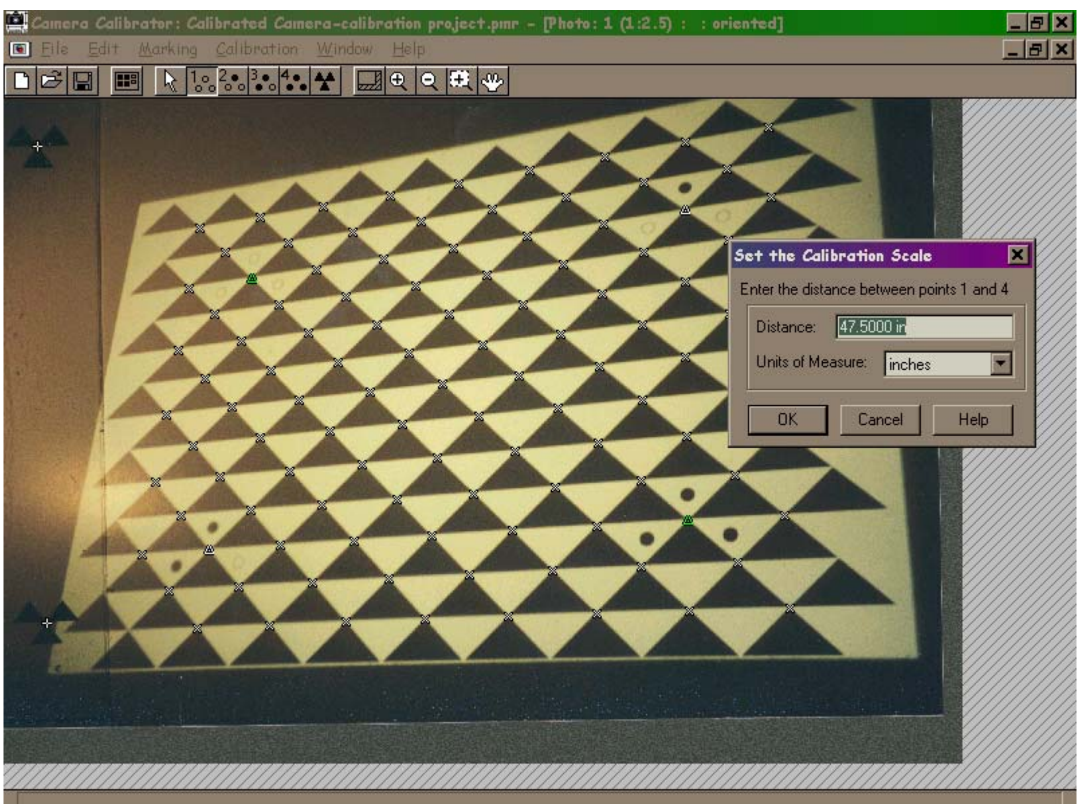


Figure 8. Scaling the Calibration Project

Process the Project

Once all the photographs have been appropriately marked and a scale distance has been determined, the actual calibration process can proceed. Under the Calibration menu, select Calibrate. This is usually a time consuming process, although necessary. If calibration is successful, the Camera Calibrator will finish with an error dialog. Refer to Figure 9 for this project's error dialog.

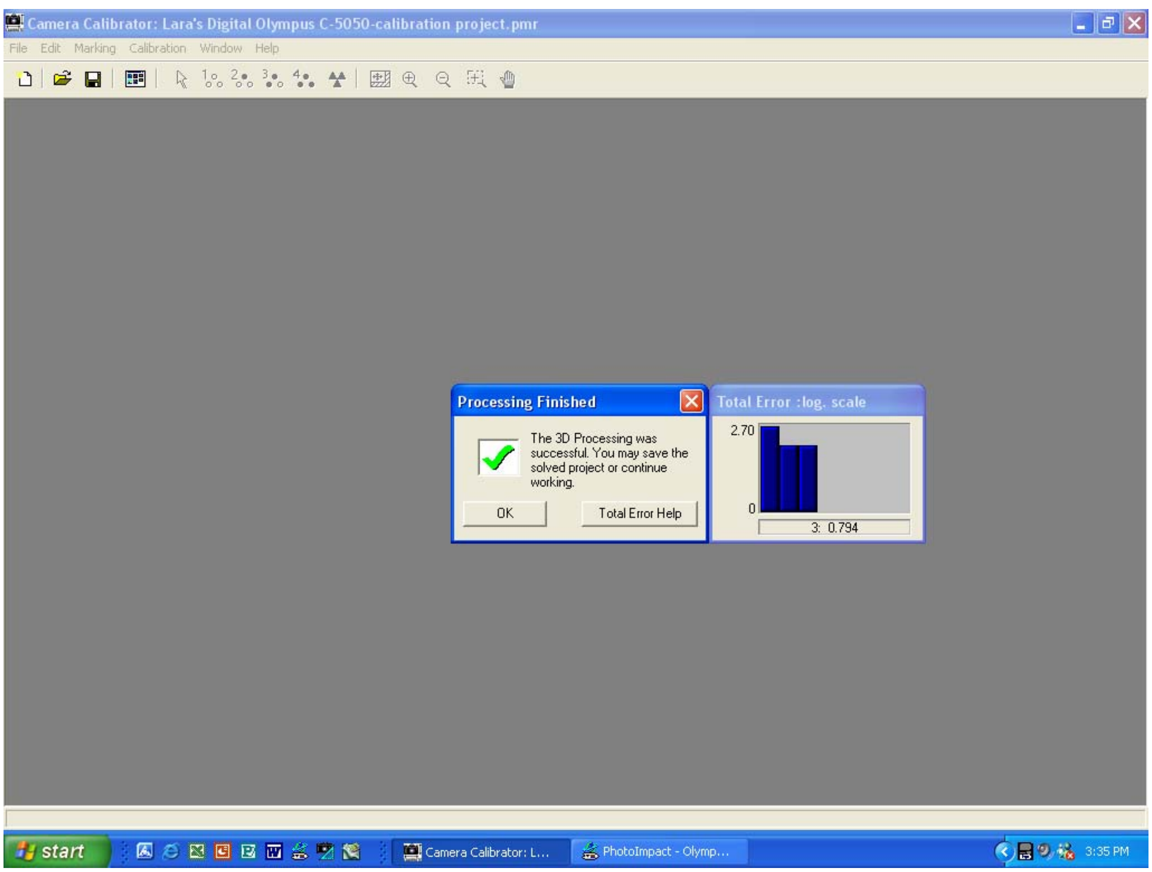


Figure 9. Error Dialog for Calibration Project

Check the Parameters

After the processing has been completed, check to see what the actual camera parameters are. For example, the initial focal length entered in this project was 38 mm (a value retrieved directly from the camera), but after calibration, the focal length was found to be 40.9076 mm. The Camera Calibrator certainly does detect variances in these parameters. Notice in Figure 10 that other camera parameters have been solved as well. Now the camera is a suitable measurement device with PhotoModeler software.

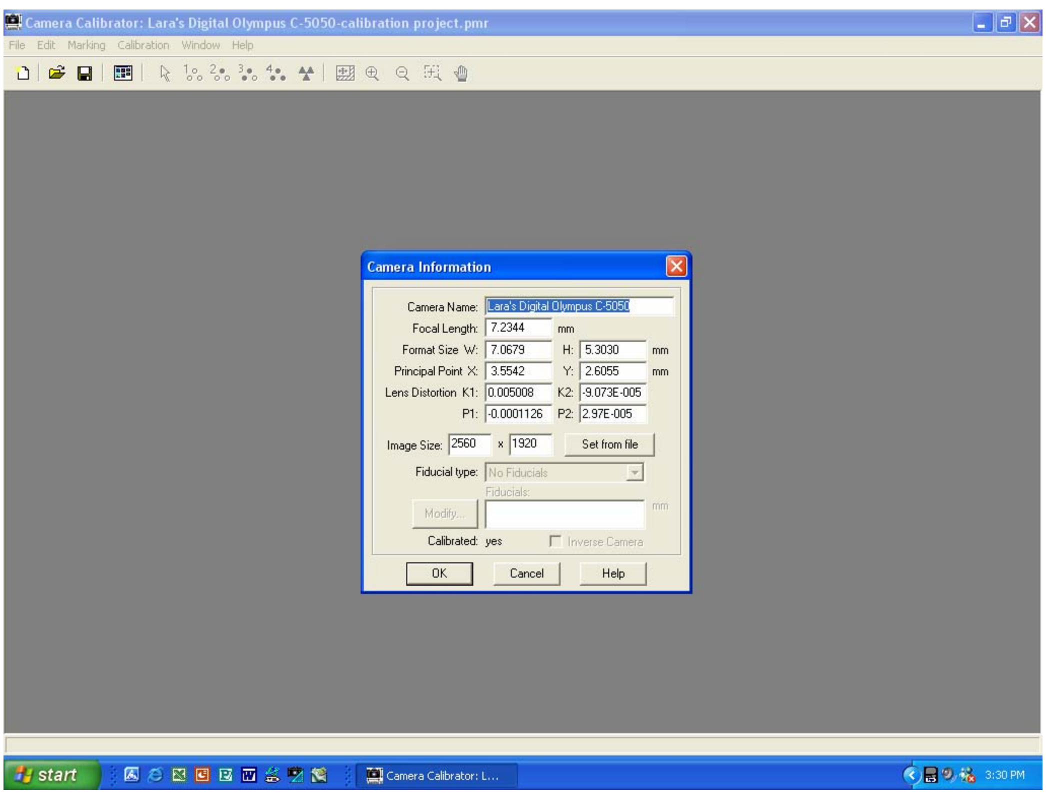


Figure 10. Solved Camera Information Olympus C-5050

The previous two figures (#9 and #10) are actually from the calibration of the Olympus C-5050. Apparently, these photos endured despite the hard disk crash. One should note that the final calibrated values for the Pentax and the Olympus are quite different; this is because the focal length for film and digital cameras are differentiated using a totally different system. For a digital camera, PhotoModeler wants the value directly off of the camera itself, and not the 35 mm equivalent. Figure 11 is another screenshot that survived the hard disk crash. Notice how there are no fiducials for a digital camera.

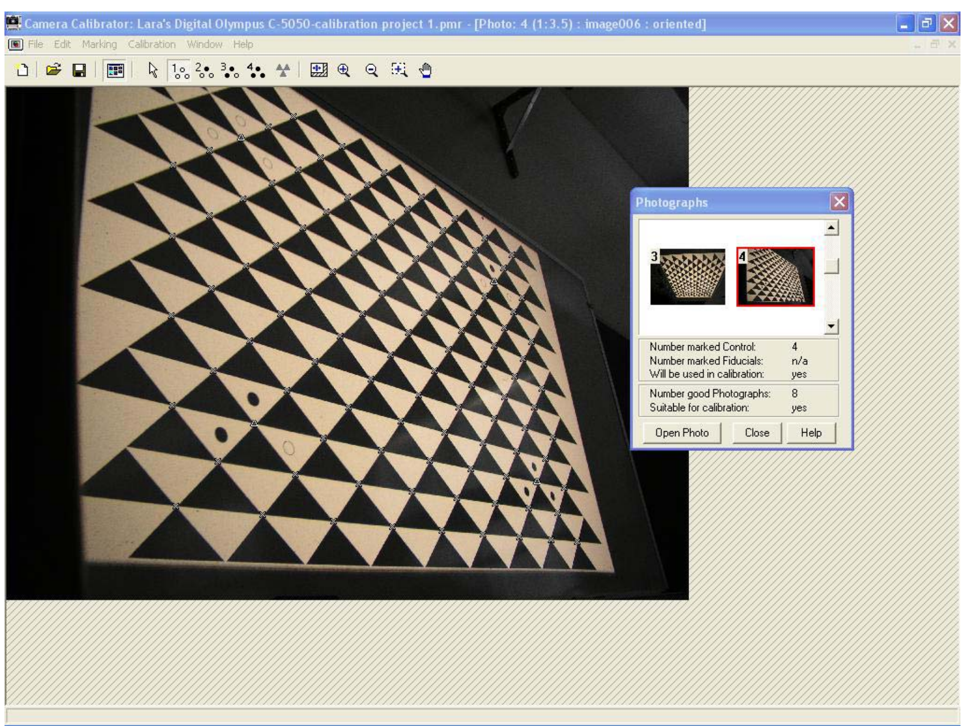
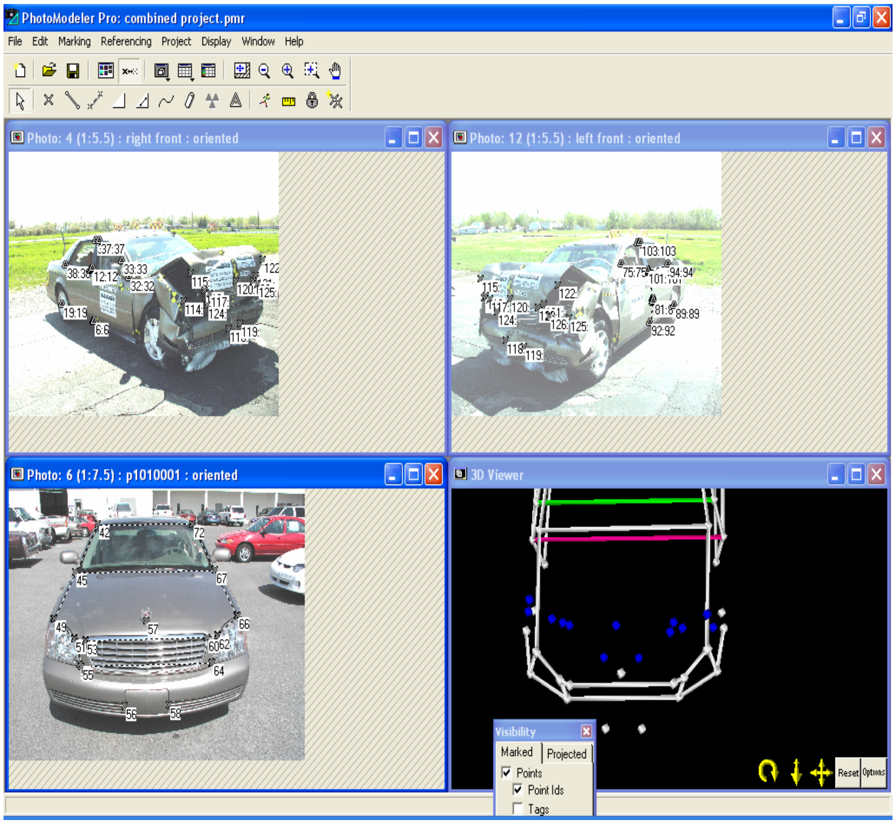


Figure 11. A Surviving Digital Camera Calibration Screenshot

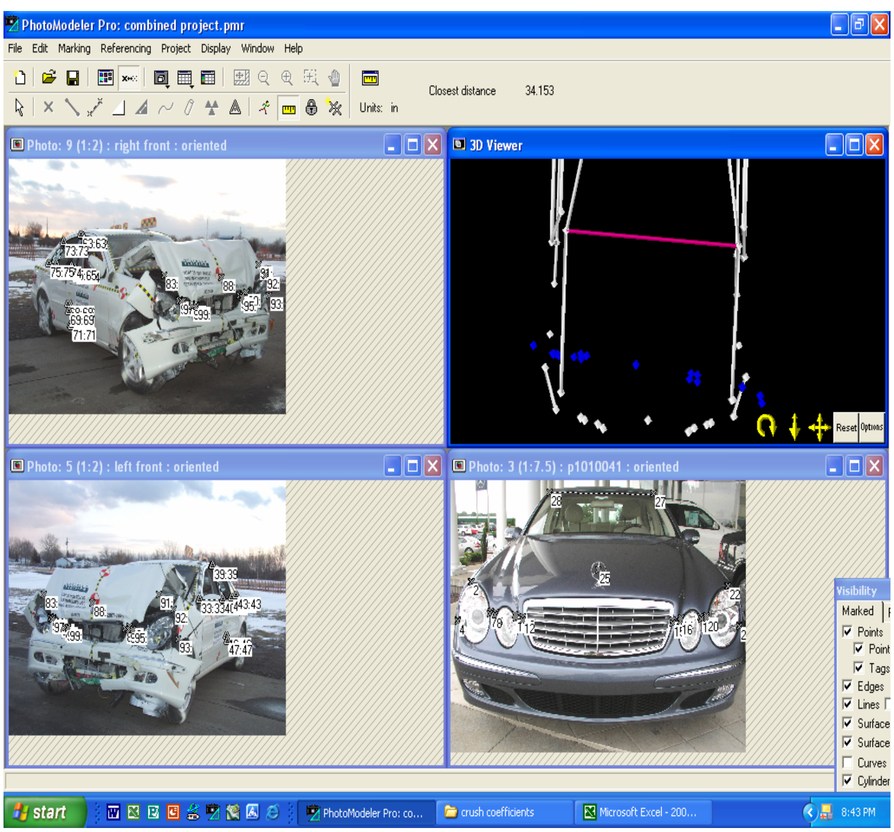
APPENDIX 2

RESULTANT SCREENSHOTS
“BETWEEN” STUDY

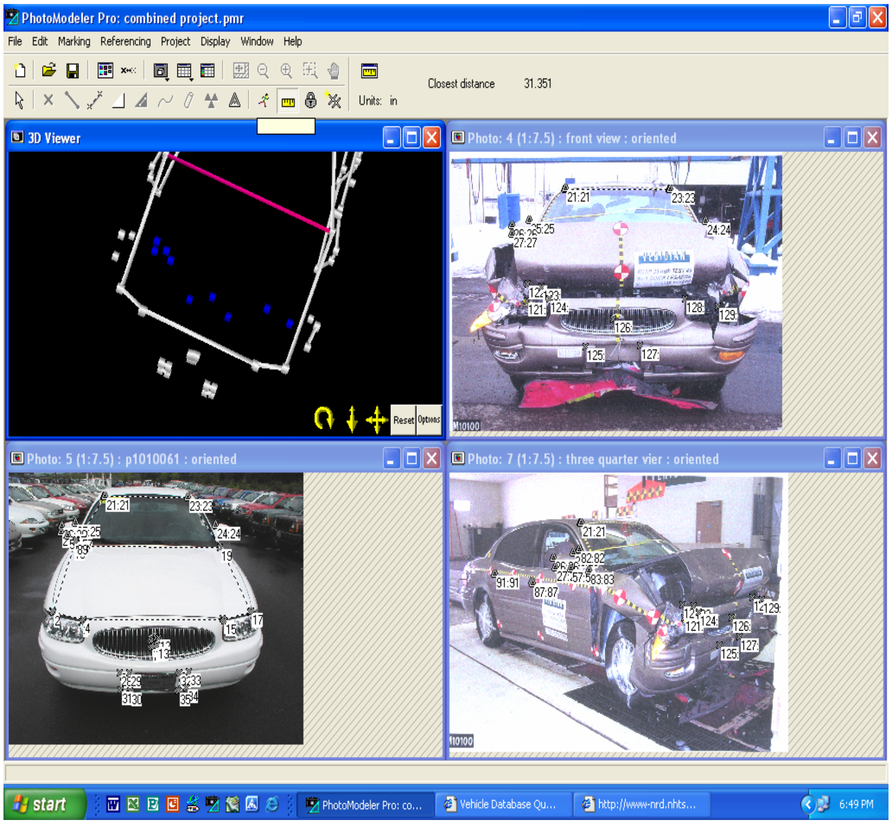
Case 1. ’02 Cadillac De Ville



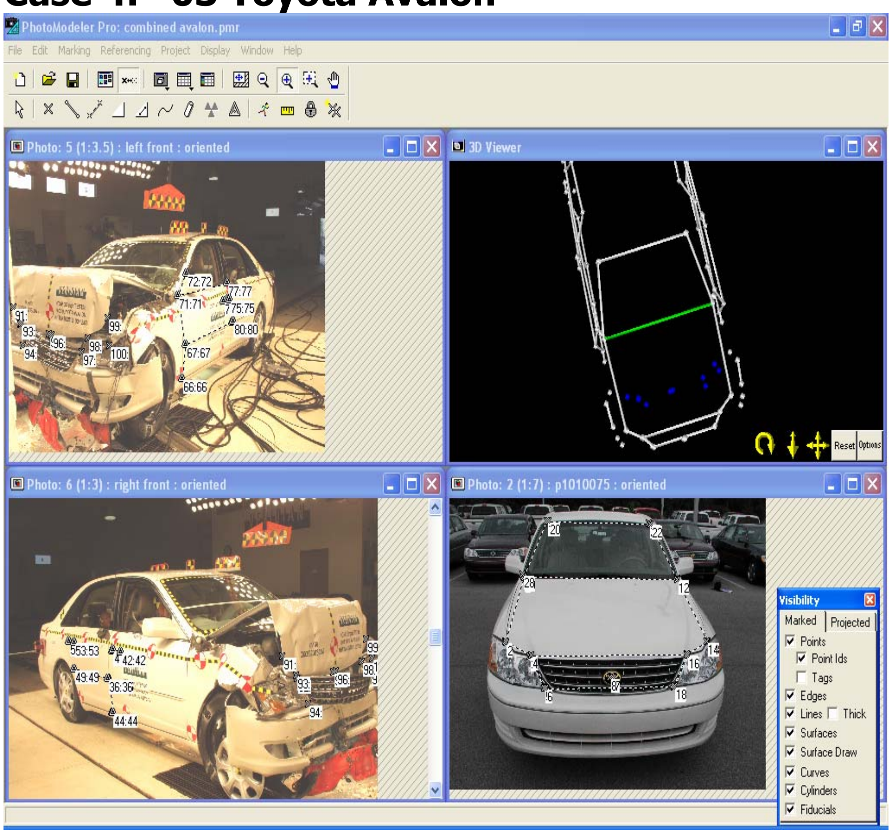
Case 2. ’03 Mercedes E320



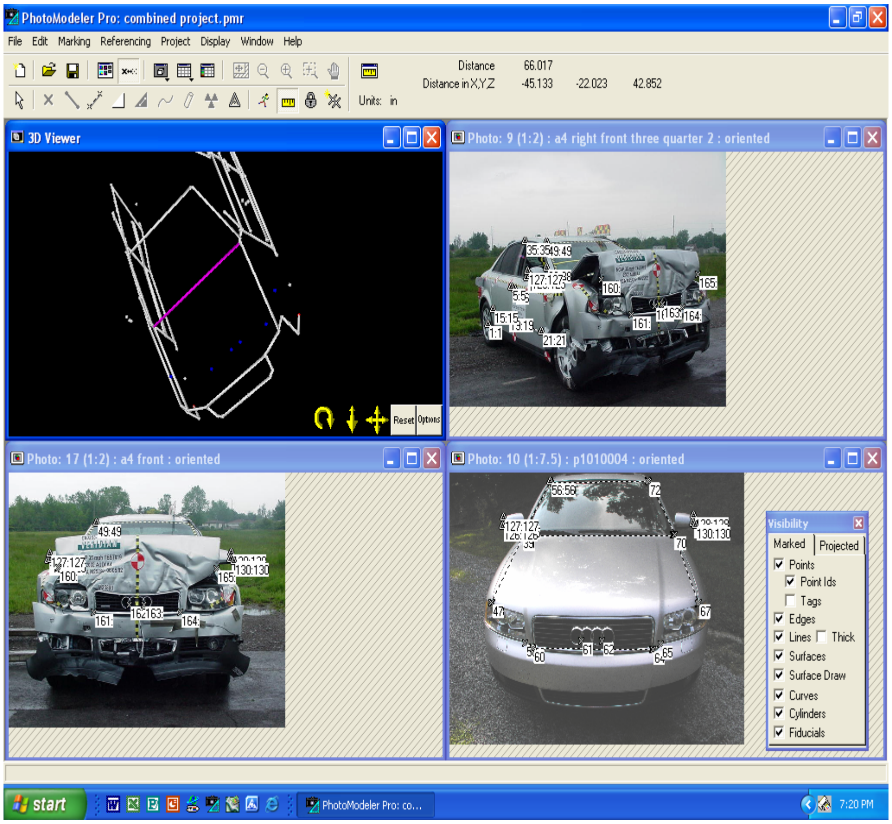
Case 3. '01 Buick LeSabre



Case 4. '03 Toyota Avalon



Case 5. '02 Audi A4

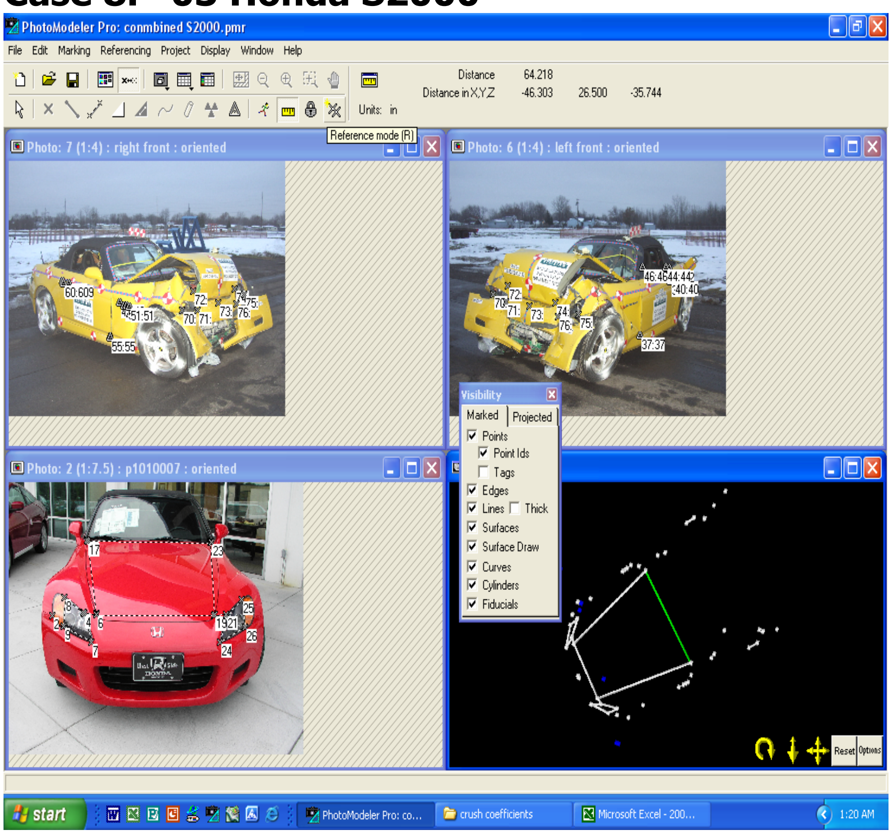


Case 6. '03 Hyundai Accent

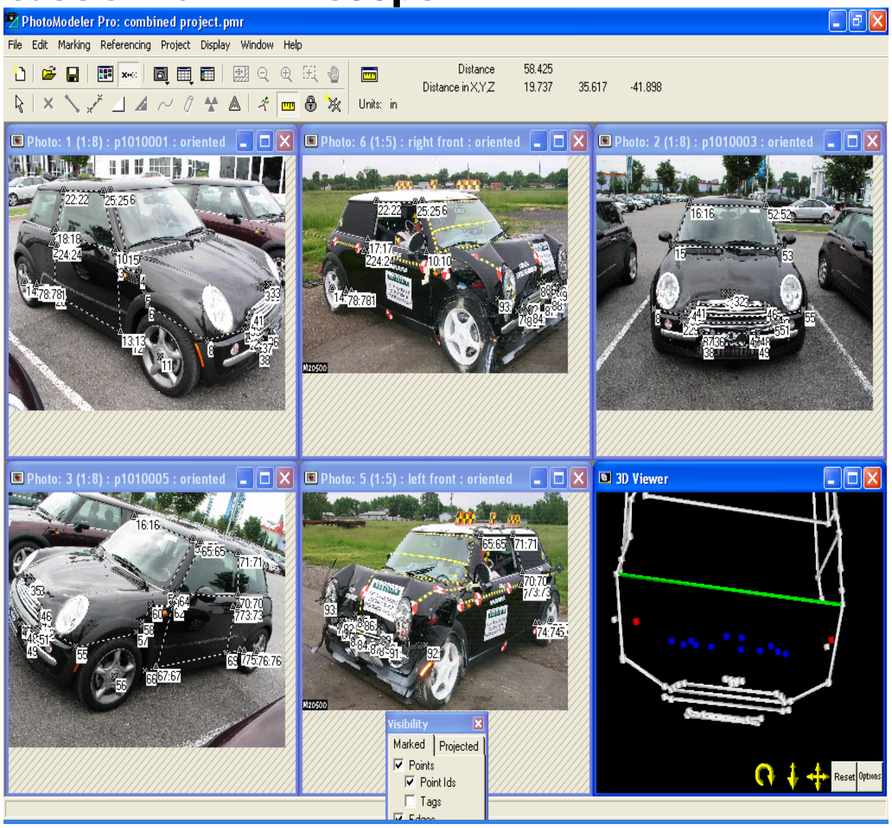
Case 7. ’01 Chevy Malibu

Missing Due To Hard Disk Crash

Case 8. ’03 Honda S2000

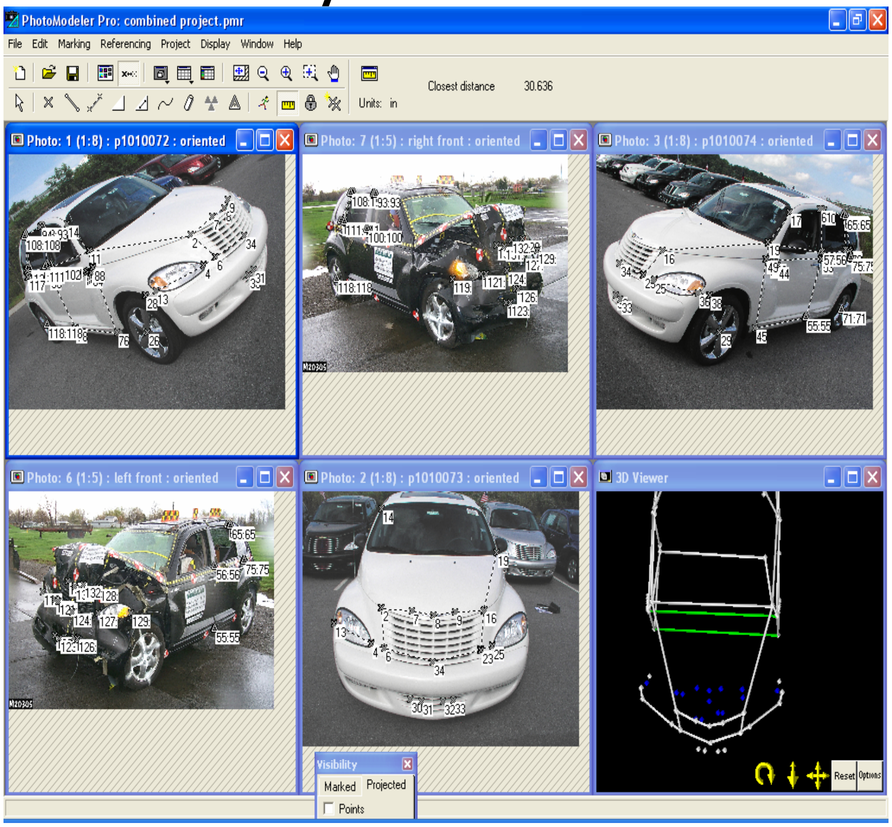


Case 9. ’02 Mini Cooper

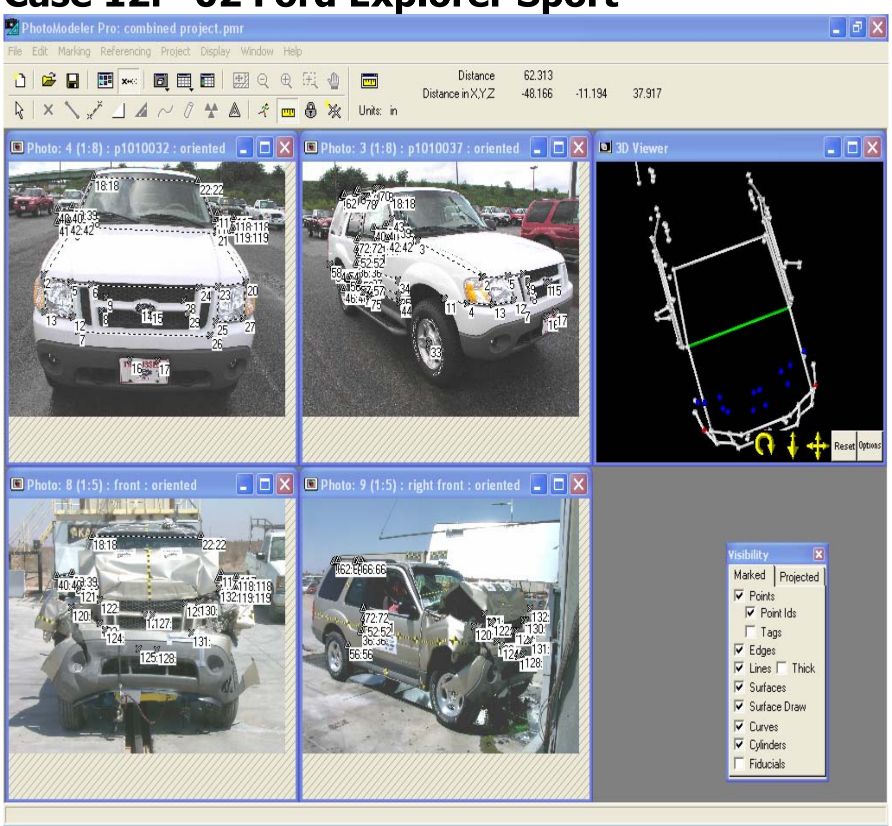


Case 10. ’03 Toyota Corolla

Case 11. '02 Chrysler PT



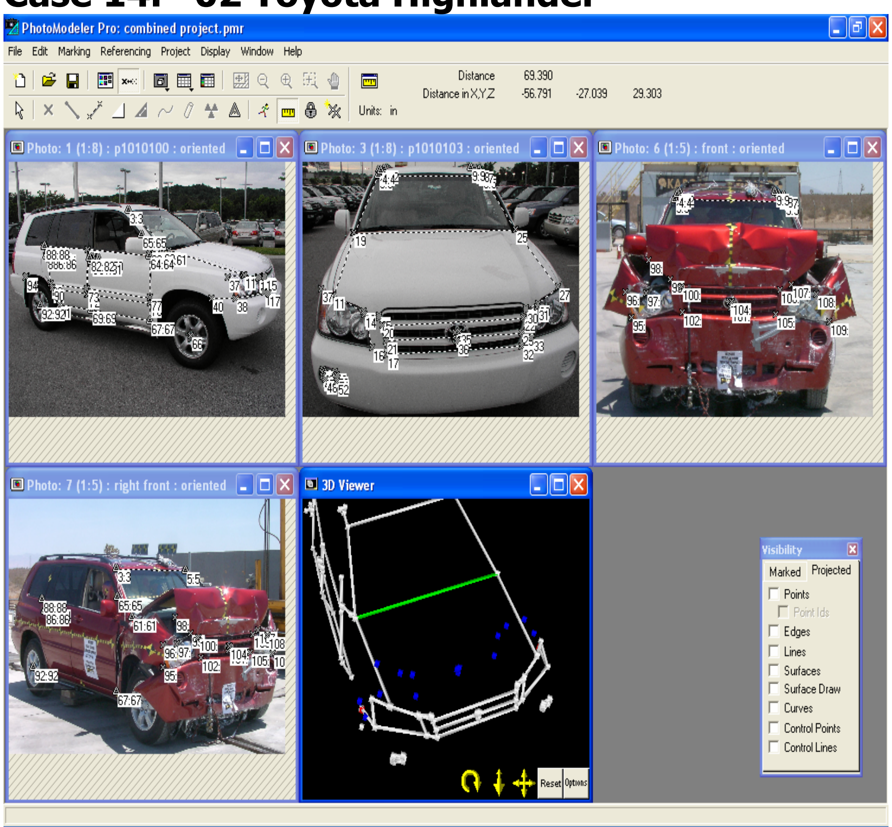
Case 12. '02 Ford Explorer Sport



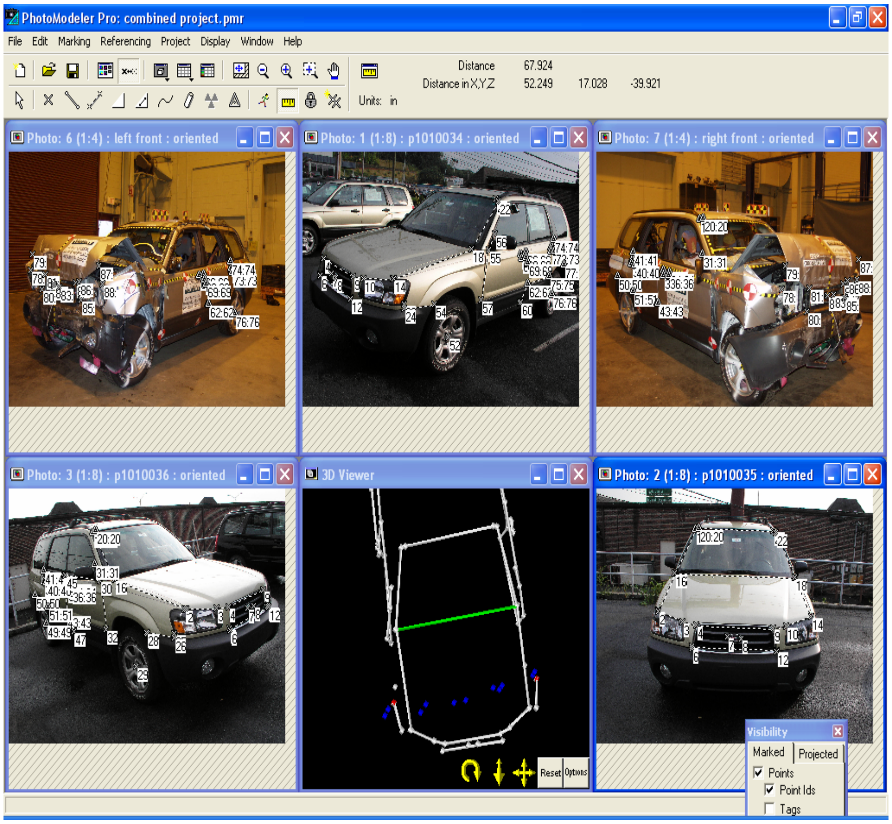
Case 13. ’02 Nissan Pathfinder

Missing Due To Hard Disk Crash

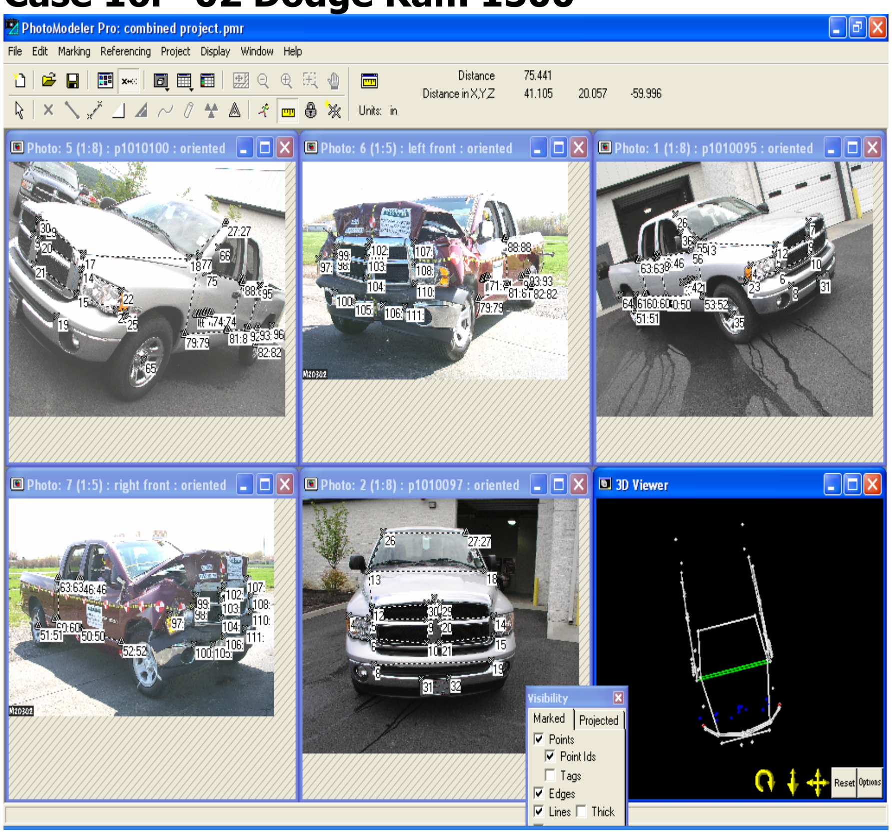
Case 14. ’02 Toyota Highlander



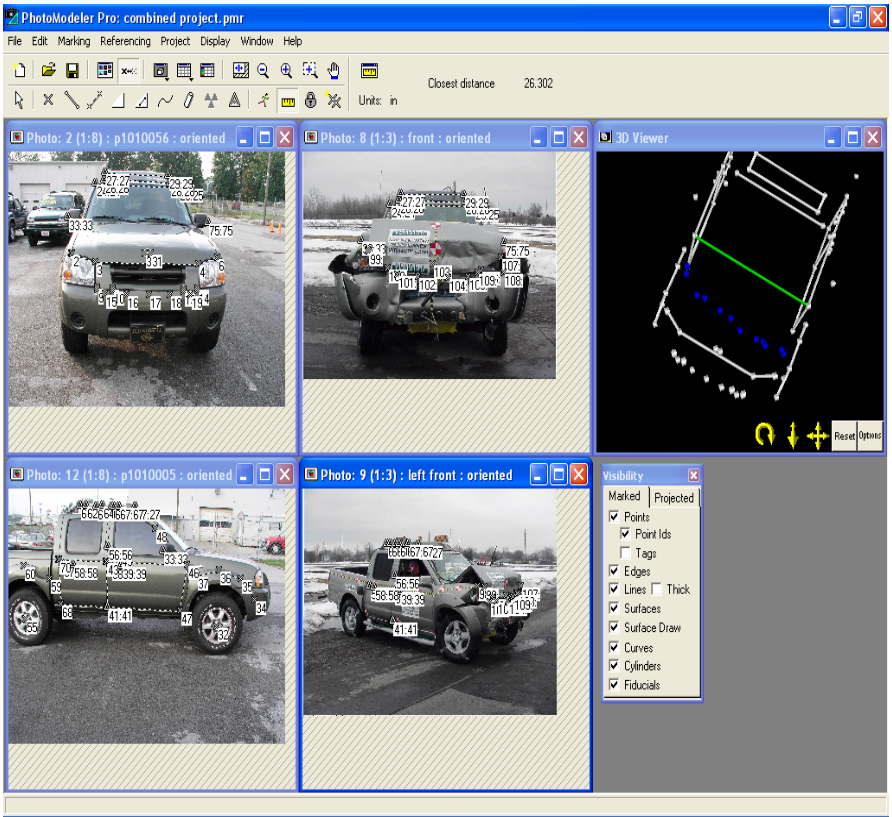
Case 15. '03 Subaru Forester



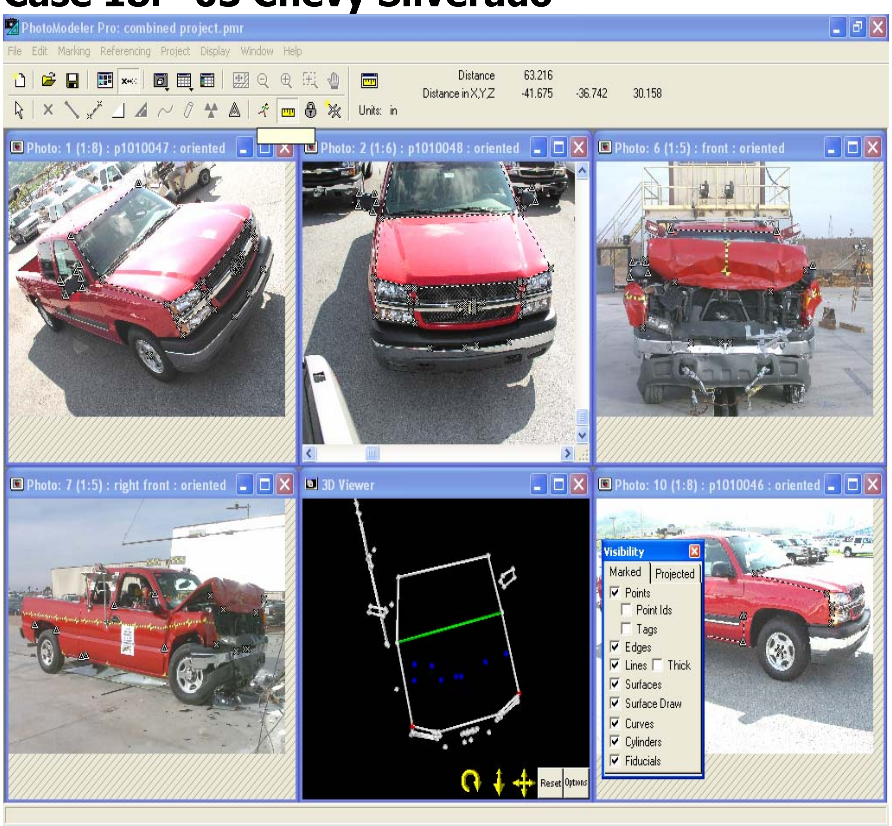
Case 16. '02 Dodge Ram 1500



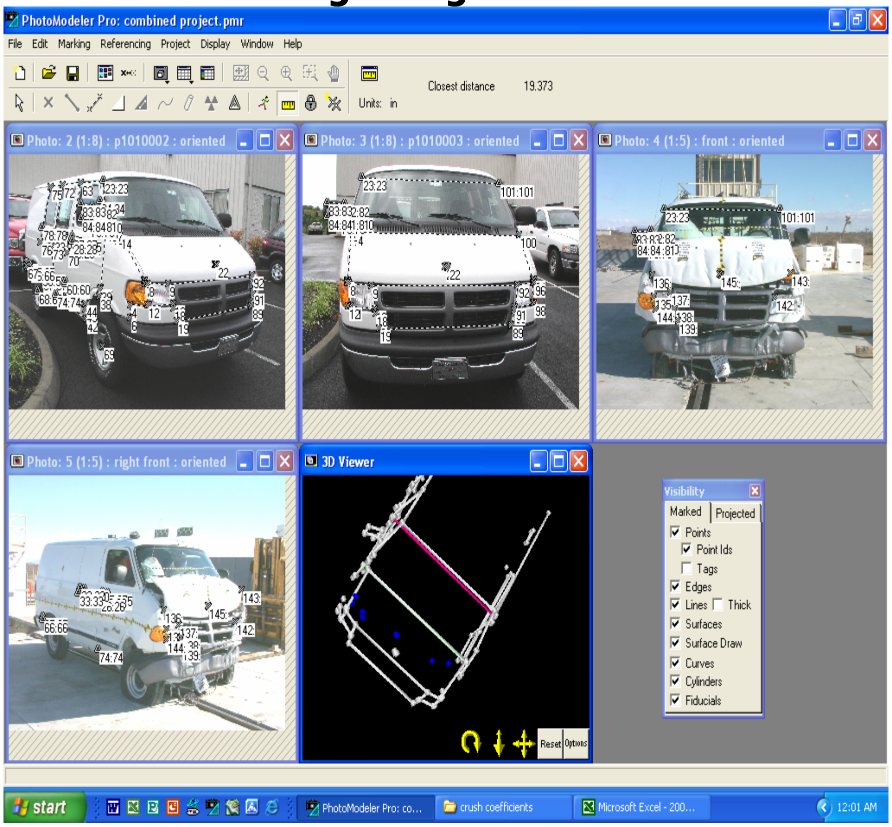
Case 17. '01 Nissan Frontier



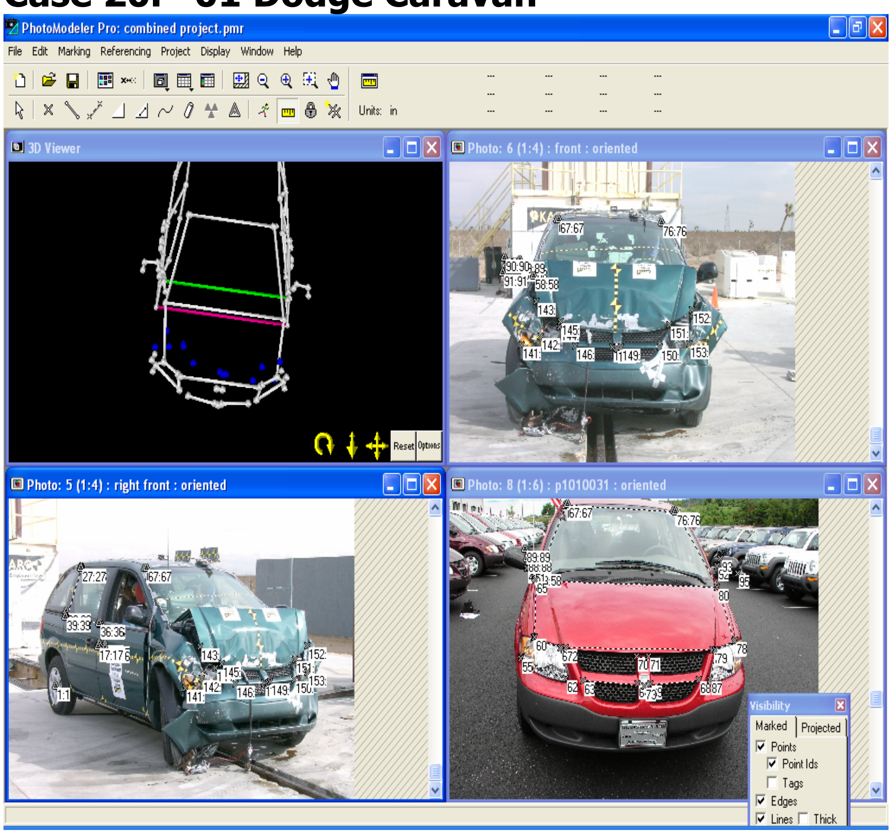
Case 18. '03 Chevy Silverado



Case 19. ’01 Dodge Wagon Van



Case 20. ’01 Dodge Caravan



APPENDIX 3

SPREADSHEETS CONTAINING INITIAL COMPUTATIONS OF CRUSH COEFFICIENTS (USING b_0=5 MPH)

Case 1. ’02 Cadillace De Ville

Crash Test Information			2002 Cadillac DeVille	case #1
Impact velocity of test:	35.30013	mph	56.81	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	17.6378	in (c1)	448	mm (c1)
	20.31496	in (c2)	516	mm (c2)
	23.46457	in (c3)	596	mm (c3)
	22.99213	in (c4)	584	mm (c4)
	20.70866	in (c5)	526	mm (c5)
	18.38583	in (c6)	467	mm (c6)
Average crush amount	20.58399	in		
Test vehicle weight	4508.453	lbs	2045	kg
Width of crush damage	74.48819	in	1892	mm
A	384.5497			
B	110.4529			

Case 2. ’03 Mercedes E320

Crash Test Information			2003 Mercedes E320	case #2
Impact velocity of test:	35.20071	mph	56.65	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	15.31496	in (c1)	389	mm (c1)
	19.88189	in (c2)	505	mm (c2)
	22.83465	in (c3)	580	mm (c3)
	22.67717	in (c4)	576	mm (c4)
	19.76378	in (c5)	502	mm (c5)
	13.97638	in (c6)	355	mm (c6)
Average crush amount	19.0748	in		
Test vehicle weight	4265.945	lbs	1935	kg
Width of crush damage	71.34646	in	1990	mm
b1	1.583277			
A	362.6139			
B	109.7281			

Case 3. ’01 Buick LeSabre

Crash Test Information	2001 Buick LeSabre			
Impact velocity of test:	35.10129	mph	56.49	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	13.77953	in (c1)	350	mm (c1)
	20.59055	in (c2)	523	mm (c2)
	23.74016	in (c3)	603	mm (c3)
	23.0315	in (c4)	585	mm (c4)
	20.94488	in (c5)	532	mm (c5)
	16.73228	in (c6)	425	mm (c6)
Average crush amount	19.80315	in		
Test vehicle weight	4102.803	lbs	1861	kg
Width of crush damage	67.50394	in	1867	mm
slope of line (b1)	1.520025			
A	354.0464	lb/in		
B	102.9059	lb/in^2		

Case 4. ’03 Toyota Avalon

Crash Test Information	2001 Toyota Avalon			
Impact velocity of test:	35.10129	mph	56.49	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	13.11024	in (c1)	333	mm (c1)
	21.5748	in (c2)	548	mm (c2)
	22.24409	in (c3)	565	mm (c3)
	22.48031	in (c4)	571	mm (c4)
	22.24409	in (c5)	565	mm (c5)
	15.19685	in (c6)	386	mm (c6)
Average crush amount	19.47507	in		
Test vehicle weight	3880.136	lbs	1760	kg
Width of crush damage	71.65354	in	1820	mm
A	347.1733			
B	101.7597			

Case 5. ’02 Audi A4

Crash Test Information	2002 Audi A4	
Impact velocity of test:	35.00187 mph	56.33 kph
Maximum speed w/o permanent damage: (b0	5 mph	
Crush measurements from crash test report:	11.49606 in (c1)	292 mm (c1)
	16.06299 in (c2)	408 mm (c2)
	19.01575 in (c3)	483 mm (c3)
	19.25197 in (c4)	489 mm (c4)
	17.00787 in (c5)	432 mm (c5)
	12.3622 in (c6)	314 mm (c6)
Average crush amount	15.86614 in	
Test vehicle weight	4012.413 lbs	1820 kg
Width of crush damage	69.25984 in	1937 mm
slope of line (b1)	1.890937	
A	418.3359 lb/in	
B	150.7293 lb/in^2	

Case 6. ’03 Hyundai Accent

Crash Test Information	2003 Hyundai Accent	case #6
Impact velocity of test:	34.6974 mph	55.84 kph
Maximum speed w/o permanent damage: (b0	5 mph	
Crush measurements from crash test report:	12.24409 in (c1)	311 mm (c1)
	18.97638 in (c2)	482 mm (c2)
	19.44882 in (c3)	494 mm (c3)
	20 in (c4)	508 mm (c4)
	19.37008 in (c5)	492 mm (c5)
	16.41732 in (c6)	417 mm (c6)
Average crush amount	17.74278 in	
Test vehicle weight	2914.511 lbs	1322 kg
Width of crush damage	65.90551 in	1674 mm
A	319.6495	
B	103.041	

Case 7. ’01 Chevy Malibu

Crash Test Information		2001 Chevy Malibu	
Impact velocity of test:	34.52341 mph		55.56 kph
Maximum speed w/o permanent damage: (b0	5 mph		
Crush measurements from crash test report:	16.02362 in (c1)		407 mm (c1)
	16.22047 in (c2)		412 mm (c2)
	22.00787 in (c3)		559 mm (c3)
	21.88976 in (c4)		556 mm (c4)
	21.06299 in (c5)		535 mm (c5)
	16.77165 in (c6)		426 mm (c6)
Average crush amount	18.99606 in		
Test vehicle weight	3545.033 lbs		1608 kg
Width of crush damage	63.29134 in		1760 mm
slope of line (b1)	1.554186		
A	339.6382 lb/in		
B	102.7611 lb/in^2		

Case 8. ’03 Honda S2000

Crash Test Information		2003 Honda S2000	case #8
Impact velocity of test:	35.39955 mph		56.97 kph
Maximum speed w/o permanent damage: (b0	5 mph		
Crush measurements from crash test report:	0.354331 in (c1)		9 mm (c1)
	15.94488 in (c2)		405 mm (c2)
	20.43307 in (c3)		519 mm (c3)
	21.45669 in (c4)		545 mm (c4)
	16.73228 in (c5)		425 mm (c5)
	1.692913 in (c6)		43 mm (c6)
Average crush amount	12.76903 in		
Test vehicle weight	3229.772 lbs		1465 kg
Width of crush damage	67.59843 in		1717 mm
A	429.5746		
B	172.7581		

Case 9. ’02 Mini Cooper

Crash Test Information			2002 Mini Cooper	case #9
Impact velocity of test:	34.89623	mph	56.16	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	7.834646	in (c1)	199	mm (c1)
	10.43307	in (c2)	265	mm (c2)
	13.38583	in (c3)	340	mm (c3)
	13.85827	in (c4)	352	mm (c4)
	12.20472	in (c5)	310	mm (c5)
	6.220472	in (c6)	158	mm (c6)
Average crush amount	10.65617	in		
Test vehicle weight	3095.29	lbs	1404	kg
Width of crush damage	66.45669	in	1688	mm
A	548.1057			
B	287.9386			

Case 10. ’03 Toyota Corolla

Crash Test Information			2003 Toyota Corolla	
Impact velocity of test:	34.74089	mph	55.91	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	15.11811	in (c1)	384	mm (c1)
	20.86614	in (c2)	530	mm (c2)
	22.08661	in (c3)	561	mm (c3)
	21.88976	in (c4)	556	mm (c4)
	20.98425	in (c5)	533	mm (c5)
	16.9685	in (c6)	431	mm (c6)
Average crush amount	19.65223	in		
Test vehicle weight	2976.241	lbs	1350	kg
Width of crush damage	63.6063	in	1768	mm
slope of line (b1)	1.51336			
A	273.7813	lb/in		
B	79.9303	lb/in^2		

Case 11. ’02 Chrysler PT Cruiser

Crash Test Information		2002 Chrysler PT Cruiser	case #11
Impact velocity of test:	35.00187 mph		56.33 kph
Maximum speed w/o permanent damage: (b0	5 mph		
Crush measurements from crash test report:	11.14173 in (c1)		283 mm (c1)
	14.29134 in (c2)		363 mm (c2)
	18.58268 in (c3)		472 mm (c3)
	19.05512 in (c4)		484 mm (c4)
	15.11811 in (c5)		384 mm (c5)
	10.31496 in (c6)		262 mm (c6)
Average crush amount	14.75066 in		
Test vehicle weight	3723.608 lbs		1689 kg
Width of crush damage	67.08661 in		1704 mm
A	430.2808		
B	165.9806		

Case 12. ’02 Ford Explorer Sport

Crash Test Information		2002 Ford Explorer Sport
Impact velocity of test:	34.560693 mph	55.62 kph
Maximum speed w/o permanent damage: (b0	5 mph	
Crush measurements from crash test report:	14.094488 in (c1)	358 mm (c1)
	14.724409 in (c2)	374 mm (c2)
	14.92126 in (c3)	379 mm (c3)
	14.96063 in (c4)	380 mm (c4)
	14.92126 in (c5)	379 mm (c5)
	13.937008 in (c6)	354 mm (c6)
Average crush amount	14.593176 in	
Test vehicle weight	4572.3873 lbs	2074 kg
Width of crush damage	71.889764 in	1826 mm
A	567.634	
B	228.1612	

Case 13. ’02 Nissan Pathfinder

Crash Test Information		2002 Nissan Pathfinder		
Impact velocity of test:	34.89623	mph	56.16	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	14.6063	in (c1)	371	mm (c1)
	22.87402	in (c2)	581	mm (c2)
	24.6063	in (c3)	625	mm (c3)
	23.93701	in (c4)	608	mm (c4)
	22.3622	in (c5)	568	mm (c5)
	13.4252	in (c6)	341	mm (c6)
Average crush amount	20.30184	in		
Test vehicle weight	4720.097	lbs	2141	kg
Width of crush damage	64.65354	in	1820	mm
slope of line (b1)	1.472588			
A	399.6121			
B	110.8298			

Case 14. ’02 Toyota Highlander

Crash Test Information		2002 Toyota Highlander		
Impact velocity of test:	34.68497	mph	55.82	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	16.41732	in (c1)	417	mm (c1)
	19.13386	in (c2)	486	mm (c2)
	19.68504	in (c3)	500	mm (c3)
	19.33071	in (c4)	491	mm (c4)
	18.38583	in (c5)	467	mm (c5)
	14.80315	in (c6)	376	mm (c6)
Average crush amount	17.95932	in		
Test vehicle weight	4455.542	lbs	2021	kg
Width of crush damage	69.04724	in	1830	mm
A	416.9089			
B	134.3082			

Case 15. ’03 Subaru Forester

Crash Test Information		2003 Subaru Forester	case #15
Impact velocity of test:	35.39955 mph	56.97 kph	
Maximum speed w/o permanent damage: (b0	5 mph		
Crush measurements from crash test report:	12.24409 in (c1)	311 mm (c1)	
	18.97638 in (c2)	482 mm (c2)	
	19.44882 in (c3)	494 mm (c3)	
	20 in (c4)	508 mm (c4)	
	19.37008 in (c5)	492 mm (c5)	
	16.41732 in (c6)	417 mm (c6)	
Average crush amount	17.74278 in		
Test vehicle weight	3615.581 lbs	1640 kg	
Width of crush damage	61.30709 in	1735 mm	
A	390.0143		
B	128.6961		

Case 16. ’02 Dodge Ram 1500

Crash Test Information		2002 Dodge Ram 1500	case #16
Impact velocity of test:	35.10129 mph	56.49 kph	
Maximum speed w/o permanent damage: (b0	5 mph		
Crush measurements from crash test report:	10.86614 in (c1)	276 mm (c1)	
	17.83465 in (c2)	453 mm (c2)	
	21.5748 in (c3)	548 mm (c3)	
	21.5748 in (c4)	548 mm (c4)	
	17.91339 in (c5)	455 mm (c5)	
	11.06299 in (c6)	281 mm (c6)	
Average crush amount	16.80446 in		
Test vehicle weight	5551.24 lbs	2518 kg	
Width of crush damage	72.88189 in	2029 mm	
A	511.3374		
B	171.2839		

Case 17. ’01 Nissan Frontier

Crash Test Information		2001 Nissan Frontier	
Impact velocity of test:	34.89002 mph		56.15 kph
Maximum speed w/o permanent damage: (b0	5 mph		
Crush measurements from crash test report:	11.88976 in (c1)		302 mm (c1)
	20.55118 in (c2)		522 mm (c2)
	23.0315 in (c3)		585 mm (c3)
	23.14961 in (c4)		588 mm (c4)
	21.45669 in (c5)		545 mm (c5)
	11.85039 in (c6)		301 mm (c6)
Average crush amount	18.65486 in		
Test vehicle weight	4521.681 lbs		2051 kg
Width of crush damage	64.1811 in		1808 mm
slope of line (b1)	1.602265		
A	426.772 lb/in		
B	127.487 lb/in^2		

Case 18. ’03 Chevy Silverado

Crash Test Information		2003 Chevy Silverado	case #18
Impact velocity of test:	34.73468 mph		55.9 kph
Maximum speed w/o permanent damage: (b0	5 mph		
Crush measurements from crash test report:	20.23622 in (c1)		514 mm (c1)
	23.34646 in (c2)		593 mm (c2)
	25.07874 in (c3)		637 mm (c3)
	25.47244 in (c4)		647 mm (c4)
	23.70079 in (c5)		602 mm (c5)
	21.06299 in (c6)		535 mm (c6)
Average crush amount	23.14961 in		
Test vehicle weight	5200.705 lbs		2359 kg
Width of crush damage	71.26772 in		1988 mm
A	367.7621		
B	92.4775		

Case 19. ’01 Dodge Wagon Van

Crash Test Information		2001 Dodge Ram Wagon Van		
Impact velocity of test:	34.70982	mph	55.86	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	12.48031	in (c1)	317	mm (c1)
	17.32283	in (c2)	440	mm (c2)
	20	in (c3)	508	mm (c3)
	20.23622	in (c4)	514	mm (c4)
	17.83465	in (c5)	453	mm (c5)
	14.09449	in (c6)	358	mm (c6)
Average crush amount	16.99475	in		
Test vehicle weight	4812.691	lbs	2183	kg
Width of crush damage	70.08661	in	1958	mm
slope of line (b1)	1.748176			
A	461.0527	lb/in		
B	154.4614	lb/in^2		

Case 20. ’01 Dodge Caravan

Crash Test Information		2001 Dodge Caravan		
Impact velocity of test:	34.55448	mph	55.61	kph
Maximum speed w/o permanent damage: (b0	5	mph		
Crush measurements from crash test report:	12.40157	in (c1)	315	mm (c1)
	15.59055	in (c2)	396	mm (c2)
	16.25984	in (c3)	413	mm (c3)
	16.77165	in (c4)	426	mm (c4)
	17.55906	in (c5)	446	mm (c5)
	14.48819	in (c6)	368	mm (c6)
Average crush amount	15.51181	in		
Test vehicle weight	4299.014	lbs	1950	kg
Width of crush damage	66.29921	in	1938	mm
slope of line (b1)	1.905289			
A	482.3483	lb/in		
B	179.0299	lb/in^2		

APPENDIX 4

SPREADSHEETS FOR CRUSH COEFFICIENT SENSITIVITY ANALYSIS

2002 Cadillac DeVille	case #1

A =	384.5497	lb/in
B =	110.4529	lb/in*2
W (width of cru	67.48818898	in
c1 =	17.63779528	in
c2 =	20.31496063	in
c3 =	23.46456693	in
c4 =	22.99212598	in
c5 =	20.70866142	in
c6 =	18.38582677	in
θ =	0	degrees
G =	669.4186924	lbs
E =	2262999.992	in-lbs
E=	188583.3326	ft-lbs
w = (weight of	4508.453262	lbs
v =	51.90160653	ft/sec
v =	35.21887314	mi/hr

bo= 5.0 mph

A =	368.3364	lb/in
B =	112.283	lb/in*2
W (width o	67.48818898	in
c1 =	17.63779528	in
c2 =	20.31496063	in
c3 =	23.46456693	in
c4 =	22.99212598	in
c5 =	20.70866142	in
c6 =	18.38582677	in
θ =	0	degrees
G =	604.1506887	lbs
E =	2263183.836	in-lbs
E=	188598.653	ft-lbs
w = (weigh	4508.453262	lbs
v =	51.90371471	ft/sec
v =	35.22030369	mi/hr

bo= 4.75 mph

A =	351.8059	lb/in
B =	114.1282	lb/in*2
W (width of	67.48819	in
c1 =	17.6378	in
c2 =	20.31496	in
c3 =	23.46457	in
c4 =	22.99213	in
c5 =	20.70866	in
c6 =	18.38583	in
θ =	0	degrees
G =	542.2297	lbs
E =	2263370	in-lbs
E=	188614.2	ft-lbs
w = (weight	4508.453	lbs
v =	51.90585	ft/sec
v =	35.22175	mi/hr

bo= 4.5 mph

A =	334.958	lb/in
B =	115.9885	lb/in*2
W (width of	67.48819	in
c1 =	17.6378	in
c2 =	20.31496	in
c3 =	23.46457	in
c4 =	22.99213	in
c5 =	20.70866	in
c6 =	18.38583	in
θ =	0	degrees
G =	483.6551	lbs
E =	2263559	in-lbs
E=	188629.9	ft-lbs
w = (weight	4508.453	lbs
v =	51.90802	ft/sec
v =	35.22322	mi/hr

bo= 4.25 mph

A =	317.7925	lb/in
B =	117.8638	lb/in*2
W (width o	67.48819	in
c1 =	17.6378	in
c2 =	20.31496	in
c3 =	23.46457	in
c4 =	22.99213	in
c5 =	20.70866	in
c6 =	18.38583	in
θ =	0	degrees
G =	428.427	lbs
E =	2263748	in-lbs
E=	188645.7	ft-lbs
w = (weigh	4508.453	lbs
v =	51.91018	ft/sec
v =	35.22469	mi/hr

bo= 4.0 mph

56.81 km/h is equal to **35.3001257** mph

A average 391.2286 lb/in

B average 109.6055 lb/in*2

v average = 35.2182 mi/hr

A =	400.4457	lb/in
B =	108.6377	lb/in*2
W (width of cru	67.48818898	in
c1 =	17.63779528	in
c2 =	20.31496063	in
c3 =	23.46456693	in
c4 =	22.99212598	in
c5 =	20.70866142	in
c6 =	18.38582677	in
θ =	0	degrees
G =	738.0345803	lbs
E =	2262815.606	in-lbs
E=	188567.9671	ft-lbs
w = (weight of	4508.453262	lbs
v =	51.89949205	ft/sec
v =	35.21743832	mi/hr

bo= 5.25 mph

A =	416.0245	lb/in
B =	106.8376	lb/in*2
W (width o	67.48818898	in
c1 =	17.63779528	in
c2 =	20.31496063	in
c3 =	23.46456693	in
c4 =	22.99212598	in
c5 =	20.70866142	in
c6 =	18.38582677	in
θ =	0	degrees
G =	809.9975318	lbs
E =	2262633.789	in-lbs
E=	188552.8158	ft-lbs
w = (weigh	4508.453262	lbs
v =	51.89740696	ft/sec
v =	35.21602344	mi/hr

bo= 5.5 mph

A =	431.2859	lb/in
B =	105.0526	lb/in*2
W (width of	67.48819	in
c1 =	17.6378	in
c2 =	20.31496	in
c3 =	23.46457	in
c4 =	22.99213	in
c5 =	20.70866	in
c6 =	18.38583	in
θ =	0	degrees
G =	885.3066	lbs
E =	2262454	in-lbs
E=	188537.8	ft-lbs
w = (weight	4508.453	lbs
v =	51.89535	ft/sec
v =	35.21463	mi/hr

bo= 5.75 mph

A =	446.23	lb/in
B =	103.2826	lb/in*2
W (width of	67.48819	in
c1 =	17.6378	in
c2 =	20.31496	in
c3 =	23.46457	in
c4 =	22.99213	in
c5 =	20.70866	in
c6 =	18.38583	in
θ =	0	degrees
G =	963.963	lbs
E =	2262276	in-lbs
E=	188523	ft-lbs
w = (weight	4508.453	lbs
v =	51.8933	ft/sec
v =	35.21324	mi/hr

bo= 6.0 mph

A =	460.8569	lb/in
B =	101.5276	lb/in*2
W (width o	67.48819	in
c1 =	17.6378	in
c2 =	20.31496	in
c3 =	23.46457	in
c4 =	22.99213	in
c5 =	20.70866	in
c6 =	18.38583	in
θ =	0	degrees
G =	1045.967	lbs
E =	2262098	in-lbs
E=	188508.2	ft-lbs
w = (weigh	4508.453	lbs
v =	51.89126	ft/sec
v =	35.21185	mi/hr

bo= 6.25 mph

2003 Mercedes E320	case #2

A =	362.6139	lb/in	A =	347.3349	lb/in	A =	331.7556	lb/in	A =	315.8762	lb/in	A =	299.6966	lb/in
B =	109.7281	lb/in*2	B =	111.5523	lb/in*2	B =	113.3915	lb/in*2	B =	115.2457	lb/in*2	B =	117.115	lb/in*2
W (width of cru	71.34645669	in	W (width o	71.34645669	in	W (width of	71.34646	in	W (width of	71.34646	in	W (width o	71.34646	in
c1 =	15.31496063	in	c1 =	15.31496063	in	c1 =	15.31496	in	c1 =	15.31496	in	c1 =	15.31496	in
c2 =	19.88188976	in	c2 =	19.88188976	in	c2 =	19.88189	in	c2 =	19.88189	in	c2 =	19.88189	in
c3 =	22.83464567	in	c3 =	22.83464567	in	c3 =	22.83465	in	c3 =	22.83465	in	c3 =	22.83465	in
c4 =	22.67716535	in	c4 =	22.67716535	in	c4 =	22.67717	in	c4 =	22.67717	in	c4 =	22.67717	in
c5 =	19.76377953	in	c5 =	19.76377953	in	c5 =	19.76378	in	c5 =	19.76378	in	c5 =	19.76378	in
c6 =	13.97637795	in	c6 =	13.97637795	in	c6 =	13.97638	in	c6 =	13.97638	in	c6 =	13.97638	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	599.1575561	lbs	G =	540.739782	lbs	G =	485.3176	lbs	G =	432.8915	lbs	G =	383.4609	lbs
E =	2144142.354	in-lbs	E =	2144565.331	in-lbs	E =	2144991	in-lbs	E =	2145420	in-lbs	E =	2145853	in-lbs
E=	178678.5295	ft-lbs	E=	178713.7776	ft-lbs	E=	178749.3	ft-lbs	E=	178785	ft-lbs	E=	178821.1	ft-lbs
w = (weight of	4265.944773	lbs	w = (weigh	4265.944773	lbs	w = (weight	4265.945	lbs	w = (weight	4265.945	lbs	w = (weigh	4265.945	lbs
v =	51.93635948	ft/sec	v =	51.94148199	ft/sec	v =	51.94664	ft/sec	v =	51.95183	ft/sec	v =	51.95707	ft/sec
v =	35.24245545	mi/hr	v =	35.24593143	mi/hr	v =	35.24943	mi/hr	v =	35.25295	mi/hr	v =	35.25651	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

56.65 km/h is equal to **35.2007062** mph

A average 368.9027 lb/in

B average 108.8837 lb/in*2

v average = 35.24085 mi/hr

A =	377.5929	lb/in	A =	392.2716	lb/in	A =	406.6502	lb/in	A =	420.7286	lb/in	A =	434.5068	lb/in
B =	107.919	lb/in*2	B =	106.1249	lb/in*2	B =	104.3458	lb/in*2	B =	102.5818	lb/in*2	B =	100.8328	lb/in*2
W (width of cru	71.34645669	in	W (width o	71.34645669	in	W (width of	71.34646	in	W (width of	71.34646	in	W (width o	71.34646	in
c1 =	15.31496063	in	c1 =	15.31496063	in	c1 =	15.31496	in	c1 =	15.31496	in	c1 =	15.31496	in
c2 =	19.88188976	in	c2 =	19.88188976	in	c2 =	19.88189	in	c2 =	19.88189	in	c2 =	19.88189	in
c3 =	22.83464567	in	c3 =	22.83464567	in	c3 =	22.83465	in	c3 =	22.83465	in	c3 =	22.83465	in
c4 =	22.67716535	in	c4 =	22.67716535	in	c4 =	22.67717	in	c4 =	22.67717	in	c4 =	22.67717	in
c5 =	19.76377953	in	c5 =	19.76377953	in	c5 =	19.76378	in	c5 =	19.76378	in	c5 =	19.76378	in
c6 =	13.97637795	in	c6 =	13.97637795	in	c6 =	13.97638	in	c6 =	13.97638	in	c6 =	13.97638	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	660.5713458	lbs	G =	724.9806981	lbs	G =	792.3864	lbs	G =	862.7873	lbs	G =	936.1843	lbs
E =	2143724.012	in-lbs	E =	2143308.4	in-lbs	E =	2142896	in-lbs	E =	2142488	in-lbs	E =	2142082	in-lbs
E=	178643.6677	ft-lbs	E=	178609.0333	ft-lbs	E=	178574.7	ft-lbs	E=	178540.6	ft-lbs	E=	178506.9	ft-lbs
w = (weight of	4265.944773	lbs	w = (weigh	4265.944773	lbs	w = (weight	4265.945	lbs	w = (weight	4265.945	lbs	w = (weigh	4265.945	lbs
v =	51.9312926	ft/sec	v =	51.92625829	ft/sec	v =	51.92126	ft/sec	v =	51.91631	ft/sec	v =	51.9114	ft/sec
v =	35.23901722	mi/hr	v =	35.23560109	mi/hr	v =	35.23221	mi/hr	v =	35.22885	mi/hr	v =	35.22552	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2001 Buick LeSabre | **case #3**

A =	354.0464	lb/in	A =	339.1375	lb/in	A =	323.9346	lb/in	A =	308.4376	lb/in	A =	292.6466	lb/in
B =	102.9059	lb/in*2	B =	104.6224	lb/in*2	B =	106.353	lb/in*2	B =	108.0978	lb/in*2	B =	109.8568	lb/in*2
W (width of cru	67.50393701	in	W (width o	67.50393701	in	W (width of	67.50394	in	W (width of	67.50394	in	W (width o	67.50394	in
c1 =	13.77952756	in	c1 =	13.77952756	in	c1 =	13.77953	in	c1 =	13.77953	in	c1 =	13.77953	in
c2 =	20.59055118	in	c2 =	20.59055118	in	c2 =	20.59055	in	c2 =	20.59055	in	c2 =	20.59055	in
c3 =	23.74015748	in	c3 =	23.74015748	in	c3 =	23.74016	in	c3 =	23.74016	in	c3 =	23.74016	in
c4 =	23.03149606	in	c4 =	23.03149606	in	c4 =	23.0315	in	c4 =	23.0315	in	c4 =	23.0315	in
c5 =	20.94488189	in	c5 =	20.94488189	in	c5 =	20.94488	in	c5 =	20.94488	in	c5 =	20.94488	in
c6 =	16.73228346	in	c6 =	16.73228346	in	c6 =	16.73228	in	c6 =	16.73228	in	c6 =	16.73228	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	609.0459991	lbs	G =	549.6635706	lbs	G =	493.3271	lbs	G =	440.0356	lbs	G =	389.7894	lbs
E =	2049422.931	in-lbs	E =	2049811.119	in-lbs	E =	2050201	in-lbs	E =	2050594	in-lbs	E =	2050991	in-lbs
E=	170785.2443	ft-lbs	E=	170817.5932	ft-lbs	E=	170850.1	ft-lbs	E=	170882.9	ft-lbs	E=	170915.9	ft-lbs
w = (weight of	4102.802699	lbs	w = (weigh	4102.802699	lbs	w = (weight	4102.803	lbs	w = (weight	4102.803	lbs	w = (weigh	4102.803	lbs
v =	51.77591588	ft/sec	v =	51.78081916	ft/sec	v =	51.78575	ft/sec	v =	51.79071	ft/sec	v =	51.79572	ft/sec
v =	35.13358324	mi/hr	v =	35.13691046	mi/hr	v =	35.14025	mi/hr	v =	35.14362	mi/hr	v =	35.14702	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

56.49 km/h is equal to **35.101287** mph | **A average** 360.1776 lb/in | **B average** 102.1116 lb/in*2 | **v average =** 35.13205 mi/hr

A =	368.6612	lb/in	A =	382.982	lb/in	A =	397.0087	lb/in	A =	410.7414	lb/in	A =	424.1801	lb/in
B =	101.2037	lb/in*2	B =	99.5157	lb/in*2	B =	97.8418	lb/in*2	B =	96.1822	lb/in*2	B =	94.5368	lb/in*2
W (width of cru	67.50393701	in	W (width o	67.50393701	in	W (width of	67.50394	in	W (width of	67.50394	in	W (width o	67.50394	in
c1 =	13.77952756	in	c1 =	13.77952756	in	c1 =	13.77953	in	c1 =	13.77953	in	c1 =	13.77953	in
c2 =	20.59055118	in	c2 =	20.59055118	in	c2 =	20.59055	in	c2 =	20.59055	in	c2 =	20.59055	in
c3 =	23.74015748	in	c3 =	23.74015748	in	c3 =	23.74016	in	c3 =	23.74016	in	c3 =	23.74016	in
c4 =	23.03149606	in	c4 =	23.03149606	in	c4 =	23.0315	in	c4 =	23.0315	in	c4 =	23.0315	in
c5 =	20.94488189	in	c5 =	20.94488189	in	c5 =	20.94488	in	c5 =	20.94488	in	c5 =	20.94488	in
c6 =	16.73228346	in	c6 =	16.73228346	in	c6 =	16.73228	in	c6 =	16.73228	in	c6 =	16.73228	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	671.4728828	lbs	G =	736.9450867	lbs	G =	805.463	lbs	G =	877.0256	lbs	G =	951.6334	lbs
E =	2049039.341	in-lbs	E =	2048659.075	in-lbs	E =	2048281	in-lbs	E =	2047907	in-lbs	E =	2047536	in-lbs
E=	170753.2784	ft-lbs	E=	170721.5896	ft-lbs	E=	170690	ft-lbs	E=	170658.9	ft-lbs	E=	170628	ft-lbs
w = (weight of	4102.802699	lbs	w = (weigh	4102.802699	lbs	w = (weight	4102.803	lbs	w = (weight	4102.803	lbs	w = (weigh	4102.803	lbs
v =	51.77107021	ft/sec	v =	51.76626608	ft/sec	v =	51.76148	ft/sec	v =	51.75676	ft/sec	v =	51.75208	ft/sec
v =	35.13029511	mi/hr	v =	35.12703517	mi/hr	v =	35.12379	mi/hr	v =	35.12058	mi/hr	v =	35.11741	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2002 Toyota Avalon	**case #4**													
A =	347.1733	lb/in	A =	332.5539	lb/in	A =	317.6461	lb/in	A =	302.4499	lb/in	A =	286.9655	lb/in
B =	101.7597	lb/in*2	B =	103.457	lb/in*2	B =	105.1683	lb/in*2	B =	106.8937	lb/in*2	B =	108.6331	lb/in*2
W (width of cru	65.65354331	in	W (width o	65.65354331	in	W (width of	65.65354	in	W (width of	65.65354	in	W (width o	65.65354	in
c1 =	13.11023622	in	c1 =	13.11023622	in	c1 =	13.11024	in	c1 =	13.11024	in	c1 =	13.11024	in
c2 =	21.57480315	in	c2 =	21.57480315	in	c2 =	21.5748	in	c2 =	21.5748	in	c2 =	21.5748	in
c3 =	22.24409449	in	c3 =	22.24409449	in	c3 =	22.24409	in	c3 =	22.24409	in	c3 =	22.24409	in
c4 =	22.48031496	in	c4 =	22.48031496	in	c4 =	22.48031	in	c4 =	22.48031	in	c4 =	22.48031	in
c5 =	22.24409449	in	c5 =	22.24409449	in	c5 =	22.24409	in	c5 =	22.24409	in	c5 =	22.24409	in
c6 =	15.19685039	in	c6 =	15.19685039	in	c6 =	15.19685	in	c6 =	15.19685	in	c6 =	15.19685	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	592.2251158	lbs	G =	534.4833912	lbs	G =	479.7027	lbs	G =	427.8828	lbs	G =	379.0244	lbs
E =	1937773.938	in-lbs	E =	1938132.919	in-lbs	E =	1938494	in-lbs	E =	1938859	in-lbs	E =	1939227	in-lbs
E=	161481.1615	ft-lbs	E=	161511.0766	ft-lbs	E=	161541.2	ft-lbs	E=	161571.6	ft-lbs	E=	161602.2	ft-lbs
w = (weight of	3880.135814	lbs	w = (weigh	3880.135814	lbs	w = (weight	3880.136	lbs	w = (weight	3880.136	lbs	w = (weigh	3880.136	lbs
v =	51.7702667	ft/sec	v =	51.77506182	ft/sec	v =	51.77989	ft/sec	v =	51.78476	ft/sec	v =	51.78967	ft/sec
v =	35.12974987	mi/hr	v =	35.1330037	mi/hr	v =	35.13628	mi/hr	v =	35.13959	mi/hr	v =	35.14292	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

56.49 km/h is equal to **35.101287** mph

A average 353.1856 lb/in

B average 100.9744 lb/in*2

v average = 35.12826 mi/hr

A =	361.5045	lb/in	A =	375.5472	lb/in	A =	389.3017	lb/in	A =	402.7678	lb/in	A =	415.9456	lb/in
B =	100.0764	lb/in*2	B =	98.4072	lb/in*2	B =	96.752	lb/in*2	B =	95.1108	lb/in*2	B =	93.4857	lb/in*2
W (width of cru	65.65354331	in	W (width o	65.65354331	in	W (width of	65.65354	in	W (width of	65.65354	in	W (width o	65.65354	in
c1 =	13.11023622	in	c1 =	13.11023622	in	c1 =	13.11024	in	c1 =	13.11024	in	c1 =	13.11024	in
c2 =	21.57480315	in	c2 =	21.57480315	in	c2 =	21.5748	in	c2 =	21.5748	in	c2 =	21.5748	in
c3 =	22.24409449	in	c3 =	22.24409449	in	c3 =	22.24409	in	c3 =	22.24409	in	c3 =	22.24409	in
c4 =	22.48031496	in	c4 =	22.48031496	in	c4 =	22.48031	in	c4 =	22.48031	in	c4 =	22.48031	in
c5 =	22.24409449	in	c5 =	22.24409449	in	c5 =	22.24409	in	c5 =	22.24409	in	c5 =	22.24409	in
c6 =	15.19685039	in	c6 =	15.19685039	in	c6 =	15.19685	in	c6 =	15.19685	in	c6 =	15.19685	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	652.9286801	lbs	G =	716.5923806	lbs	G =	783.218	lbs	G =	852.8048	lbs	G =	925.3327	lbs
E =	1937417.618	in-lbs	E =	1937064.849	in-lbs	E =	1936715	in-lbs	E =	1936367	in-lbs	E =	1936050	in-lbs
E=	161451.4681	ft-lbs	E=	161422.0708	ft-lbs	E=	161392.9	ft-lbs	E=	161363.9	ft-lbs	E=	161337.5	ft-lbs
w = (weight of	3880.135814	lbs	w = (weigh	3880.135814	lbs	w = (weight	3880.136	lbs	w = (weight	3880.136	lbs	w = (weigh	3880.136	lbs
v =	51.76550669	ft/sec	v =	51.7607937	ft/sec	v =	51.75612	ft/sec	v =	51.75147	ft/sec	v =	51.74723	ft/sec
v =	35.12651988	mi/hr	v =	35.12332178	mi/hr	v =	35.12015	mi/hr	v =	35.11699	mi/hr	v =	35.11412	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2002 Audi A4	**case #5**

A =	418.3359 lb/in	A =	400.7307 lb/in	A =	382.7769 lb/in	A =	364.4746 lb/in	A =	345.8236 lb/in
B =	150.7293 lb/in*2	B =	153.2518 lb/in*2	B =	155.7952 lb/in*2	B =	158.3595 lb/in*2	B =	160.9448 lb/in*2
W (width of cru	69.25984252 in	W (width o	69.25984252 in	W (width of	69.25984 in	W (width of	69.25984 in	W (width o	69.25984 in
c1 =	11.49606299 in	c1 =	11.49606299 in	c1 =	11.49606 in	c1 =	11.49606 in	c1 =	11.49606 in
c2 =	16.06299213 in	c2 =	16.06299213 in	c2 =	16.06299 in	c2 =	16.06299 in	c2 =	16.06299 in
c3 =	19.01574803 in	c3 =	19.01574803 in	c3 =	19.01575 in	c3 =	19.01575 in	c3 =	19.01575 in
c4 =	19.2519685 in	c4 =	19.2519685 in	c4 =	19.25197 in	c4 =	19.25197 in	c4 =	19.25197 in
c5 =	17.00787402 in	c5 =	17.00787402 in	c5 =	17.00787 in	c5 =	17.00787 in	c5 =	17.00787 in
c6 =	12.36220472 in	c6 =	12.36220472 in	c6 =	12.3622 in	c6 =	12.3622 in	c6 =	12.3622 in
θ =	0 degrees	θ =	0 degrees	θ =	0 degrees	θ =	0 degrees	θ =	0 degrees
G =	580.5272274 lbs	G =	523.9256372 lbs	G =	470.2268 lbs	G =	419.4309 lbs	G =	371.5372 lbs
E =	1997450.105 in-lbs	E =	1997903.634 in-lbs	E =	1998361 in-lbs	E =	1998821 in-lbs	E =	1999286 in-lbs
E=	166454.1755 ft-lbs	E=	166491.9695 ft-lbs	E=	166530.1 ft-lbs	E=	166568.4 ft-lbs	E=	166607.2 ft-lbs
w = (weight of	4012.413172 lbs	w = (weigh	4012.413172 lbs	w = (weight	4012.413 lbs	w = (weight	4012.413 lbs	w = (weigh	4012.413 lbs
v =	51.68772969 ft/sec	v =	51.69359731 ft/sec	v =	51.69951 ft/sec	v =	51.70547 ft/sec	v =	51.71148 ft/sec
v =	35.07374274 mi/hr	v =	35.07772433 mi/hr	v =	35.08174 mi/hr	v =	35.08578 mi/hr	v =	35.08986 mi/hr
bo= 5.0 mph		**bo= 4.75 mph**		**bo= 4.5 mph**		**bo= 4.25 mph**		**bo= 4.0 mph**	

56.33 km/h is equal to **35.0018673** mph **A average** 425.5698 lb/in **B average** 149.5623 lb/in*2 **v average =** 35.0719 mi/hr

A =	435.5924 lb/in	A =	452.5004 lb/in	A =	469.0598 lb/in	A =	485.2706 lb/in	A =	501.1329 lb/in
B =	148.2278 lb/in*2	B =	145.7472 lb/in*2	B =	143.2875 lb/in*2	B =	140.8488 lb/in*2	B =	138.431 lb/in*2
W (width of cru	69.25984252 in	W (width o	69.25984252 in	W (width of	69.25984 in	W (width of	69.25984 in	W (width o	69.25984 in
c1 =	11.49606299 in	c1 =	11.49606299 in	c1 =	11.49606 in	c1 =	11.49606 in	c1 =	11.49606 in
c2 =	16.06299213 in	c2 =	16.06299213 in	c2 =	16.06299 in	c2 =	16.06299 in	c2 =	16.06299 in
c3 =	19.01574803 in	c3 =	19.01574803 in	c3 =	19.01575 in	c3 =	19.01575 in	c3 =	19.01575 in
c4 =	19.2519685 in	c4 =	19.2519685 in	c4 =	19.25197 in	c4 =	19.25197 in	c4 =	19.25197 in
c5 =	17.00787402 in	c5 =	17.00787402 in	c5 =	17.00787 in	c5 =	17.00787 in	c5 =	17.00787 in
c6 =	12.36220472 in	c6 =	12.36220472 in	c6 =	12.3622 in	c6 =	12.3622 in	c6 =	12.3622 in
θ =	0 degrees	θ =	0 degrees	θ =	0 degrees	θ =	0 degrees	θ =	0 degrees
G =	640.0308813 lbs	G =	702.4375494 lbs	G =	767.747 lbs	G =	835.9587 lbs	G =	907.0735 lbs
E =	1997000.838 in-lbs	E =	1996555.149 in-lbs	E =	1996113 in-lbs	E =	1995675 in-lbs	E =	1995241 in-lbs
E=	166416.7365 ft-lbs	E=	166379.5957 ft-lbs	E=	166342.7 ft-lbs	E=	166306.3 ft-lbs	E=	166270.1 ft-lbs
w = (weight of	4012.413172 lbs	w = (weigh	4012.413172 lbs	w = (weight	4012.413 lbs	w = (weight	4012.413 lbs	w = (weigh	4012.413 lbs
v =	51.68191655 ft/sec	v =	51.67614907 ft/sec	v =	51.67043 ft/sec	v =	51.66476 ft/sec	v =	51.65914 ft/sec
v =	35.06979811 mi/hr	v =	35.06588447 mi/hr	v =	35.062 mi/hr	v =	35.05815 mi/hr	v =	35.05434 mi/hr
bo= 5.25 mph		**bo= 5.5 mph**		**bo= 5.75 mph**		**bo= 6.0 mph**		**bo= 6.25 mph**	

2003 Hyundai Accent | **case #6**

A =	319.6495	lb/in	A =	306.2235	lb/in	A =	292.5282	lb/in	A =	278.5639	lb/in	A =	264.3305	lb/in
B =	103.041	lb/in*2	B =	104.7832	lb/in*2	B =	106.54	lb/in*2	B =	108.3113	lb/in*2	B =	110.0973	lb/in*2
W (width of cru	58.90551181	in	W (width o	58.90551181	in	W (width of	58.90551	in	W (width of	58.90551	in	W (width o	58.90551	in
c1 =	12.24409449	in	c1 =	12.24409449	in	c1 =	12.24409	in	c1 =	12.24409	in	c1 =	12.24409	in
c2 =	18.97637795	in	c2 =	18.97637795	in	c2 =	18.97638	in	c2 =	18.97638	in	c2 =	18.97638	in
c3 =	19.4488189	in	c3 =	19.4488189	in	c3 =	19.44882	in	c3 =	19.44882	in	c3 =	19.44882	in
c4 =	20	in	c4 =	20	in	c4 =	20	in	c4 =	20	in	c4 =	20	in
c5 =	19.37007874	in	c5 =	19.37007874	in	c5 =	19.37008	in	c5 =	19.37008	in	c5 =	19.37008	in
c6 =	16.41732283	in	c6 =	16.41732283	in	c6 =	16.41732	in	c6 =	16.41732	in	c6 =	16.41732	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	495.801685	lbs	G =	447.4611958	lbs	G =	401.5992	lbs	G =	358.2168	lbs	G =	317.313	lbs
E =	1416553.07	in-lbs	E =	1416724.902	in-lbs	E =	1416898	in-lbs	E =	1417071	in-lbs	E =	1417247	in-lbs
E=	118046.0892	ft-lbs	E=	118060.4085	ft-lbs	E=	118074.8	ft-lbs	E=	118089.3	ft-lbs	E=	118103.9	ft-lbs
w = (weight of	2914.511106	lbs	w = (weigh	2914.511106	lbs	w = (weight	2914.511	lbs	w = (weight	2914.511	lbs	w = (weigh	2914.511	lbs
v =	51.0723543	ft/sec	v =	51.07545182	ft/sec	v =	51.07857	ft/sec	v =	51.0817	ft/sec	v =	51.08487	ft/sec
v =	34.65616746	mi/hr	v =	34.65826934	mi/hr	v =	34.66038	mi/hr	v =	34.66251	mi/hr	v =	34.66466	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

55.84 km/h is equal to **34.6973951** mph

A average 325.1518 lb/in

B average 102.2357 lb/in*2

v average = 34.65521 mi/hr

A =	332.8066	lb/in	A =	345.6946	lb/in	A =	358.3135	lb/in	A =	370.6633	lb/in	A =	382.744	lb/in
B =	101.3135	lb/in*2	B =	99.6006	lb/in*2	B =	97.9022	lb/in*2	B =	96.2185	lb/in*2	B =	94.5494	lb/in*2
W (width of cru	58.90551181	in	W (width o	58.90551181	in	W (width of	58.90551	in	W (width of	58.90551	in	W (width o	58.90551	in
c1 =	12.24409449	in	c1 =	12.24409449	in	c1 =	12.24409	in	c1 =	12.24409	in	c1 =	12.24409	in
c2 =	18.97637795	in	c2 =	18.97637795	in	c2 =	18.97638	in	c2 =	18.97638	in	c2 =	18.97638	in
c3 =	19.4488189	in	c3 =	19.4488189	in	c3 =	19.44882	in	c3 =	19.44882	in	c3 =	19.44882	in
c4 =	20	in	c4 =	20	in	c4 =	20	in	c4 =	20	in	c4 =	20	in
c5 =	19.37007874	in	c5 =	19.37007874	in	c5 =	19.37008	in	c5 =	19.37008	in	c5 =	19.37008	in
c6 =	16.41732283	in	c6 =	16.41732283	in	c6 =	16.41732	in	c6 =	16.41732	in	c6 =	16.41732	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	546.6212943	lbs	G =	599.9198623	lbs	G =	655.6981	lbs	G =	713.9546	lbs	G =	774.6901	lbs
E =	1416383.85	in-lbs	E =	1416216.006	in-lbs	E =	1416049	in-lbs	E =	1415883	in-lbs	E =	1415720	in-lbs
E=	118031.9875	ft-lbs	E=	118018.0005	ft-lbs	E=	118004	ft-lbs	E=	117990.3	ft-lbs	E=	117976.6	ft-lbs
w = (weight of	2914.511106	lbs	w = (weigh	2914.511106	lbs	w = (weight	2914.511	lbs	w = (weight	2914.511	lbs	w = (weigh	2914.511	lbs
v =	51.06930369	ft/sec	v =	51.0662777	ft/sec	v =	51.06326	ft/sec	v =	51.06028	ft/sec	v =	51.05733	ft/sec
v =	34.6540974	mi/hr	v =	34.65204406	mi/hr	v =	34.65	mi/hr	v =	34.64798	mi/hr	v =	34.64597	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2001 Chevy Malibu | **case #7**

A =	339.6382	lb/in	A =	325.3885	lb/in	A =	310.8512	lb/in	A =	296.0263	lb/in	A =	280.9138	lb/in
B =	102.7611	lb/in*2	B =	104.5088	lb/in*2	B =	106.2713	lb/in*2	B =	108.0484	lb/in*2	B =	109.8404	lb/in*2
W (width of cru	63.29133858	in	W (width o	63.29133858	in	W (width of	63.29134	in	W (width of	63.29134	in	W (width o	63.29134	in
c1 =	16.02362205	in	c1 =	16.02362205	in	c1 =	16.02362	in	c1 =	16.02362	in	c1 =	16.02362	in
c2 =	16.22047244	in	c2 =	16.22047244	in	c2 =	16.22047	in	c2 =	16.22047	in	c2 =	16.22047	in
c3 =	22.00787402	in	c3 =	22.00787402	in	c3 =	22.00787	in	c3 =	22.00787	in	c3 =	22.00787	in
c4 =	21.88976378	in	c4 =	21.88976378	in	c4 =	21.88976	in	c4 =	21.88976	in	c4 =	21.88976	in
c5 =	21.06299213	in	c5 =	21.06299213	in	c5 =	21.06299	in	c5 =	21.06299	in	c5 =	21.06299	in
c6 =	16.77165354	in	c6 =	16.77165354	in	c6 =	16.77165	in	c6 =	16.77165	in	c6 =	16.77165	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	561.2732196	lbs	G =	506.5490941	lbs	G =	454.6311	lbs	G =	405.52	lbs	G =	359.2147	lbs
E =	1710619.137	in-lbs	E =	1710908.854	in-lbs	E =	1711202	in-lbs	E =	1711495	in-lbs	E =	1711794	in-lbs
E=	142551.5948	ft-lbs	E=	142575.7378	ft-lbs	E=	142600.1	ft-lbs	E=	142624.6	ft-lbs	E=	142649.5	ft-lbs
w = (weight of	3545.033176	lbs	w = (weigh	3545.033176	lbs	w = (weight	3545.033	lbs	w = (weight	3545.033	lbs	w = (weigh	3545.033	lbs
v =	50.888403	ft/sec	v =	50.89271214	ft/sec	v =	50.89707	ft/sec	v =	50.90144	ft/sec	v =	50.90587	ft/sec
v =	34.53134362	mi/hr	v =	34.53426768	mi/hr	v =	34.53722	mi/hr	v =	34.54019	mi/hr	v =	34.5432	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

55.56 km/h is equal to **34.523411** mph   **A average** 345.4688 lb/in   **B average** 101.9536 lb/in*2   **v average =** 34.52999 mi/hr

A =	353.6004	lb/in	A =	367.2747	lb/in	A =	380.6616	lb/in	A =	393.7609	lb/in	A =	406.5726	lb/in
B =	101.0282	lb/in*2	B =	99.3099	lb/in*2	B =	97.6064	lb/in*2	B =	95.9176	lb/in*2	B =	94.2436	lb/in*2
W (width of cru	63.29133858	in	W (width o	63.29133858	in	W (width of	63.29134	in	W (width of	63.29134	in	W (width o	63.29134	in
c1 =	16.02362205	in	c1 =	16.02362205	in	c1 =	16.02362	in	c1 =	16.02362	in	c1 =	16.02362	in
c2 =	16.22047244	in	c2 =	16.22047244	in	c2 =	16.22047	in	c2 =	16.22047	in	c2 =	16.22047	in
c3 =	22.00787402	in	c3 =	22.00787402	in	c3 =	22.00787	in	c3 =	22.00787	in	c3 =	22.00787	in
c4 =	21.88976378	in	c4 =	21.88976378	in	c4 =	21.88976	in	c4 =	21.88976	in	c4 =	21.88976	in
c5 =	21.06299213	in	c5 =	21.06299213	in	c5 =	21.06299	in	c5 =	21.06299	in	c5 =	21.06299	in
c6 =	16.77165354	in	c6 =	16.77165354	in	c6 =	16.77165	in	c6 =	16.77165	in	c6 =	16.77165	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	618.803675	lbs	G =	679.1402733	lbs	G =	742.2836	lbs	G =	808.2336	lbs	G =	876.9894	lbs
E =	1710332.757	in-lbs	E =	1710046.762	in-lbs	E =	1709764	in-lbs	E =	1709484	in-lbs	E =	1709206	in-lbs
E=	142527.7297	ft-lbs	E=	142503.8968	ft-lbs	E=	142480.4	ft-lbs	E=	142457	ft-lbs	E=	142433.9	ft-lbs
w = (weight of	3545.033176	lbs	w = (weigh	3545.033176	lbs	w = (weight	3545.033	lbs	w = (weight	3545.033	lbs	w = (weigh	3545.033	lbs
v =	50.88414312	ft/sec	v =	50.87988863	ft/sec	v =	50.87569	ft/sec	v =	50.87151	ft/sec	v =	50.86739	ft/sec
v =	34.528453	mi/hr	v =	34.52556603	mi/hr	v =	34.52271	mi/hr	v =	34.51988	mi/hr	v =	34.51708	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2003 Honda S2000	case #8

A =	429.5746	lb/in
B =	172.7581	lb/in*2
W (width of cru	60.5984252	in
c1 =	0.354330709	in
c2 =	15.94488189	in
c3 =	20.43307087	in
c4 =	21.45669291	in
c5 =	16.73228346	in
c6 =	1.692913386	in
θ =	0	degrees
G =	534.0830241	lbs
E =	1816329.335	in-lbs
E=	151360.7779	ft-lbs
w = (weight of	3229.772141	lbs
v =	54.93683901	ft/sec
v =	37.27849085	mi/hr

bo= 5.0 mph

A =	411.452	lb/in
B =	175.6112	lb/in*2
W (width o	60.5984252	in
c1 =	0.354330709	in
c2 =	15.94488189	in
c3 =	20.43307087	in
c4 =	21.45669291	in
c5 =	16.73228346	in
c6 =	1.692913386	in
θ =	0	degrees
G =	482.0101118	lbs
E =	1819533.81	in-lbs
E=	151627.8175	ft-lbs
w = (weigh	3229.772141	lbs
v =	54.98527907	ft/sec
v =	37.31136082	mi/hr

bo= 4.75 mph

A =	392.9761	lb/in
B =	178.4877	lb/in*2
W (width of	60.59843	in
c1 =	0.354331	in
c2 =	15.94488	in
c3 =	20.43307	in
c4 =	21.45669	in
c5 =	16.73228	in
c6 =	1.692913	in
θ =	0	degrees
G =	432.6074	lbs
E =	1822765	in-lbs
E=	151897.1	ft-lbs
w = (weight	3229.772	lbs
v =	55.03408	ft/sec
v =	37.34447	mi/hr

bo= 4.5 mph

A =	374.1469	lb/in
B =	181.3876	lb/in*2
W (width of	60.59843	in
c1 =	0.354331	in
c2 =	15.94488	in
c3 =	20.43307	in
c4 =	21.45669	in
c5 =	16.73228	in
c6 =	1.692913	in
θ =	0	degrees
G =	385.8751	lbs
E =	1826022	in-lbs
E=	152168.5	ft-lbs
w = (weight	3229.772	lbs
v =	55.08323	ft/sec
v =	37.37783	mi/hr

bo= 4.25 mph

A =	354.9644	lb/in
B =	184.3109	lb/in*2
W (width o	60.59843	in
c1 =	0.354331	in
c2 =	15.94488	in
c3 =	20.43307	in
c4 =	21.45669	in
c5 =	16.73228	in
c6 =	1.692913	in
θ =	0	degrees
G =	341.813	lbs
E =	1829306	in-lbs
E=	152442.2	ft-lbs
w = (weigh	3229.772	lbs
v =	55.13274	ft/sec
v =	37.41142	mi/hr

bo= 4.0 mph

56.97 km/h is equal to **35.3995451** mph

A average 437.0462 lb/in

B average 171.4367 lb/in*2

v average = 37.26314 mi/hr

A =	447.344	lb/in
B =	169.9283	lb/in*2
W (width of cru	60.5984252	in
c1 =	0.354330709	in
c2 =	15.94488189	in
c3 =	20.43307087	in
c4 =	21.45669291	in
c5 =	16.73228346	in
c6 =	1.692913386	in
θ =	0	degrees
G =	588.8267414	lbs
E =	1813150.653	in-lbs
E=	151095.8878	ft-lbs
w = (weight of	3229.772141	lbs
v =	54.88874664	ft/sec
v =	37.24585681	mi/hr

bo= 5.25 mph

A =	464.76	lb/in
B =	167.1219	lb/in*2
W (width o	60.5984252	in
c1 =	0.354330709	in
c2 =	15.94488189	in
c3 =	20.43307087	in
c4 =	21.45669291	in
c5 =	16.73228346	in
c6 =	1.692913386	in
θ =	0	degrees
G =	646.2404317	lbs
E =	1809998.338	in-lbs
E=	150833.1948	ft-lbs
w = (weigh	3229.772141	lbs
v =	54.84101153	ft/sec
v =	37.21346519	mi/hr

bo= 5.5 mph

A =	481.8229	lb/in
B =	164.3389	lb/in*2
W (width of	60.59843	in
c1 =	0.354331	in
c2 =	15.94488	in
c3 =	20.43307	in
c4 =	21.45669	in
c5 =	16.73228	in
c6 =	1.692913	in
θ =	0	degrees
G =	706.3249	lbs
E =	1806873	in-lbs
E=	150572.7	ft-lbs
w = (weight	3229.772	lbs
v =	54.79364	ft/sec
v =	37.18132	mi/hr

bo= 5.75 mph

A =	498.5324	lb/in
B =	161.5792	lb/in*2
W (width of	60.59843	in
c1 =	0.354331	in
c2 =	15.94488	in
c3 =	20.43307	in
c4 =	21.45669	in
c5 =	16.73228	in
c6 =	1.692913	in
θ =	0	degrees
G =	769.0797	lbs
E =	1803773	in-lbs
E=	150314.4	ft-lbs
w = (weight	3229.772	lbs
v =	54.74661	ft/sec
v =	37.14941	mi/hr

bo= 6.0 mph

A =	514.8886	lb/in
B =	158.8429	lb/in*2
W (width o	60.59843	in
c1 =	0.354331	in
c2 =	15.94488	in
c3 =	20.43307	in
c4 =	21.45669	in
c5 =	16.73228	in
c6 =	1.692913	in
θ =	0	degrees
G =	834.5046	lbs
E =	1800699	in-lbs
E=	150058.3	ft-lbs
w = (weigh	3229.772	lbs
v =	54.69995	ft/sec
v =	37.11775	mi/hr

bo= 6.25 mph

2002 Mini Cooper	case #9

A =	548.1057	lb/in	A =	525.0547	lb/in	A =	501.5453	lb/in	A =	477.5775	lb/in	A =	453.1515	lb/in
B =	287.9386	lb/in*2	B =	292.7743	lb/in*2	B =	297.6504	lb/in*2	B =	302.5667	lb/in*2	B =	307.5233	lb/in*2
W (width of cru	59.45669291	in	W (width o	59.45669291	in	W (width of	59.45669	in	W (width of	59.45669	in	W (width o	59.45669	in
c1 =	7.834645669	in	c1 =	7.834645669	in	c1 =	7.834646	in	c1 =	7.834646	in	c1 =	7.834646	in
c2 =	10.43307087	in	c2 =	10.43307087	in	c2 =	10.43307	in	c2 =	10.43307	in	c2 =	10.43307	in
c3 =	13.38582677	in	c3 =	13.38582677	in	c3 =	13.38583	in	c3 =	13.38583	in	c3 =	13.38583	in
c4 =	13.85826772	in	c4 =	13.85826772	in	c4 =	13.85827	in	c4 =	13.85827	in	c4 =	13.85827	in
c5 =	12.20472441	in	c5 =	12.20472441	in	c5 =	12.20472	in	c5 =	12.20472	in	c5 =	12.20472	in
c6 =	6.220472441	in	c6 =	6.220472441	in	c6 =	6.220472	in	c6 =	6.220472	in	c6 =	6.220472	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	521.673472	lbs	G =	470.8105151	lbs	G =	422.5556	lbs	G =	376.9091	lbs	G =	333.8711	lbs
E =	1549026.775	in-lbs	E =	1549667.813	in-lbs	E =	1550315	in-lbs	E =	1550967	in-lbs	E =	1551624	in-lbs
E=	129085.5646	ft-lbs	E=	129138.9844	ft-lbs	E=	129192.9	ft-lbs	E=	129247.2	ft-lbs	E=	129302	ft-lbs
w = (weight of	3095.290161	lbs	w = (weigh	3095.290161	lbs	w = (weight	3095.29	lbs	w = (weight	3095.29	lbs	w = (weigh	3095.29	lbs
v =	51.82401894	ft/sec	v =	51.83474107	ft/sec	v =	51.84556	ft/sec	v =	51.85646	ft/sec	v =	51.86745	ft/sec
v =	35.16622453	mi/hr	v =	35.17350025	mi/hr	v =	35.18084	mi/hr	v =	35.18824	mi/hr	v =	35.19569	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

56.16 km/h is equal to **34.8962341** mph

A average 557.5687 lb/in

B average 285.7019 lb/in*2

v average = 35.16285 mi/hr

A =	570.6984	lb/in	A =	592.8328	lb/in	A =	614.5089	lb/in	A =	635.7266	lb/in	A =	656.4859	lb/in
B =	283.1431	lb/in*2	B =	278.3878	lb/in*2	B =	273.6729	lb/in*2	B =	268.9982	lb/in*2	B =	264.3638	lb/in*2
W (width of cru	59.45669291	in	W (width o	59.45669291	in	W (width of	59.45669	in	W (width of	59.45669	in	W (width o	59.45669	in
c1 =	7.834645669	in	c1 =	7.834645669	in	c1 =	7.834646	in	c1 =	7.834646	in	c1 =	7.834646	in
c2 =	10.43307087	in	c2 =	10.43307087	in	c2 =	10.43307	in	c2 =	10.43307	in	c2 =	10.43307	in
c3 =	13.38582677	in	c3 =	13.38582677	in	c3 =	13.38583	in	c3 =	13.38583	in	c3 =	13.38583	in
c4 =	13.85826772	in	c4 =	13.85826772	in	c4 =	13.85827	in	c4 =	13.85827	in	c4 =	13.85827	in
c5 =	12.20472441	in	c5 =	12.20472441	in	c5 =	12.20472	in	c5 =	12.20472	in	c5 =	12.20472	in
c6 =	6.220472441	in	c6 =	6.220472441	in	c6 =	6.220472	in	c6 =	6.220472	in	c6 =	6.220472	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	575.1449775	lbs	G =	631.225091	lbs	G =	689.9134	lbs	G =	751.2101	lbs	G =	815.1149	lbs
E =	1548390.837	in-lbs	E =	1547760.001	in-lbs	E =	1547135	in-lbs	E =	1546515	in-lbs	E =	1545901	in-lbs
E=	129032.5697	ft-lbs	E=	128980.0001	ft-lbs	E=	128927.9	ft-lbs	E=	128876.3	ft-lbs	E=	128825	ft-lbs
w = (weight of	3095.290161	lbs	w = (weigh	3095.290161	lbs	w = (weight	3095.29	lbs	w = (weight	3095.29	lbs	w = (weigh	3095.29	lbs
v =	51.81337992	ft/sec	v =	51.8028241	ft/sec	v =	51.79236	ft/sec	v =	51.78199	ft/sec	v =	51.7717	ft/sec
v =	35.15900521	mi/hr	v =	35.15184235	mi/hr	v =	35.14474	mi/hr	v =	35.1377	mi/hr	v =	35.13072	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2003 Toyota Corolla | **case #10**

A =	273.7813 lb/in	262.2785 lb/in	250.5456 lb/in	238.5826 lb/in	226.3894 lb/in
B =	79.9303 lb/in*2	81.2797 lb/in*2	82.6404 lb/in*2	84.0124 lb/in*2	85.3957 lb/in*2
W (width of cru	63.60629921 in	63.60629921 in	63.6063 in	63.6063 in	63.6063 in
c1 =	15.11811024 in	15.11811024 in	15.11811 in	15.11811 in	15.11811 in
c2 =	20.86614173 in	20.86614173 in	20.86614 in	20.86614 in	20.86614 in
c3 =	22.08661417 in	22.08661417 in	22.08661 in	22.08661 in	22.08661 in
c4 =	21.88976378 in	21.88976378 in	21.88976 in	21.88976 in	21.88976 in
c5 =	20.98425197 in	20.98425197 in	20.98425 in	20.98425 in	20.98425 in
c6 =	16.96850394 in	16.96850394 in	16.9685 in	16.9685 in	16.9685 in
θ =	0 degrees	0 degrees	0 degrees	0 degrees	0 degrees
G =	468.8847673 lbs	423.1684637 lbs	379.7967 lbs	338.7694 lbs	300.0863 lbs
E =	1448398.697 in-lbs	1448543.101 in-lbs	1448689 in-lbs	1448836 in-lbs	1448984 in-lbs
E=	120699.8914 ft-lbs	120711.9251 ft-lbs	120724.1 ft-lbs	120736.3 ft-lbs	120748.7 ft-lbs
w = (weight of	2976.240539 lbs	2976.240539 lbs	2976.241 lbs	2976.241 lbs	2976.241 lbs
v =	51.10487842 ft/sec	51.10742591 ft/sec	51.11 ft/sec	51.11259 ft/sec	51.11521 ft/sec
v =	34.67823735 mi/hr	34.679966 mi/hr	34.68171 mi/hr	34.68347 mi/hr	34.68524 mi/hr
bo=	5.0 mph	4.75 mph	4.5 mph	4.25 mph	4.0 mph

55.91 km/h is equal to **34.7408912** mph

A average 278.497 lb/in

B average 79.30638 lb/in*2

v average = 34.67743 mi/hr

A =	285.0539 lb/in	296.0963 lb/in	306.9087 lb/in	317.4909 lb/in	327.8429 lb/in
B =	78.5921 lb/in*2	77.2653 lb/in*2	75.9498 lb/in*2	74.6455 lb/in*2	73.3526 lb/in*2
W (width of cru	63.60629921 in	63.60629921 in	63.6063 in	63.6063 in	63.6063 in
c1 =	15.11811024 in	15.11811024 in	15.11811 in	15.11811 in	15.11811 in
c2 =	20.86614173 in	20.86614173 in	20.86614 in	20.86614 in	20.86614 in
c3 =	22.08661417 in	22.08661417 in	22.08661 in	22.08661 in	22.08661 in
c4 =	21.88976378 in	21.88976378 in	21.88976 in	21.88976 in	21.88976 in
c5 =	20.98425197 in	20.98425197 in	20.98425 in	20.98425 in	20.98425 in
c6 =	16.96850394 in	16.96850394 in	16.9685 in	16.9685 in	16.9685 in
θ =	0 degrees	0 degrees	0 degrees	0 degrees	0 degrees
G =	516.9458884 lbs	567.3505369 lbs	620.1001 lbs	675.1946 lbs	732.6323 lbs
E =	1448254.178 in-lbs	1448112.122 in-lbs	1447972 in-lbs	1447831 in-lbs	1447693 in-lbs
E=	120687.8481 ft-lbs	120676.0101 ft-lbs	120664.3 ft-lbs	120652.6 ft-lbs	120641.1 ft-lbs
w = (weight of	2976.240539 lbs	2976.240539 lbs	2976.241 lbs	2976.241 lbs	2976.241 lbs
v =	51.10232877 ft/sec	51.09982245 ft/sec	51.09734 ft/sec	51.09486 ft/sec	51.09242 ft/sec
v =	34.67650723 mi/hr	34.67480652 mi/hr	34.67312 mi/hr	34.67144 mi/hr	34.66978 mi/hr
bo=	5.25 mph	5.5 mph	5.75 mph	6.0 mph	6.25 mph

2002 Chrysler PT Cruiser | **case #11**

A =	430.2808	lb/in	A =	412.1729	lb/in	A =	393.7065	lb/in	A =	374.8816	lb/in	A =	355.6981	lb/in
B =	165.9806	lb/in*2	B =	168.7583	lb/in*2	B =	171.5591	lb/in*2	B =	174.3829	lb/in*2	B =	177.2297	lb/in*2
W (width of cru	67.08661417	in	W (width o	67.08661417	in	W (width of	67.08661	in	W (width of	67.08661	in	W (width o	67.08661	in
c1 =	11.14173228	in	c1 =	11.14173228	in	c1 =	11.14173	in	c1 =	11.14173	in	c1 =	11.14173	in
c2 =	14.29133858	in	c2 =	14.29133858	in	c2 =	14.29134	in	c2 =	14.29134	in	c2 =	14.29134	in
c3 =	18.58267717	in	c3 =	18.58267717	in	c3 =	18.58268	in	c3 =	18.58268	in	c3 =	18.58268	in
c4 =	19.05511811	in	c4 =	19.05511811	in	c4 =	19.05512	in	c4 =	19.05512	in	c4 =	19.05512	in
c5 =	15.11811024	in	c5 =	15.11811024	in	c5 =	15.11811	in	c5 =	15.11811	in	c5 =	15.11811	in
c6 =	10.31496063	in	c6 =	10.31496063	in	c6 =	10.31496	in	c6 =	10.31496	in	c6 =	10.31496	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	557.7205012	lbs	G =	503.3426489	lbs	G =	451.7534	lbs	G =	402.953	lbs	G =	356.9411	lbs
E =	1873074.349	in-lbs	E =	1873735.602	in-lbs	E =	1874403	in-lbs	E =	1875075	in-lbs	E =	1875752	in-lbs
E=	156089.5291	ft-lbs	E=	156144.6335	ft-lbs	E=	156200.2	ft-lbs	E=	156256.3	ft-lbs	E=	156312.7	ft-lbs
w = (weight of	3723.607608	lbs	w = (weigh	3723.607608	lbs	w = (weight	3723.608	lbs	w = (weight	3723.608	lbs	w = (weigh	3723.608	lbs
v =	51.95745431	ft/sec	v =	51.96662479	ft/sec	v =	51.97588	ft/sec	v =	51.9852	ft/sec	v =	51.99459	ft/sec
v =	35.25676977	mi/hr	v =	35.26299258	mi/hr	v =	35.26927	mi/hr	v =	35.2756	mi/hr	v =	35.28197	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

56.33 km/h is equal to **35.0018673** mph

A average 437.7213 lb/in

B average 164.6955 lb/in*2

v average = 35.25389 mi/hr

A =	448.0301	lb/in	A =	465.4209	lb/in	A =	482.4531	lb/in	A =	499.1268	lb/in	A =	515.442	lb/in
B =	163.226	lb/in*2	B =	160.4944	lb/in*2	B =	157.7858	lb/in*2	B =	155.1003	lb/in*2	B =	152.4379	lb/in*2
W (width of cru	67.08661417	in	W (width o	67.08661417	in	W (width of	67.08661	in	W (width of	67.08661	in	W (width o	67.08661	in
c1 =	11.14173228	in	c1 =	11.14173228	in	c1 =	11.14173	in	c1 =	11.14173	in	c1 =	11.14173	in
c2 =	14.29133858	in	c2 =	14.29133858	in	c2 =	14.29134	in	c2 =	14.29134	in	c2 =	14.29134	in
c3 =	18.58267717	in	c3 =	18.58267717	in	c3 =	18.58268	in	c3 =	18.58268	in	c3 =	18.58268	in
c4 =	19.05511811	in	c4 =	19.05511811	in	c4 =	19.05512	in	c4 =	19.05512	in	c4 =	19.05512	in
c5 =	15.11811024	in	c5 =	15.11811024	in	c5 =	15.11811	in	c5 =	15.11811	in	c5 =	15.11811	in
c6 =	10.31496063	in	c6 =	10.31496063	in	c6 =	10.31496	in	c6 =	10.31496	in	c6 =	10.31496	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	614.8866311	lbs	G =	674.8416585	lbs	G =	737.5854	lbs	G =	803.1176	lbs	G =	871.4383	lbs
E =	1872418.922	in-lbs	E =	1871768.631	in-lbs	E =	1871123	in-lbs	E =	1870484	in-lbs	E =	1869851	in-lbs
E=	156034.9101	ft-lbs	E=	155980.7192	ft-lbs	E=	155926.9	ft-lbs	E=	155873.7	ft-lbs	E=	155820.9	ft-lbs
w = (weight of	3723.607608	lbs	w = (weigh	3723.607608	lbs	w = (weight	3723.608	lbs	w = (weight	3723.608	lbs	w = (weigh	3723.608	lbs
v =	51.94836302	ft/sec	v =	51.93934141	ft/sec	v =	51.93039	ft/sec	v =	51.92152	ft/sec	v =	51.91272	ft/sec
v =	35.25060069	mi/hr	v =	35.2444789	mi/hr	v =	35.2384	mi/hr	v =	35.23238	mi/hr	v =	35.22642	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2002 Ford Explorer Sport | **case #12**

A =	567.634	lb/in
B =	228.1612	lb/in*2
W (width of cru	64.88976378	in
c1 =	14.09448819	in
c2 =	14.72440945	in
c3 =	14.92125984	in
c4 =	14.96062992	in
c5 =	14.92125984	in
c6 =	13.93700787	in
θ =	0	degrees
G =	706.0980525	lbs
E =	2189720.058	in-lbs
E=	182476.6715	ft-lbs
w = (weight of	4572.387318	lbs
v =	50.69616448	ft/sec
v =	34.40089633	mi/hr

bo= 5.0 mph

A =	543.8128	lb/in
B =	232.0367	lb/in*2
W (width o	64.88976378	in
c1 =	14.09448819	in
c2 =	14.72440945	in
c3 =	14.92125984	in
c4 =	14.96062992	in
c5 =	14.92125984	in
c6 =	13.93700787	in
θ =	0	degrees
G =	637.2534204	lbs
E =	2189730.225	in-lbs
E=	182477.5188	ft-lbs
w = (weigh	4572.387318	lbs
v =	50.69628218	ft/sec
v =	34.4009762	mi/hr

bo= 4.75 mph

A =	519.5116	lb/in
B =	235.9448	lb/in*2
W (width of	64.88976	in
c1 =	14.09449	in
c2 =	14.72441	in
c3 =	14.92126	in
c4 =	14.96063	in
c5 =	14.92126	in
c6 =	13.93701	in
θ =	0	degrees
G =	571.9395	lbs
E =	2189740	in-lbs
E=	182478.4	ft-lbs
w = (weight	4572.387	lbs
v =	50.6964	ft/sec
v =	34.40106	mi/hr

bo= 4.5 mph

A =	494.7304	lb/in
B =	239.8856	lb/in*2
W (width of	64.88976	in
c1 =	14.09449	in
c2 =	14.72441	in
c3 =	14.92126	in
c4 =	14.96063	in
c5 =	14.92126	in
c6 =	13.93701	in
θ =	0	degrees
G =	510.156	lbs
E =	2189751	in-lbs
E=	182479.2	ft-lbs
w = (weight	4572.387	lbs
v =	50.69652	ft/sec
v =	34.40114	mi/hr

bo= 4.25 mph

A =	469.469	lb/in
B =	243.8591	lb/in*2
W (width o	64.88976	in
c1 =	14.09449	in
c2 =	14.72441	in
c3 =	14.92126	in
c4 =	14.96063	in
c5 =	14.92126	in
c6 =	13.93701	in
θ =	0	degrees
G =	451.9026	lbs
E =	2189762	in-lbs
E=	182480.2	ft-lbs
w = (weigh	4572.387	lbs
v =	50.69665	ft/sec
v =	34.40123	mi/hr

bo= 4.0 mph

55.62 km/h is equal to **34.5606934** mph

A average 577.3843 lb/in

B average 226.3703 lb/in*2

v average = 34.40086 mi/hr

A =	590.9751	lb/in
B =	224.3183	lb/in*2
W (width of cru	64.88976378	in
c1 =	14.09448819	in
c2 =	14.72440945	in
c3 =	14.92125984	in
c4 =	14.96062992	in
c5 =	14.92125984	in
c6 =	13.93700787	in
θ =	0	degrees
G =	778.4731982	lbs
E =	2189709.672	in-lbs
E=	182475.806	ft-lbs
w = (weight of	4572.387318	lbs
v =	50.69604425	ft/sec
v =	34.40081475	mi/hr

bo= 5.25 mph

A =	613.8361	lb/in
B =	220.508	lb/in*2
W (width o	64.88976378	in
c1 =	14.09448819	in
c2 =	14.72440945	in
c3 =	14.92125984	in
c4 =	14.96062992	in
c5 =	14.92125984	in
c6 =	13.93700787	in
θ =	0	degrees
G =	854.3788834	lbs
E =	2189699.068	in-lbs
E=	182474.9223	ft-lbs
w = (weigh	4572.387318	lbs
v =	50.6959215	ft/sec
v =	34.40073145	mi/hr

bo= 5.5 mph

A =	636.2171	lb/in
B =	216.7304	lb/in*2
W (width of	64.88976	in
c1 =	14.09449	in
c2 =	14.72441	in
c3 =	14.92126	in
c4 =	14.96063	in
c5 =	14.92126	in
c6 =	13.93701	in
θ =	0	degrees
G =	933.815	lbs
E =	2189689	in-lbs
E=	182474.1	ft-lbs
w = (weight	4572.387	lbs
v =	50.69581	ft/sec
v =	34.40065	mi/hr

bo= 5.75 mph

A =	658.118	lb/in
B =	212.9855	lb/in*2
W (width of	64.88976	in
c1 =	14.09449	in
c2 =	14.72441	in
c3 =	14.92126	in
c4 =	14.96063	in
c5 =	14.92126	in
c6 =	13.93701	in
θ =	0	degrees
G =	1016.781	lbs
E =	2189679	in-lbs
E=	182473.3	ft-lbs
w = (weight	4572.387	lbs
v =	50.69569	ft/sec
v =	34.40058	mi/hr

bo= 6.0 mph

A =	679.5389	lb/in
B =	209.2731	lb/in*2
W (width o	64.88976	in
c1 =	14.09449	in
c2 =	14.72441	in
c3 =	14.92126	in
c4 =	14.96063	in
c5 =	14.92126	in
c6 =	13.93701	in
θ =	0	degrees
G =	1103.279	lbs
E =	2189669	in-lbs
E=	182472.4	ft-lbs
w = (weigh	4572.387	lbs
v =	50.69557	ft/sec
v =	34.4005	mi/hr

bo= 6.25 mph

2002 Nissan Pathfinder **case #13**

A =	399.6121	lb/in	A =	382.8062	lb/in	A =	365.666	lb/in	A =	348.1917	lb/in	A =	330.3831	lb/in
B =	110.8298	lb/in*2	B =	112.6911	lb/in*2	B =	114.568	lb/in*2	B =	116.4603	lb/in*2	B =	118.3681	lb/in*2
W (width of cru	64.65354331	in	W (width o	64.65354331	in	W (width of	64.65354	in	W (width of	64.65354	in	W (width o	64.65354	in
c1 =	14.60629921	in	c1 =	14.60629921	in	c1 =	14.6063	in	c1 =	14.6063	in	c1 =	14.6063	in
c2 =	22.87401575	in	c2 =	22.87401575	in	c2 =	22.87402	in	c2 =	22.87402	in	c2 =	22.87402	in
c3 =	24.60629921	in	c3 =	24.60629921	in	c3 =	24.6063	in	c3 =	24.6063	in	c3 =	24.6063	in
c4 =	23.93700787	in	c4 =	23.93700787	in	c4 =	23.93701	in	c4 =	23.93701	in	c4 =	23.93701	in
c5 =	22.36220472	in	c5 =	22.36220472	in	c5 =	22.3622	in	c5 =	22.3622	in	c5 =	22.3622	in
c6 =	13.42519685	in	c6 =	13.42519685	in	c6 =	13.4252	in	c6 =	13.4252	in	c6 =	13.4252	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	720.4282173	lbs	G =	650.1870456	lbs	G =	583.547	lbs	G =	520.5098	lbs	G =	461.0744	lbs
E =	2303850.742	in-lbs	E =	2304438.805	in-lbs	E =	2305033	in-lbs	E =	2305631	in-lbs	E =	2306233	in-lbs
E=	191987.5618	ft-lbs	E=	192036.5671	ft-lbs	E=	192086.1	ft-lbs	E=	192135.9	ft-lbs	E=	192186.1	ft-lbs
w = (weight of	4720.097033	lbs	w = (weigh	4720.097033	lbs	w = (weight	4720.097	lbs	w = (weight	4720.097	lbs	w = (weigh	4720.097	lbs
v =	51.1804402	ft/sec	v =	51.18697175	ft/sec	v =	51.19357	ft/sec	v =	51.20021	ft/sec	v =	51.2069	ft/sec
v =	34.72951131	mi/hr	v =	34.73394342	mi/hr	v =	34.73842	mi/hr	v =	34.74293	mi/hr	v =	34.74746	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

56.16 km/h is equal to **34.8962341** mph **A average** 406.5115 lb/in **B average** 109.9689 lb/in*2 **v average =** 34.72746 mi/hr

A =	416.0841	lb/in	A =	432.2218	lb/in	A =	448.0254	lb/in	A =	463.4948	lb/in	A =	478.63	lb/in
B =	108.984	lb/in*2	B =	107.1537	lb/in*2	B =	105.3388	lb/in*2	B =	103.5395	lb/in*2	B =	101.7554	lb/in*2
W (width of cru	64.65354331	in	W (width o	64.65354331	in	W (width of	64.65354	in	W (width of	64.65354	in	W (width o	64.65354	in
c1 =	14.60629921	in	c1 =	14.60629921	in	c1 =	14.6063	in	c1 =	14.6063	in	c1 =	14.6063	in
c2 =	22.87401575	in	c2 =	22.87401575	in	c2 =	22.87402	in	c2 =	22.87402	in	c2 =	22.87402	in
c3 =	24.60629921	in	c3 =	24.60629921	in	c3 =	24.6063	in	c3 =	24.6063	in	c3 =	24.6063	in
c4 =	23.93700787	in	c4 =	23.93700787	in	c4 =	23.93701	in	c4 =	23.93701	in	c4 =	23.93701	in
c5 =	22.36220472	in	c5 =	22.36220472	in	c5 =	22.3622	in	c5 =	22.3622	in	c5 =	22.3622	in
c6 =	13.42519685	in	c6 =	13.42519685	in	c6 =	13.4252	in	c6 =	13.4252	in	c6 =	13.4252	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	794.2724541	lbs	G =	871.7183093	lbs	G =	952.7674	lbs	G =	1037.418	lbs	G =	1125.673	lbs
E =	2303268.006	in-lbs	E =	2302689.946	in-lbs	E =	2302115	in-lbs	E =	2301547	in-lbs	E =	2300979	in-lbs
E=	191939.0005	ft-lbs	E=	191890.8288	ft-lbs	E=	191843	ft-lbs	E=	191795.6	ft-lbs	E=	191748.3	ft-lbs
w = (weight of	4720.097033	lbs	w = (weigh	4720.097033	lbs	w = (weight	4720.097	lbs	w = (weight	4720.097	lbs	w = (weigh	4720.097	lbs
v =	51.17396701	ft/sec	v =	51.16754494	ft/sec	v =	51.16116	ft/sec	v =	51.15485	ft/sec	v =	51.14854	ft/sec
v =	34.72511879	mi/hr	v =	34.72076097	mi/hr	v =	34.71643	mi/hr	v =	34.71214	mi/hr	v =	34.70786	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2002 Toyota Highlander **case #14**

A =	416.9089	lb/in	A =	399.399	lb/in	A =	381.538	lb/in	A =	363.3259	lb/in	A =	344.7627	lb/in
B =	134.3082	lb/in*2	B =	136.5799	lb/in*2	B =	138.8708	lb/in*2	B =	141.1806	lb/in*2	B =	143.5095	lb/in*2
W (width of cru	69.04724409	in	W (width o	69.04724409	in	W (width of	69.04724	in	W (width of	69.04724	in	W (width o	69.04724	in
c1 =	16.41732283	in	c1 =	16.41732283	in	c1 =	16.41732	in	c1 =	16.41732	in	c1 =	16.41732	in
c2 =	19.13385827	in	c2 =	19.13385827	in	c2 =	19.13386	in	c2 =	19.13386	in	c2 =	19.13386	in
c3 =	19.68503937	in	c3 =	19.68503937	in	c3 =	19.68504	in	c3 =	19.68504	in	c3 =	19.68504	in
c4 =	19.33070866	in	c4 =	19.33070866	in	c4 =	19.33071	in	c4 =	19.33071	in	c4 =	19.33071	in
c5 =	18.38582677	in	c5 =	18.38582677	in	c5 =	18.38583	in	c5 =	18.38583	in	c5 =	18.38583	in
c6 =	14.80314961	in	c6 =	14.80314961	in	c6 =	14.80315	in	c6 =	14.80315	in	c6 =	14.80315	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	647.0678294	lbs	G =	583.9789061	lbs	G =	524.1247	lbs	G =	467.5065	lbs	G =	414.1235	lbs
E =	2157321.988	in-lbs	E =	2157445.222	in-lbs	E =	2157571	in-lbs	E =	2157697	in-lbs	E =	2157823	in-lbs
E=	179776.8323	ft-lbs	E=	179787.1019	ft-lbs	E=	179797.6	ft-lbs	E=	179808	ft-lbs	E=	179818.6	ft-lbs
w = (weight of	4455.542319	lbs	w = (weigh	4455.542319	lbs	w = (weight	4455.542	lbs	w = (weight	4455.542	lbs	w = (weigh	4455.542	lbs
v =	50.97526699	ft/sec	v =	50.97672292	ft/sec	v =	50.97821	ft/sec	v =	50.97969	ft/sec	v =	50.98119	ft/sec
v =	34.59028692	mi/hr	v =	34.59127487	mi/hr	v =	34.59228	mi/hr	v =	34.59329	mi/hr	v =	34.59431	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

55.82 km/h is equal to **34.6849677** mph

A average 424.0838 lb/in

B average 133.258 lb/in*2

v average = 34.58983 mi/hr

A =	434.0676	lb/in	A =	450.8753	lb/in	A =	467.3318	lb/in	A =	483.4373	lb/in	A =	499.1916	lb/in
B =	132.0555	lb/in*2	B =	129.8218	lb/in*2	B =	127.6072	lb/in*2	B =	125.4117	lb/in*2	B =	123.2352	lb/in*2
W (width of cru	69.04724409	in	W (width o	69.04724409	in	W (width of	69.04724	in	W (width of	69.04724	in	W (width o	69.04724	in
c1 =	16.41732283	in	c1 =	16.41732283	in	c1 =	16.41732	in	c1 =	16.41732	in	c1 =	16.41732	in
c2 =	19.13385827	in	c2 =	19.13385827	in	c2 =	19.13386	in	c2 =	19.13386	in	c2 =	19.13386	in
c3 =	19.68503937	in	c3 =	19.68503937	in	c3 =	19.68504	in	c3 =	19.68504	in	c3 =	19.68504	in
c4 =	19.33070866	in	c4 =	19.33070866	in	c4 =	19.33071	in	c4 =	19.33071	in	c4 =	19.33071	in
c5 =	18.38582677	in	c5 =	18.38582677	in	c5 =	18.38583	in	c5 =	18.38583	in	c5 =	18.38583	in
c6 =	14.80314961	in	c6 =	14.80314961	in	c6 =	14.80315	in	c6 =	14.80315	in	c6 =	14.80315	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	713.392026	lbs	G =	782.952232	lbs	G =	855.7472	lbs	G =	931.7776	lbs	G =	1011.043	lbs
E =	2157199.062	in-lbs	E =	2157076.751	in-lbs	E =	2156956	in-lbs	E =	2156837	in-lbs	E =	2156718	in-lbs
E=	179766.5885	ft-lbs	E=	179756.3959	ft-lbs	E=	179746.3	ft-lbs	E=	179736.4	ft-lbs	E=	179726.5	ft-lbs
w = (weight of	4455.542319	lbs	w = (weigh	4455.542319	lbs	w = (weight	4455.542	lbs	w = (weight	4455.542	lbs	w = (weigh	4455.542	lbs
v =	50.97381467	ft/sec	v =	50.97236957	ft/sec	v =	50.97094	ft/sec	v =	50.96953	ft/sec	v =	50.96813	ft/sec
v =	34.58930142	mi/hr	v =	34.58832082	mi/hr	v =	34.58735	mi/hr	v =	34.5864	mi/hr	v =	34.58544	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2003 Subaru Forester | **case #15**

A =	390.0143 lb/in	A =	373.5606 lb/in	A =	356.7862 lb/in	A =	339.691 lb/in	A =	322.2751 lb/in
B =	128.6961 lb/in*2	B =	130.8215 lb/in*2	B =	132.9644 lb/in*2	B =	135.1246 lb/in*2	B =	137.3023 lb/in*2
W (width of cru	61.30708661 in	W (width o	61.30708661 in	W (width of	61.30709 in	W (width of	61.30709 in	W (width o	61.30709 in
c1 =	12.24409449 in	c1 =	12.24409449 in	c1 =	12.24409 in	c1 =	12.24409 in	c1 =	12.24409 in
c2 =	18.97637795 in	c2 =	18.97637795 in	c2 =	18.97638 in	c2 =	18.97638 in	c2 =	18.97638 in
c3 =	19.4488189 in	c3 =	19.4488189 in	c3 =	19.44882 in	c3 =	19.44882 in	c3 =	19.44882 in
c4 =	20 in	c4 =	20 in	c4 =	20 in	c4 =	20 in	c4 =	20 in
c5 =	19.37007874 in	c5 =	19.37007874 in	c5 =	19.37008 in	c5 =	19.37008 in	c5 =	19.37008 in
c6 =	16.41732283 in	c6 =	16.41732283 in	c6 =	16.41732 in	c6 =	16.41732 in	c6 =	16.41732 in
θ =	0 degrees	θ =	0 degrees	θ =	0 degrees	θ =	0 degrees	θ =	0 degrees
G =	590.9703332 lbs	G =	533.3508707 lbs	G =	478.686 lbs	G =	426.9762 lbs	G =	378.221 lbs
E =	1829227.916 in-lbs	E =	1829444.776 in-lbs	E =	1829664 in-lbs	E =	1829885 in-lbs	E =	1830108 in-lbs
E=	152435.6597 ft-lbs	E=	152453.7314 ft-lbs	E=	152472 ft-lbs	E=	152490.4 ft-lbs	E=	152509 ft-lbs
w = (weight of	3615.5811 lbs	w = (weigh	3615.5811 lbs	w = (weight	3615.581 lbs	w = (weight	3615.581 lbs	w = (weigh	3615.581 lbs
v =	52.10713166 ft/sec	v =	52.11022029 ft/sec	v =	52.11335 ft/sec	v =	52.11648 ft/sec	v =	52.11966 ft/sec
v =	35.35833633 mi/hr	v =	35.36043218 mi/hr	v =	35.36255 mi/hr	v =	35.36468 mi/hr	v =	35.36684 mi/hr
bo= 5.0 mph		**bo= 4.75 mph**		**bo= 4.5 mph**		**bo= 4.25 mph**		**bo= 4.0 mph**	

56.97 km/h is equal to **35.3995451** mph   **A average** 396.7978 lb/in   **B average** 127.7117 lb/in*2   **v average =** 35.35736 mi/hr

A =	406.1472 lb/in	A =	421.9594 lb/in	A =	437.4509 lb/in	A =	452.6216 lb/in	A =	467.4716 lb/in
B =	126.588 lb/in*2	B =	124.4974 lb/in*2	B =	122.4242 lb/in*2	B =	120.3683 lb/in*2	B =	118.3299 lb/in*2
W (width of cru	61.30708661 in	W (width o	61.30708661 in	W (width of	61.30709 in	W (width of	61.30709 in	W (width o	61.30709 in
c1 =	12.24409449 in	c1 =	12.24409449 in	c1 =	12.24409 in	c1 =	12.24409 in	c1 =	12.24409 in
c2 =	18.97637795 in	c2 =	18.97637795 in	c2 =	18.97638 in	c2 =	18.97638 in	c2 =	18.97638 in
c3 =	19.4488189 in	c3 =	19.4488189 in	c3 =	19.44882 in	c3 =	19.44882 in	c3 =	19.44882 in
c4 =	20 in	c4 =	20 in	c4 =	20 in	c4 =	20 in	c4 =	20 in
c5 =	19.37007874 in	c5 =	19.37007874 in	c5 =	19.37008 in	c5 =	19.37008 in	c5 =	19.37008 in
c6 =	16.41732283 in	c6 =	16.41732283 in	c6 =	16.41732 in	c6 =	16.41732 in	c6 =	16.41732 in
θ =	0 degrees	θ =	0 degrees	θ =	0 degrees	θ =	0 degrees	θ =	0 degrees
G =	651.544965 lbs	G =	715.074111 lbs	G =	781.5583 lbs	G =	850.9978 lbs	G =	923.3917 lbs
E =	1829011.657 in-lbs	E =	1828798.173 in-lbs	E =	1828586 in-lbs	E =	1828375 in-lbs	E =	1828167 in-lbs
E=	152417.6381 ft-lbs	E=	152399.8477 ft-lbs	E=	152382.2 ft-lbs	E=	152364.6 ft-lbs	E=	152347.2 ft-lbs
w = (weight of	3615.5811 lbs	w = (weigh	3615.5811 lbs	w = (weight	3615.581 lbs	w = (weight	3615.581 lbs	w = (weigh	3615.581 lbs
v =	52.1040514 ft/sec	v =	52.1010105 ft/sec	v =	52.09799 ft/sec	v =	52.09499 ft/sec	v =	52.09202 ft/sec
v =	35.35624616 mi/hr	v =	35.35418269 mi/hr	v =	35.35214 mi/hr	v =	35.3501 mi/hr	v =	35.34808 mi/hr
bo= 5.25 mph		**bo= 5.5 mph**		**bo= 5.75 mph**		**bo= 6.0 mph**		**bo= 6.25 mph**	

2002 Dodge Ram 1500	case #16

A =	511.3374	lb/in	A =	489.805	lb/in	A =	467.8479	lb/in	A =	445.4661	lb/in	A =	422.6597	lb/in
B =	171.2839	lb/in*2	B =	174.1408	lb/in*2	B =	177.0214	lb/in*2	B =	179.9256	lb/in*2	B =	182.8534	lb/in*2
W (width of cru	72.88188976	in	W (width o	72.88188976	in	W (width of	72.88189	in	W (width of	72.88189	in	W (width o	72.88189	in
c1 =	10.86614173	in	c1 =	10.86614173	in	c1 =	10.86614	in	c1 =	10.86614	in	c1 =	10.86614	in
c2 =	17.83464567	in	c2 =	17.83464567	in	c2 =	17.83465	in	c2 =	17.83465	in	c2 =	17.83465	in
c3 =	21.57480315	in	c3 =	21.57480315	in	c3 =	21.5748	in	c3 =	21.5748	in	c3 =	21.5748	in
c4 =	21.57480315	in	c4 =	21.57480315	in	c4 =	21.5748	in	c4 =	21.5748	in	c4 =	21.5748	in
c5 =	17.91338583	in	c5 =	17.91338583	in	c5 =	17.91339	in	c5 =	17.91339	in	c5 =	17.91339	in
c6 =	11.06299213	in	c6 =	11.06299213	in	c6 =	11.06299	in	c6 =	11.06299	in	c6 =	11.06299	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	763.2531039	lbs	G =	688.8360971	lbs	G =	618.235	lbs	G =	551.4503	lbs	G =	488.4821	lbs
E =	2809728.648	in-lbs	E =	2810865.47	in-lbs	E =	2812013	in-lbs	E =	2813169	in-lbs	E =	2814334	in-lbs
E=	234144.054	ft-lbs	E=	234238.7892	ft-lbs	E=	234334.4	ft-lbs	E=	234430.7	ft-lbs	E=	234527.8	ft-lbs
w = (weight of	5551.239762	lbs	w = (weigh	5551.239762	lbs	w = (weight	5551.24	lbs	w = (weight	5551.24	lbs	w = (weigh	5551.24	lbs
v =	52.11821197	ft/sec	v =	52.12875447	ft/sec	v =	52.13939	ft/sec	v =	52.15011	ft/sec	v =	52.16091	ft/sec
v =	35.36585509	mi/hr	v =	35.37300892	mi/hr	v =	35.38023	mi/hr	v =	35.3875	mi/hr	v =	35.39483	mi/hr
bo= 5.0 mph			**bo= 4.75 mph**			**bo= 4.5 mph**			**bo= 4.25 mph**			**bo= 4.0 mph**		

56.49 km/h is equal to **35.1012867** mph   **A average** 520.1925 lb/in   **B average** 169.9617 lb/in*2   **v average =** 35.36253 mi/hr

A =	532.4451	lb/in	A =	553.1281	lb/in	A =	573.3865	lb/in	A =	593.2202	lb/in	A =	612.6292	lb/in
B =	168.4506	lb/in*2	B =	165.6409	lb/in*2	B =	162.8548	lb/in*2	B =	160.0924	lb/in*2	B =	157.3536	lb/in*2
W (width of cru	72.88188976	in	W (width o	72.88188976	in	W (width of	72.88189	in	W (width of	72.88189	in	W (width o	72.88189	in
c1 =	10.86614173	in	c1 =	10.86614173	in	c1 =	10.86614	in	c1 =	10.86614	in	c1 =	10.86614	in
c2 =	17.83464567	in	c2 =	17.83464567	in	c2 =	17.83465	in	c2 =	17.83465	in	c2 =	17.83465	in
c3 =	21.57480315	in	c3 =	21.57480315	in	c3 =	21.5748	in	c3 =	21.5748	in	c3 =	21.5748	in
c4 =	21.57480315	in	c4 =	21.57480315	in	c4 =	21.5748	in	c4 =	21.5748	in	c4 =	21.5748	in
c5 =	17.91338583	in	c5 =	17.91338583	in	c5 =	17.91339	in	c5 =	17.91339	in	c5 =	17.91339	in
c6 =	11.06299213	in	c6 =	11.06299213	in	c6 =	11.06299	in	c6 =	11.06299	in	c6 =	11.06299	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	841.4864195	lbs	G =	923.5360802	lbs	G =	1009.402	lbs	G =	1099.085	lbs	G =	1192.583	lbs
E =	2808600.849	in-lbs	E =	2807482.077	in-lbs	E =	2806372	in-lbs	E =	2805273	in-lbs	E =	2804183	in-lbs
E=	234050.0708	ft-lbs	E=	233956.8397	ft-lbs	E=	233864.4	ft-lbs	E=	233772.8	ft-lbs	E=	233681.9	ft-lbs
w = (weight of	5551.239762	lbs	w = (weigh	5551.239762	lbs	w = (weight	5551.24	lbs	w = (weight	5551.24	lbs	w = (weigh	5551.24	lbs
v =	52.10775104	ft/sec	v =	52.09737175	ft/sec	v =	52.08708	ft/sec	v =	52.07687	ft/sec	v =	52.06675	ft/sec
v =	35.35875662	mi/hr	v =	35.35171355	mi/hr	v =	35.34473	mi/hr	v =	35.3378	mi/hr	v =	35.33093	mi/hr
bo= 5.25 mph			**bo= 5.5 mph**			**bo= 5.75 mph**			**bo= 6.0 mph**			**bo= 6.25 mph**		

2001 Nissan Frontier **case #17**

A =	426.772	lb/in
B =	127.487	lb/in*2
W (width of cru	64.18110236	in
c1 =	11.88976378	in
c2 =	20.5511811	in
c3 =	23.03149606	in
c4 =	23.1496063	in
c5 =	21.45669291	in
c6 =	11.8503937	in
θ =	0	degrees
G =	714.3251468	lbs
E =	2280023.538	in-lbs
E=	190001.9615	ft-lbs
w = (weight of	4521.680997	lbs
v =	52.02019981	ft/sec
v =	35.29934699	mi/hr

bo= 5.0 mph

A =	408.8244	lb/in
B =	129.6285	lb/in*2
W (width o	64.18110236	in
c1 =	11.88976378	in
c2 =	20.5511811	in
c3 =	23.03149606	in
c4 =	23.1496063	in
c5 =	21.45669291	in
c6 =	11.8503937	in
θ =	0	degrees
G =	644.678408	lbs
E =	2280823.74	in-lbs
E=	190068.645	ft-lbs
w = (weigh	4521.680997	lbs
v =	52.02932757	ft/sec
v =	35.30554081	mi/hr

bo= 4.75 mph

A =	390.5199	lb/in
B =	131.7879	lb/in*2
W (width of	64.1811	in
c1 =	11.88976	in
c2 =	20.55118	in
c3 =	23.0315	in
c4 =	23.14961	in
c5 =	21.45669	in
c6 =	11.85039	in
θ =	0	degrees
G =	578.6032	lbs
E =	2281631	in-lbs
E=	190136	ft-lbs
w = (weight	4521.681	lbs
v =	52.03854	ft/sec
v =	35.31179	mi/hr

bo= 4.5 mph

A =	371.8585	lb/in
B =	133.9651	lb/in*2
W (width of	64.1811	in
c1 =	11.88976	in
c2 =	20.55118	in
c3 =	23.0315	in
c4 =	23.14961	in
c5 =	21.45669	in
c6 =	11.85039	in
θ =	0	degrees
G =	516.0999	lbs
E =	2282446	in-lbs
E=	190203.8	ft-lbs
w = (weight	4521.681	lbs
v =	52.04782	ft/sec
v =	35.31809	mi/hr

bo= 4.25 mph

A =	352.84	lb/in
B =	136.1601	lb/in*2
W (width o	64.1811	in
c1 =	11.88976	in
c2 =	20.55118	in
c3 =	23.0315	in
c4 =	23.14961	in
c5 =	21.45669	in
c6 =	11.85039	in
θ =	0	degrees
G =	457.1679	lbs
E =	2283266	in-lbs
E=	190272.1	ft-lbs
w = (weigh	4521.681	lbs
v =	52.05717	ft/sec
v =	35.32443	mi/hr

bo= 4.0 mph

56.15 km/h is equal to **34.8900204** mph

A average 434.1395 lb/in

B average 126.4965 lb/in*2

v average = 35.29648 mi/hr

A =	444.3626	lb/in
B =	125.3633	lb/in*2
W (width of cru	64.18110236	in
c1 =	11.88976378	in
c2 =	20.5511811	in
c3 =	23.03149606	in
c4 =	23.1496063	in
c5 =	21.45669291	in
c6 =	11.8503937	in
θ =	0	degrees
G =	787.5435645	lbs
E =	2279229.456	in-lbs
E=	189935.788	ft-lbs
w = (weight of	4521.680997	lbs
v =	52.01114027	ft/sec
v =	35.29319945	mi/hr

bo= 5.25 mph

A =	461.5962	lb/in
B =	123.2575	lb/in*2
W (width o	64.18110236	in
c1 =	11.88976378	in
c2 =	20.5511811	in
c3 =	23.03149606	in
c4 =	23.1496063	in
c5 =	21.45669291	in
c6 =	11.8503937	in
θ =	0	degrees
G =	864.3330096	lbs
E =	2278442.773	in-lbs
E=	189870.2311	ft-lbs
w = (weigh	4521.680997	lbs
v =	52.0021636	ft/sec
v =	35.28710815	mi/hr

bo= 5.5 mph

A =	478.4729	lb/in
B =	121.1694	lb/in*2
W (width of	64.1811	in
c1 =	11.88976	in
c2 =	20.55118	in
c3 =	23.0315	in
c4 =	23.14961	in
c5 =	21.45669	in
c6 =	11.85039	in
θ =	0	degrees
G =	944.6953	lbs
E =	2277661	in-lbs
E=	189805.1	ft-lbs
w = (weight	4521.681	lbs
v =	51.99324	ft/sec
v =	35.28105	mi/hr

bo= 5.75 mph

A =	494.9927	lb/in
B =	119.0993	lb/in*2
W (width of	64.1811	in
c1 =	11.88976	in
c2 =	20.55118	in
c3 =	23.0315	in
c4 =	23.14961	in
c5 =	21.45669	in
c6 =	11.85039	in
θ =	0	degrees
G =	1028.628	lbs
E =	2276888	in-lbs
E=	189740.7	ft-lbs
w = (weight	4521.681	lbs
v =	51.98442	ft/sec
v =	35.27507	mi/hr

bo= 6.0 mph

A =	511.1555	lb/in
B =	117.0469	lb/in*2
W (width o	64.1811	in
c1 =	11.88976	in
c2 =	20.55118	in
c3 =	23.0315	in
c4 =	23.14961	in
c5 =	21.45669	in
c6 =	11.85039	in
θ =	0	degrees
G =	1116.134	lbs
E =	2276120	in-lbs
E=	189676.7	ft-lbs
w = (weigh	4521.681	lbs
v =	51.97565	ft/sec
v =	35.26912	mi/hr

bo= 6.25 mph

2003 Chevy Silverado	case #18

A =	367.7621	lb/in	A =	352.3114	lb/in	A =	336.5515	lb/in	A =	320.4825	lb/in	A =	304.1042	lb/in
B =	92.4775	lb/in*2	B =	94.0391	lb/in*2	B =	95.6138	lb/in*2	B =	97.2015	lb/in*2	B =	98.8023	lb/in*2
W (width of cru	71.26771654	in	W (width o	71.26771654	in	W (width of	71.26772	in	W (width of	71.26772	in	W (width o	71.26772	in
c1 =	20.23622047	in	c1 =	20.23622047	in	c1 =	20.23622	in	c1 =	20.23622	in	c1 =	20.23622	in
c2 =	23.34645669	in	c2 =	23.34645669	in	c2 =	23.34646	in	c2 =	23.34646	in	c2 =	23.34646	in
c3 =	25.07874016	in	c3 =	25.07874016	in	c3 =	25.07874	in	c3 =	25.07874	in	c3 =	25.07874	in
c4 =	25.47244094	in	c4 =	25.47244094	in	c4 =	25.47244	in	c4 =	25.47244	in	c4 =	25.47244	in
c5 =	23.7007874	in	c5 =	23.7007874	in	c5 =	23.70079	in	c5 =	23.70079	in	c5 =	23.70079	in
c6 =	21.06299213	in	c6 =	21.06299213	in	c6 =	21.06299	in	c6 =	21.06299	in	c6 =	21.06299	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	731.2533438	lbs	G =	659.9559256	lbs	G =	592.3147	lbs	G =	528.3305	lbs	G =	468.0021	lbs
E =	2522175.773	in-lbs	E =	2522296.365	in-lbs	E =	2522418	in-lbs	E =	2522540	in-lbs	E =	2522664	in-lbs
E=	210181.3144	ft-lbs	E=	210191.3637	ft-lbs	E=	210201.5	ft-lbs	E=	210211.7	ft-lbs	E=	210222	ft-lbs
w = (weight of	5200.704765	lbs	w = (weigh	5200.704765	lbs	w = (weight	5200.705	lbs	w = (weight	5200.705	lbs	w = (weigh	5200.705	lbs
v =	51.01629149	ft/sec	v =	51.01751108	ft/sec	v =	51.01875	ft/sec	v =	51.01998	ft/sec	v =	51.02122	ft/sec
v =	34.61812491	mi/hr	v =	34.61895249	mi/hr	v =	34.61979	mi/hr	v =	34.62063	mi/hr	v =	34.62147	mi/hr
bo= 5.0 mph			bo= 4.75 mph			bo= 4.5 mph			bo= 4.25 mph			bo= 4.0 mph		

55.9 km/h is equal to **34.7346774** mph **A average** 374.096 lb/in **B average** 91.75556 lb/in*2 **v average =** 34.61775 mi/hr

A =	382.9036	lb/in	A =	397.7358	lb/in	A =	412.2589	lb/in	A =	426.4728	lb/in	A =	440.3774	lb/in
B =	90.929	lb/in*2	B =	89.3936	lb/in*2	B =	87.8712	lb/in*2	B =	86.3619	lb/in*2	B =	84.8657	lb/in*2
W (width of cru	71.26771654	in	W (width o	71.26771654	in	W (width of	71.26772	in	W (width of	71.26772	in	W (width o	71.26772	in
c1 =	20.23622047	in	c1 =	20.23622047	in	c1 =	20.23622	in	c1 =	20.23622	in	c1 =	20.23622	in
c2 =	23.34645669	in	c2 =	23.34645669	in	c2 =	23.34646	in	c2 =	23.34646	in	c2 =	23.34646	in
c3 =	25.07874016	in	c3 =	25.07874016	in	c3 =	25.07874	in	c3 =	25.07874	in	c3 =	25.07874	in
c4 =	25.47244094	in	c4 =	25.47244094	in	c4 =	25.47244	in	c4 =	25.47244	in	c4 =	25.47244	in
c5 =	23.7007874	in	c5 =	23.7007874	in	c5 =	23.70079	in	c5 =	23.70079	in	c5 =	23.70079	in
c6 =	21.06299213	in	c6 =	21.06299213	in	c6 =	21.06299	in	c6 =	21.06299	in	c6 =	21.06299	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	806.2068586	lbs	G =	884.8159522	lbs	G =	967.0825	lbs	G =	1053.005	lbs	G =	1142.583	lbs
E =	2522056.695	in-lbs	E =	2521938.925	in-lbs	E =	2521821	in-lbs	E =	2521704	in-lbs	E =	2521589	in-lbs
E=	210171.3912	ft-lbs	E=	210161.5771	ft-lbs	E=	210151.7	ft-lbs	E=	210142	ft-lbs	E=	210132.4	ft-lbs
w = (weight of	5200.704765	lbs	w = (weigh	5200.704765	lbs	w = (weight	5200.705	lbs	w = (weight	5200.705	lbs	w = (weigh	5200.705	lbs
v =	51.01508717	ft/sec	v =	51.01389606	ft/sec	v =	51.0127	ft/sec	v =	51.01152	ft/sec	v =	51.01036	ft/sec
v =	34.6173077	mi/hr	v =	34.61649945	mi/hr	v =	34.61569	mi/hr	v =	34.61489	mi/hr	v =	34.6141	mi/hr
bo= 5.25 mph			bo= 5.5 mph			bo= 5.75 mph			bo= 6.0 mph			bo= 6.25 mph		

2001 Dodge Ram Wagon Van	case #19

A =	461.0527	lb/in	A =	441.6857	lb/in	A =	421.9308	lb/in	A =	401.7879	lb/in	A =	381.257	lb/in
B =	154.4614	lb/in*2	B =	157.0718	lb/in*2	B =	159.7042	lb/in*2	B =	162.3583	lb/in*2	B =	165.0344	lb/in*2
W (width of cru	70.08661417	in	W (width o	70.08661417	in	W (width of	70.08661	in	W (width of	70.08661	in	W (width o	70.08661	in
c1 =	12.48031496	in	c1 =	12.48031496	in	c1 =	12.48031	in	c1 =	12.48031	in	c1 =	12.48031	in
c2 =	17.32283465	in	c2 =	17.32283465	in	c2 =	17.32283	in	c2 =	17.32283	in	c2 =	17.32283	in
c3 =	20	in	c3 =	20	in	c3 =	20	in	c3 =	20	in	c3 =	20	in
c4 =	20.23622047	in	c4 =	20.23622047	in	c4 =	20.23622	in	c4 =	20.23622	in	c4 =	20.23622	in
c5 =	17.83464567	in	c5 =	17.83464567	in	c5 =	17.83465	in	c5 =	17.83465	in	c5 =	17.83465	in
c6 =	14.09448819	in	c6 =	14.09448819	in	c6 =	14.09449	in	c6 =	14.09449	in	c6 =	14.09449	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	688.0993963	lbs	G =	621.0098108	lbs	G =	557.3604	lbs	G =	497.152	lbs	G =	440.3836	lbs
E =	2349625.505	in-lbs	E =	2350056.769	in-lbs	E =	2350493	in-lbs	E =	2350931	in-lbs	E =	2351374	in-lbs
E=	195802.1254	ft-lbs	E=	195838.0641	ft-lbs	E=	195874.4	ft-lbs	E=	195910.9	ft-lbs	E=	195947.8	ft-lbs
w = (weight of	4812.691183	lbs	w = (weigh	4812.691183	lbs	w = (weight	4812.691	lbs	w = (weight	4812.691	lbs	w = (weigh	4812.691	lbs
v =	51.18675957	ft/sec	v =	51.19145692	ft/sec	v =	51.19621	ft/sec	v =	51.20098	ft/sec	v =	51.2058	ft/sec
v =	34.73379944	mi/hr	v =	34.73698692	mi/hr	v =	34.74021	mi/hr	v =	34.74345	mi/hr	v =	34.74672	mi/hr
bo= 5.0 mph			bo= 4.75 mph			bo= 4.5 mph			bo= 4.25 mph			bo= 4.0 mph		

55.86 km/h is equal to **34.7098226** mph **A average** 468.9903 lb/in **B average** 153.2546 lb/in*2 **v average =** 34.73232 mi/hr

A =	480.0317	lb/in	A =	498.6228	lb/in	A =	516.8259	lb/in	A =	534.6406	lb/in	A =	552.0678	lb/in
B =	151.8728	lb/in*2	B =	149.3062	lb/in*2	B =	146.7613	lb/in*2	B =	144.2382	lb/in*2	B =	141.7371	lb/in*2
W (width of cru	70.08661417	in	W (width o	70.08661417	in	W (width of	70.08661	in	W (width of	70.08661	in	W (width o	70.08661	in
c1 =	12.48031496	in	c1 =	12.48031496	in	c1 =	12.48031	in	c1 =	12.48031	in	c1 =	12.48031	in
c2 =	17.32283465	in	c2 =	17.32283465	in	c2 =	17.32283	in	c2 =	17.32283	in	c2 =	17.32283	in
c3 =	20	in	c3 =	20	in	c3 =	20	in	c3 =	20	in	c3 =	20	in
c4 =	20.23622047	in	c4 =	20.23622047	in	c4 =	20.23622	in	c4 =	20.23622	in	c4 =	20.23622	in
c5 =	17.83464567	in	c5 =	17.83464567	in	c5 =	17.83465	in	c5 =	17.83465	in	c5 =	17.83465	in
c6 =	14.09448819	in	c6 =	14.09448819	in	c6 =	14.09449	in	c6 =	14.09449	in	c6 =	14.09449	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	758.6296987	lbs	G =	832.6000417	lbs	G =	910.0117	lbs	G =	990.8629	lbs	G =	1075.156	lbs
E =	2349196.999	in-lbs	E =	2348773.565	in-lbs	E =	2348352	in-lbs	E =	2347932	in-lbs	E =	2347518	in-lbs
E=	195766.4166	ft-lbs	E=	195731.1304	ft-lbs	E=	195696	ft-lbs	E=	195661	ft-lbs	E=	195626.5	ft-lbs
w = (weight of	4812.691183	lbs	w = (weigh	4812.691183	lbs	w = (weight	4812.691	lbs	w = (weight	4812.691	lbs	w = (weigh	4812.691	lbs
v =	51.18209184	ft/sec	v =	51.17747894	ft/sec	v =	51.17288	ft/sec	v =	51.16831	ft/sec	v =	51.1638	ft/sec
v =	34.73063206	mi/hr	v =	34.72750189	mi/hr	v =	34.72438	mi/hr	v =	34.72128	mi/hr	v =	34.71822	mi/hr
bo= 5.25 mph			bo= 5.5 mph			bo= 5.75 mph			bo= 6.0 mph			bo= 6.25 mph		

2001 Dodge Caravan **case #20**

A =	482.3483	lb/in
B =	179.0299	lb/in*2
W (width of cru	66.2992126	in
c1 =	12.4015748	in
c2 =	15.59055118	in
c3 =	16.25984252	in
c4 =	16.77165354	in
c5 =	17.55905512	in
c6 =	14.48818898	in
θ =	0	degrees
G =	649.7794014	lbs
E =	2066223.659	in-lbs
E=	172185.3049	ft-lbs
w = (weight of	4299.014113	lbs
v =	50.78746549	ft/sec
v =	34.46285046	mi/hr
bo= 5.0 mph	difference -0.091629184	

A =	462.1032	lb/in
B =	182.0715	lb/in*2
W (width o	66.2992126	in
c1 =	12.4015748	in
c2 =	15.59055118	in
c3 =	16.25984252	in
c4 =	16.77165354	in
c5 =	17.55905512	in
c6 =	14.48818898	in
θ =	0	degrees
G =	586.4162361	lbs
E =	2066366.989	in-lbs
E=	172197.2491	ft-lbs
w = (weigh	4299.014113	lbs
v =	50.78922698	ft/sec
v =	34.46404575	mi/hr
bo= 4.75 mph		

A =	441.4541	lb/in
B =	185.1387	lb/in*2
W (width of	66.29921	in
c1 =	12.40157	in
c2 =	15.59055	in
c3 =	16.25984	in
c4 =	16.77165	in
c5 =	17.55906	in
c6 =	14.48819	in
θ =	0	degrees
G =	526.3128	lbs
E =	2066516	in-lbs
E=	172209.7	ft-lbs
w = (weight	4299.014	lbs
v =	50.79106	ft/sec
v =	34.46529	mi/hr
bo= 4.5 mph		

A =	420.3969	lb/in
B =	188.2316	lb/in*2
W (width of	66.29921	in
c1 =	12.40157	in
c2 =	15.59055	in
c3 =	16.25984	in
c4 =	16.77165	in
c5 =	17.55906	in
c6 =	14.48819	in
θ =	0	degrees
G =	469.4577	lbs
E =	2066668	in-lbs
E=	172222.3	ft-lbs
w = (weight	4299.014	lbs
v =	50.79292	ft/sec
v =	34.46655	mi/hr
bo= 4.25 mph		

A =	398.9318	lb/in
B =	191.3501	lb/in*2
W (width o	66.29921	in
c1 =	12.40157	in
c2 =	15.59055	in
c3 =	16.25984	in
c4 =	16.77165	in
c5 =	17.55906	in
c6 =	14.48819	in
θ =	0	degrees
G =	415.8518	lbs
E =	2066820	in-lbs
E=	172235	ft-lbs
w = (weigh	4299.014	lbs
v =	50.79479	ft/sec
v =	34.46782	mi/hr
bo= 4.0 mph		

55.61 km/h is equal to **34.5544796** mph

A average 490.6292 lb/in **B average** 177.6244 lb/in*2 **v average =** 34.46224 mi/hr

A =	502.1773	lb/in
B =	176.0139	lb/in*2
W (width of cru	66.2992126	in
c1 =	12.4015748	in
c2 =	15.59055118	in
c3 =	16.25984252	in
c4 =	16.77165354	in
c5 =	17.55905512	in
c6 =	14.48818898	in
θ =	0	degrees
G =	716.3696749	lbs
E =	2066071.426	in-lbs
E=	172172.6188	ft-lbs
w = (weight of	4299.014113	lbs
v =	50.78559453	ft/sec
v =	34.46158088	mi/hr
bo= 5.25 mph		

A =	521.6024	lb/in
B =	173.0235	lb/in*2
W (width o	66.2992126	in
c1 =	12.4015748	in
c2 =	15.59055118	in
c3 =	16.25984252	in
c4 =	16.77165354	in
c5 =	17.55905512	in
c6 =	14.48818898	in
θ =	0	degrees
G =	786.219975	lbs
E =	2065925.353	in-lbs
E=	172160.4461	ft-lbs
w = (weigh	4299.014113	lbs
v =	50.78379921	ft/sec
v =	34.46036263	mi/hr
bo= 5.5 mph		

A =	540.6195	lb/in
B =	170.0587	lb/in*2
W (width of	66.29921	in
c1 =	12.40157	in
c2 =	15.59055	in
c3 =	16.25984	in
c4 =	16.77165	in
c5 =	17.55906	in
c6 =	14.48819	in
θ =	0	degrees
G =	859.3193	lbs
E =	2065780	in-lbs
E=	172148.4	ft-lbs
w = (weight	4299.014	lbs
v =	50.78202	ft/sec
v =	34.45915	mi/hr
bo= 5.75 mph		

A =	559.2285	lb/in
B =	167.1196	lb/in*2
W (width of	66.29921	in
c1 =	12.40157	in
c2 =	15.59055	in
c3 =	16.25984	in
c4 =	16.77165	in
c5 =	17.55906	in
c6 =	14.48819	in
θ =	0	degrees
G =	935.6668	lbs
E =	2065637	in-lbs
E=	172136.4	ft-lbs
w = (weight	4299.014	lbs
v =	50.78026	ft/sec
v =	34.45796	mi/hr
bo= 6.0 mph		

A =	577.4295	lb/in
B =	164.2061	lb/in*2
W (width o	66.29921	in
c1 =	12.40157	in
c2 =	15.59055	in
c3 =	16.25984	in
c4 =	16.77165	in
c5 =	17.55906	in
c6 =	14.48819	in
θ =	0	degrees
G =	1015.263	lbs
E =	2065495	in-lbs
E=	172124.6	ft-lbs
w = (weigh	4299.014	lbs
v =	50.77851	ft/sec
v =	34.45677	mi/hr
bo= 6.25 mph		

APPENDIX 5

EBS DETERMINATIONS FOR THE “WITHIN” SUBJECTS DESIGN

WITHIN SUBJECTS DESIGN--1998 FORD CONTOUR									**56.3 km/h**	**=**	**34.9832261095204 mph**			
CASE #1			**CASE #2**			**CASE #3**			**CASE #4**			**CASE #5**		
A =	354	lb/in	A =	354	lb/in	A =	354	lb/in	A =	354	lb/in	A =	354	lb/in
B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2
W (width)=	66.726	in	W (width)=	67.147	in	W (width)=	66.777	in	W (width)=	66.608	in	W (width)=	66.985	in
c1 =	4.038	in	c1 =	3.888	in	c1 =	4.149	in	c1 =	4.293	in	c1 =	4.091	in
c2 =	9.374	in	c2 =	8.792	in	c2 =	7.965	in	c2 =	9.336	in	c2 =	9.044	in
c3 =	16.091	in	c3 =	15.172	in	c3 =	16.071	in	c3 =	17.339	in	c3 =	16.941	in
c4 =	17.399	in	c4 =	17.449	in	c4 =	17.879	in	c4 =	17.879	in	c4 =	17.566	in
c5 =	17.255	in	c5 =	17.335	in	c5 =	18.669	in	c5 =	18.564	in	c5 =	17.257	in
c6 =	7.901	in	c6 =	8.128	in	c6 =	9.714	in	c6 =	9.512	in	c6 =	9.095	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	336.87097	lbs	G =	336.871	lbs	G =	336.87	lbs	G =	336.871	lbs	G =	336.871	lbs
E =	1525509.2	in-lbs	E =	1488560	in-lbs	E =	2E+06	in-lbs	E =	1687990	in-lbs	E =	1587167	in-lbs
E=	127125.76	ft-lbs	E=	124047	ft-lbs	E=	133874	ft-lbs	E=	140665.8	ft-lbs	E=	132264	ft-lbs
w = (weight)	3310	lbs	w = (weight)	3310	lbs	w = (weight)	3310	lbs	w = (weight)	3310	lbs	w = (weight)	3310	lbs
v =	49.733122	ft/sec	v =	49.1271	ft/sec	v =	51.036	ft/sec	v =	52.31464	ft/sec	v =	50.72823	ft/sec
v =	33.747405	mi/hr	v =	33.3362	mi/hr	v =	34.631	mi/hr	v =	35.49914	mi/hr	v =	34.42265	mi/hr
CASE #6			**CASE #7**			**CASE #8**			**CASE #9**			**CASE #10**		
A =	354	lb/in	A =	354	lb/in	A =	354	lb/in	A =	354	lb/in	A =	354	lb/in
B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2
W (width)=	66.873	in	W (width)=	67.385	in	W (width)=	67.063	in	W (width)=	67.199	in	W (width)=	67.09	in
c1 =	4.14	in	c1 =	3.759	in	c1 =	3.986	in	c1 =	3.967	in	c1 =	3.971	in
c2 =	9.111	in	c2 =	8.728	in	c2 =	8.849	in	c2 =	8.798	in	c2 =	8.905	in
c3 =	18.086	in	c3 =	16.782	in	c3 =	16.995	in	c3 =	16.037	in	c3 =	16.554	in
c4 =	17.644	in	c4 =	17.169	in	c4 =	17.353	in	c4 =	17.299	in	c4 =	17.5	in
c5 =	17.518	in	c5 =	17.096	in	c5 =	17.261	in	c5 =	17.222	in	c5 =	18.161	in
c6 =	9.261	in	c6 =	8.656	in	c6 =	8.852	in	c6 =	8.765	in	c6 =	8.998	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	336.87097	lbs	G =	336.871	lbs	G =	336.87	lbs	G =	336.871	lbs	G =	336.871	lbs
E =	1656541.7	in-lbs	E =	1543935	in-lbs	E =	2E+06	in-lbs	E =	1525121	in-lbs	E =	1603759	in-lbs
E=	138045.14	ft-lbs	E=	128661	ft-lbs	E=	130890	ft-lbs	E=	127093.4	ft-lbs	E=	133646.6	ft-lbs
w = (weight)	3310	lbs	w = (weight)	3310	lbs	w = (weight)	3310	lbs	w = (weight)	3310	lbs	w = (weight)	3310	lbs
v =	51.825023	ft/sec	v =	50.0326	ft/sec	v =	50.464	ft/sec	v =	49.72679	ft/sec	v =	50.99268	ft/sec
v =	35.166906	mi/hr	v =	33.9506	mi/hr	v =	34.243	mi/hr	v =	33.74311	mi/hr	v =	34.6021	mi/hr

WITHIN SUBJECTS DESIGN--1998 FORD CONTOUR									56.3 km/h	=	34.9832261095204 mph			
CASE #11			**CASE #12**			**CASE #13**			**CASE #14**			**CASE #15**		
A =	354	lb/in	A =	354	lb/in	A =	354	lb/in	A =	354	lb/in	A =	354	lb/in
B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2
W (width)=	66.864	in	W (width)=	67.138	in	W (width)=	66.796	in	W (width)=	66.876	in	W (width)=	66.962	in
c1 =	4.078	in	c1 =	4.017	in	c1 =	4.185	in	c1 =	4.064	in	c1 =	3.981	in
c2 =	9.153	in	c2 =	8.94	in	c2 =	9.213	in	c2 =	9.007	in	c2 =	9.104	in
c3 =	17.22	in	c3 =	16.084	in	c3 =	17.717	in	c3 =	16.883	in	c3 =	17.02	in
c4 =	17.667	in	c4 =	17.468	in	c4 =	17.724	in	c4 =	17.618	in	c4 =	17.549	in
c5 =	17.556	in	c5 =	17.288	in	c5 =	18.323	in	c5 =	18.192	in	c5 =	17.98	in
c6 =	9.288	in	c6 =	9.072	in	c6 =	9.397	in	c6 =	8.986	in	c6 =	8.974	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degree	θ =	0	degree	θ =	0	degrees
G =	336.87097	lbs	G =	336.871	lbs	G =	336.87	lbs	G =	336.871	lbs	G =	336.871	lbs
E =	1621168	in-lbs	E =	1546342	in-lbs	E =	2E+06	in-lbs	E =	1623608	in-lbs	E =	1620430	in-lbs
E=	135097.33	ft-lbs	E=	128862	ft-lbs	E=	140353	ft-lbs	E=	135300.6	ft-lbs	E=	135035.8	ft-lbs
w= (weight)	3310	lbs	w= (weight)	3310	lbs	w= (weight)	3310	lbs	w= (weight)	3310	lbs	w= (weight)	3310	lbs
v =	51.268702	ft/sec	v =	50.0716	ft/sec	v =	52.256	ft/sec	v =	51.30726	ft/sec	v =	51.25703	ft/sec
v =	34.789403	mi/hr	v =	33.9771	mi/hr	v =	35.46	mi/hr	v =	34.81557	mi/hr	v =	34.78148	mi/hr

CASE #16			**CASE #17**			**CASE #18**			**CASE #19**			**CASE #20**		
A =	354	lb/in	A =	354	lb/in	A =	354	lb/in	A =	354	lb/in	A =	354	lb/in
B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2	B =	186	lb/in^2
W (width)=	66.566	in	W (width)=	63.601	in	W (width)=	63.239	in	W (width)=	62.627	in	W (width)=	63.015	in
c1 =	5.179	in	c1 =	5.35	in	c1 =	5.564	in	c1 =	5.005	in	c1 =	4.878	in
c2 =	11.93	in	c2 =	10.303	in	c2 =	10.845	in	c2 =	10.165	in	c2 =	10.527	in
c3 =	18.274	in	c3 =	17.432	in	c3 =	18.436	in	c3 =	18.128	in	c3 =	17.791	in
c4 =	19.344	in	c4 =	19.407	in	c4 =	19.631	in	c4 =	18.416	in	c4 =	19.306	in
c5 =	19.222	in	c5 =	19.373	in	c5 =	20.162	in	c5 =	18.157	in	c5 =	19.868	in
c6 =	12.803	in	c6 =	10.885	in	c6 =	10.116	in	c6 =	9.639	in	c6 =	11.485	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degree	θ =	0	degree	θ =	0	degrees
G =	336.87097	lbs	G =	336.871	lbs	G =	336.87	lbs	G =	336.871	lbs	G =	336.871	lbs
E =	1990970.6	in-lbs	E =	1789259	in-lbs	E =	2E+06	in-lbs	E =	1660541	in-lbs	E =	1819705	in-lbs
E=	165914.21	ft-lbs	E=	149105	ft-lbs	E=	156397	ft-lbs	E=	138378.4	ft-lbs	E=	151642.1	ft-lbs
w= (weight)	3310	lbs	w= (weight)	3310	lbs	w= (weight)	3310	lbs	w= (weight)	3310	lbs	w= (weight)	3310	lbs
v =	56.81601	ft/sec	v =	53.8611	ft/sec	v =	55.162	ft/sec	v =	51.88754	ft/sec	v =	54.31738	ft/sec
v =	38.55364	mi/hr	v =	36.5485	mi/hr	v =	37.432	mi/hr	v =	35.20933	mi/hr	v =	36.85815	mi/hr

APPENDIX 6

EBS DETERMINATIONS FOR THE "BETWEEN" SUBJECTS DESIGN

Between Subjects Design-----Using Various Models														
2002 Cadillac DeVille		case #1	2003 Mercedes E320		case #2	2001 Buick LeSabre		case #3	2003 Toyota Avalon		case #4	2002 Audi A4		case #5
A =	391.22855	lb/in	A =	368.90273	lb/in	A =	360.1776	lb/in	A =	384.91497	lb/in	A =	425.56978	lb/in
B =	109.60545	lb/in^2	B =	108.88369	lb/in^2	B =	102.1116	lb/in^2	B =	118.64122	lb/in^2	B =	149.56229	lb/in^2
W (width of	70.935	in	W (width c	70.088	in	W (width of	70.301	in	W (width of	65.971	in	W (width of	66.017	in
c1 =	15.684	in	c1 =	17.142	in	c1 =	18.489	in	c1 =	15.445	in	c1 =	12.025	in
c2 =	17.07	in	c2 =	18.621	in	c2 =	20.557	in	c2 =	16.065	in	c2 =	18.162	in
c3 =	19.254	in	c3 =	19.126	in	c3 =	22.23	in	c3 =	20.026	in	c3 =	18.831	in
c4 =	21.119	in	c4 =	19.839	in	c4 =	21.49	in	c4 =	20.087	in	c4 =	18.701	in
c5 =	21.349	in	c5 =	18.018	in	c5 =	20.034	in	c5 =	15.46	in	c5 =	16.803	in
c6 =	20.147	in	c6 =	17.616	in	c6 =	16.578	in	c6 =	14.61	in	c6 =	8.965	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	698.2306917	lbs	G =	624.9293361	lbs	G =	635.2261	lbs	G =	624.4016	lbs	G =	605.46558	lbs
E =	2054101.75	in-lbs	E =	1846235.645	in-lbs	E =	2056903	in-lbs	E =	1672004.5	in-lbs	E =	1900287.5	in-lbs
E=	171175.1458	ft-lbs	E=	153852.9704	ft-lbs	E=	171408.6	ft-lbs	E=	139333.7	ft-lbs	E=	158357.29	ft-lbs
w = (weigh	4508.453262	lbs	w = (weig	4265.944773	lbs	w = (weight	4102.803	lbs	w = (weight	3862.4988	lbs	w = (weight	4012.4132	lbs
v =	49.44808772	ft/sec	v =	48.19347719	ft/sec	v =	51.87031	ft/sec	v =	48.198869	ft/sec	v =	50.414927	ft/sec
v =	**33.55398888**	mi/hr	v =	**32.70264782**	mi/hr	v =	**35.19764**	mi/hr	v =	**32.706306**	mi/hr	v =	**34.210057**	mi/hr

2003 Hyundai Accent		case #6	2001 Chevy Malibu		case #7	2003 Honda S2000		case #8	2002 Mini Cooper		case #9	2003 Toyota Corolla		case #10
A =	325.15176	lb/in	A =	345.46882	lb/in	A =	437.046	lb/in	A =	557.569	lb/in	A =	278.49701	lb/in
B =	102.2357	lb/in^2	B =	101.95357	lb/in^2	B =	171.437	lb/in^2	B =	285.702	lb/in^2	B =	79.30638	lb/in^2
W (width	57.173	in	W (width	61.338	in	W (width c	64.218	in	W (width c	58.425	in	W (width c	59.993	in
c1 =	11.896	in	c1 =	22.67	in	c1 =	12.51	in	c1 =	7.434	in	c1 =	14.593	in
c2 =	18.695	in	c2 =	24.821	in	c2 =	16.543	in	c2 =	11.563	in	c2 =	19.252	in
c3 =	19.757	in	c3 =	25.071	in	c3 =	16.315	in	c3 =	15.588	in	c3 =	20.375	in
c4 =	18.34	in	c4 =	20.667	in	c4 =	12.301	in	c4 =	12.127	in	c4 =	22.053	in
c5 =	18.872	in	c5 =	16.548	in	c5 =	13.549	in	c5 =	11.851	in	c5 =	21.267	in
c6 =	16.219	in	c6 =	6.827	in	c6 =	10.287	in	c6 =	10.887	in	c6 =	20.399	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	517.05846	lbs	G =	585.309105	lbs	G =	557.084	lbs	G =	544.069	lbs	G =	488.99335	lbs
E =	1313086.8	in-lbs	E =	1845419.17	in-lbs	E =	1528540	in-lbs	E =	1665460	in-lbs	E =	1332912.1	in-lbs
E=	109423.9	ft-lbs	E=	153784.931	ft-lbs	E=	127378	ft-lbs	E=	138788	ft-lbs	E=	111076	ft-lbs
w = (weig	2914.5111	lbs	w = (wei	3545.03318	lbs	w = (weigh	3229.77	lbs	w = (weigh	3095.29	lbs	w = (weigh	2976.2405	lbs
v =	49.171808	ft/sec	v =	52.8554376	ft/sec	v =	50.397	ft/sec	v =	53.7364	ft/sec	v =	49.025163	ft/sec
v =	**33.366514**	mi/hr	v =	**35.8661143**	mi/hr	v =	**34.1979**	mi/hr	v =	**36.4639**	mi/hr	v =	33.267005	mi/hr

2002 Chrysler PT Cruiser		case #11	2002 Ford Explorer Spt		case #12	2002 Nissan Pathfdr		case #13	2002 Toyota Highldr		case #14	2003 Subaru Forester		case #15
A =	487.37757	lb/in	A =	577.3843	lb/in	A =	406.512	lb/in	A =	424.084	lb/in	A =	396.79779	lb/in
B =	183.379	lb/in*2	B =	226.37027	lb/in*2	B =	109.969	lb/in*2	B =	133.258	lb/in*2	B =	127.71167	lb/in*2
W (width c	66.903	in	W (width	62.313	in	W (width c	61.163	in	W (width c	69.39	in	W (width c	67.924	in
c1 =	13.631	in	c1 =	12.96	in	c1 =	16.98	in	c1 =	4.994	in	c1 =	15.763	in
c2 =	11.59	in	c2 =	15.249	in	c2 =	27.44	in	c2 =	16.132	in	c2 =	16.169	in
c3 =	15.659	in	c3 =	16.19	in	c3 =	27.873	in	c3 =	16.305	in	c3 =	16.479	in
c4 =	13.537	in	c4 =	17.446	in	c4 =	21.03	in	c4 =	21.242	in	c4 =	16.819	in
c5 =	13.031	in	c5 =	16.306	in	c5 =	25.835	in	c5 =	20.838	in	c5 =	19.231	in
c6 =	12.584	in	c6 =	14.023	in	c6 =	9.429	in	c6 =	17.863	in	c6 =	15.123	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	647.66657	lbs	G =	736.343668	lbs	G =	751.356	lbs	G =	674.808	lbs	G =	616.42169	lbs
E =	1584425.7	in-lbs	E =	2367994.79	in-lbs	E =	2471661	in-lbs	E =	1992659	in-lbs	E =	1727619.1	in-lbs
E=	132035.47	ft-lbs	E=	197332.899	ft-lbs	E=	205972	ft-lbs	E=	166055	ft-lbs	E=	143968.26	ft-lbs
w = (weigh	3723.6076	lbs	w = (wei	4572.38732	lbs	w = (weigh	4720.1	lbs	w = (weigh	4455.54	lbs	w = (weigh	3615.5811	lbs
v =	47.786617	ft/sec	v =	52.719487	ft/sec	v =	53.0117	ft/sec	v =	48.9912	ft/sec	v =	50.639249	ft/sec
v =	**32.426565**	mi/hr	v =	**35.7738623**	mi/hr	v =	**35.9721**	mi/hr	v =	**33.244**	mi/hr	v =	**34.362275**	mi/hr

2002 Dodge Ram 1500		case #16	2001 Nissan Frontier		case #17	2003 Chevy Silverado		case #18	01 Dodge Ram Wagon V		case #19	2001 Dodge Caravan		case #20
A =	520.19252	lb/in	A =	434.13947	lb/in	A =	374.096	lb/in	A =	468.9903	lb/in	A =	490.62915	lb/in
B =	169.96174	lb/in*2	B =	126.4965	lb/in*2	B =	91.75556	lb/in*2	B =	153.2546	lb/in*2	B =	177.62436	lb/in*2
W (width of	75.441	in	W (width c	59.114	in	W (width of	63.216	in	W (width of	68.947	in	W (width of	66.771	in
c1 =	14.924	in	c1 =	16.943	in	c1 =	23.045	in	c1 =	11.296	in	c1 =	13.209	in
c2 =	22.356	in	c2 =	16.34	in	c2 =	28.999	in	c2 =	14.495	in	c2 =	18.65	in
c3 =	19.527	in	c3 =	24.804	in	c3 =	30.226	in	c3 =	18.73	in	c3 =	19.543	in
c4 =	20.137	in	c4 =	24.259	in	c4 =	30.027	in	c4 =	12.315	in	c4 =	17.956	in
c5 =	13.348	in	c5 =	20.848	in	c5 =	24.911	in	c5 =	28.105	in	c5 =	13.865	in
c6 =	11.513	in	c6 =	12.451	in	c6 =	18.412	in	c6 =	20.757	in	c6 =	4.388	in
θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees	θ =	0	degrees
G =	796.0622722	lbs	G =	744.9893057	lbs	G =	762.6123	lbs	G =	717.603	lbs	G =	677.601211	lbs
E =	2837086.734	in-lbs	E =	2133006.34	in-lbs	E =	2829007	in-lbs	E =	2446384	in-lbs	E =	2124822.91	in-lbs
E=	236423.8945	ft-lbs	E=	177750.5283	ft-lbs	E=	235750.6	ft-lbs	E=	203865.3	ft-lbs	E=	177068.576	ft-lbs
w = (weigh	5551.239762	lbs	w = (weig	4521.680997	lbs	w = (weight	5200.705	lbs	w = (weight	4812.691	lbs	w = (weight	4299.01411	lbs
v =	52.37133258	ft/sec	v =	50.3151097	ft/sec	v =	54.0304	ft/sec	v =	52.23007	ft/sec	v =	51.5026108	ft/sec
v =	**35.53761515**	mi/hr	v =	**34.14232399**	mi/hr	v =	**36.66341**	mi/hr	v =	**35.44176**	mi/hr	v =	34.9481266	mi/hr

APPENDIX 7
"WITHIN" BOOTSTRAP DATA"

The Actual Within		Bootstrap Sample									
Differences (Seed Data)		1	2	3	4	5	6	7	8	9	10
-1.23582145		-0.19382	1.874921	0.226101	0.515916	1.565276	0.476458	-0.73981	0.515916	-0.73981	-0.73981
-1.647020556		-1.64702	0.226101	0.515916	1.874921	0.226101	0.226101	-0.35175	-0.16766	-0.73981	-0.16766
-0.351750929		-0.38112	2.448286	-1.23582	3.570414	0.18368	-0.16766	-1.23582	-1.64702	1.565276	1.874921
0.515916268		-1.24012	2.448286	-1.00617	-0.38112	-1.00617	-0.73981	1.874921	-0.38112	-0.16766	2.448286
-0.560572586		-0.19382	-1.03263	1.874921	-0.56057	-0.16766	-1.24012	0.476458	-0.35175	-0.16766	1.874921
0.183679795		0.515916	3.570414	0.226101	0.226101	-0.20174	-0.56057	1.874921	2.448286	-0.73981	-1.03263
-1.032627733		-0.35175	0.476458	-0.56057	-1.03263	0.226101	0.515916	0.226101	3.570414	-0.73981	-0.19382
-0.73981005		0.18368	3.570414	0.515916	2.448286	0.515916	-0.38112	-1.23582	-1.24012	-0.19382	-0.73981
-1.240118814		1.565276	-0.73981	-1.00617	-0.35175	0.226101	3.570414	-1.00617	-0.56057	1.874921	0.476458
-0.381123119		1.565276	0.226101	2.448286	-1.23582	-0.56057	0.226101	-0.38112	-1.03263	1.874921	-1.00617
-0.193823157		-1.64702	1.874921	-1.24012	0.18368	0.476458	0.476458	-1.00617	-0.35175	-0.20174	-1.03263
-1.006171272		-0.73981	-0.16766	0.515916	3.570414	0.515916	-0.73981	-0.16766	-0.73981	1.565276	-0.56057
0.476458007		-1.64702	-1.24012	2.448286	0.18368	-0.73981	-0.19382	0.18368	1.874921	1.874921	-1.03263
-0.167657171		-0.56057	0.515916	3.570414	-1.03263	-1.23582	-1.24012	0.226101	-0.56057	0.476458	-1.24012
-0.201743692		-0.56057	-0.56057	-0.16766	3.570414	-1.00617	2.448286	-1.23582	0.476458	0.226101	1.565276
3.570413842		0.476458	-0.35175	-1.03263	-1.23582	0.226101	0.18368	-1.23582	0.476458	1.565276	-0.73981
1.565275502		-0.73981	2.448286	-0.38112	-0.16766	-0.38112	0.515916	0.18368	-1.24012	-1.64702	-1.00617
2.448286293		-1.23582	-0.19382	-0.73981	0.476458	-1.23582	-1.24012	-1.03263	0.476458	-1.00617	-1.24012
0.226101071		-1.23582	-1.00617	-1.00617	1.565276	0.515916	-0.56057	-0.16766	-0.73981	-1.24012	-1.03263
1.874921215		-0.38112	-0.35175	-1.03263	-0.38112	-0.56057	-1.24012	1.565276	1.565276	0.226101	-0.73981
	mean	-0.42243	0.701791	0.146649	0.590322	-0.12089	0.016774	-0.15926	0.119563	0.183291	-0.21323
	variance	0.884266	2.423431	1.999573	2.620474	0.520561	1.470753	1.023308	1.808811	1.323174	1.406715

		11	12	13	14	15	16	17	18	19	20
		3.570414	1.565276	-0.35175	0.476458	-0.35175	0.476458	-0.19382	-1.00617	-0.20174	-0.16766
		-1.00617	0.515916	0.476458	-1.03263	-1.03263	-1.23582	-0.35175	-1.64702	-0.38112	-1.24012
		-1.23582	2.448286	2.448286	-1.64702	-1.24012	-1.03263	3.570414	0.18368	-0.35175	-1.23582
		-1.64702	-1.23582	-0.73981	-0.16766	0.476458	-0.20174	-0.20174	-0.73981	-0.73981	0.515916
		-0.16766	0.476458	0.18368	0.476458	-1.24012	0.515916	-1.23582	0.18368	-0.35175	3.570414
		0.515916	-1.24012	1.565276	-1.00617	-1.03263	-1.64702	0.18368	-1.24012	-0.16766	-1.00617
		-0.35175	0.226101	-1.03263	-1.24012	-0.35175	-1.00617	-0.20174	1.874921	3.570414	2.448286
		0.515916	-0.20174	-1.03263	2.448286	2.448286	-0.16766	-1.00617	-1.64702	0.476458	-1.03263
		-0.16766	1.874921	-1.64702	1.874921	-1.64702	-0.19382	0.226101	-0.38112	-1.00617	-1.23582
		-1.00617	0.515916	-0.20174	-0.35175	0.476458	-1.00617	-1.64702	2.448286	-0.35175	-0.20174
		0.476458	0.515916	-1.03263	-1.64702	-1.00617	3.570414	1.565276	-0.38112	1.874921	0.18368
		0.18368	-1.03263	0.476458	1.874921	-0.73981	-0.35175	-1.23582	-1.24012	0.515916	-0.20174
		2.448286	-1.00617	-0.20174	-1.64702	-0.20174	1.874921	-1.03263	-1.23582	2.448286	-0.73981
		0.226101	-0.38112	1.565276	0.226101	-0.73981	-0.16766	2.448286	-0.16766	-0.56057	-1.64702
		-1.23582	0.476458	0.226101	1.874921	-0.38112	-1.24012	-0.38112	-0.35175	0.226101	1.874921
		3.570414	-0.56057	-1.23582	-0.73981	3.570414	-0.38112	-1.23582	0.226101	0.476458	-0.16766
		-0.56057	-1.64702	0.515916	-1.00617	1.874921	-0.16766	1.565276	3.570414	-0.73981	-1.00617
		-1.03263	-1.03263	-1.00617	0.515916	-0.20174	-1.64702	0.515916	-0.35175	0.476458	0.515916
		-1.23582	-0.56057	-0.38112	-1.64702	0.18368	3.570414	1.874921	0.18368	0.515916	0.476458
		0.226101	3.570414	0.476458	-0.73981	-1.23582	1.874921	3.570414	-1.03263	-0.56057	-0.19382
	mean	0.10431	0.164363	-0.04646	-0.15521	-0.1186	0.071834	0.339841	-0.13757	0.258411	-0.02453
	variance	2.265645	1.853053	1.117482	1.766093	1.815433	2.364711	2.510927	1.855349	1.342475	1.797738

		21	22	23	24	25	26	27	28	29	30
		-1.00617	-1.03263	-1.23582	2.448286	2.448286	-0.19382	-0.56057	-0.20174	-0.20174	-0.73981
		0.18368	-1.23582	-0.35175	0.476458	-1.24012	0.18368	1.874921	-0.19382	-1.64702	2.448286
		-0.73981	1.874921	-1.03263	-0.20174	-0.19382	0.515916	-1.24012	1.565276	-0.73981	1.565276
		-0.19382	0.515916	-1.64702	-1.23582	3.570414	-0.20174	0.476458	3.570414	1.874921	-0.38112
		-1.00617	0.18368	0.18368	3.570414	0.476458	-0.73981	2.448286	-1.03263	3.570414	2.448286
		-1.03263	0.515916	0.226101	0.18368	-0.56057	-1.64702	2.448286	-1.23582	-1.24012	-1.64702
		1.565276	-0.35175	-0.35175	0.476458	-0.38112	-0.38112	-0.38112	-0.19382	1.565276	1.874921
		0.18368	1.874921	-0.19382	-1.03263	0.515916	1.565276	-0.20174	-0.16766	-0.19382	0.476458
		-0.19382	-1.03263	3.570414	-1.64702	-1.03263	-1.24012	-0.73981	-0.73981	0.18368	2.448286
		1.565276	-0.56057	0.18368	2.448286	-1.03263	-1.03263	-1.23582	-0.20174	1.565276	-1.00617
		2.448286	-0.56057	3.570414	-1.00617	0.476458	-0.16766	-0.19382	-1.23582	3.570414	1.565276
		0.226101	-1.23582	0.476458	0.226101	0.476458	-1.00617	-0.73981	0.226101	1.874921	-0.56057
		-1.24012	-1.64702	0.476458	0.18368	-0.56057	-1.24012	-0.73981	-0.16766	-0.20174	-0.16766
		-0.38112	-1.23582	0.476458	-1.23582	-0.35175	-0.20174	1.565276	0.18368	0.18368	1.565276
		-0.38112	-0.19382	0.226101	-0.20174	3.570414	-1.24012	0.18368	1.565276	0.18368	-1.64702
		1.565276	-1.03263	-0.35175	-1.23582	-0.38112	3.570414	0.476458	3.570414	-1.24012	-1.24012
		-0.35175	-0.19382	0.18368	-1.03263	-1.03263	-1.03263	-0.73981	1.565276	0.476458	1.565276
		-0.35175	0.515916	-0.16766	-1.03263	0.226101	1.565276	-0.38112	-0.73981	-1.23582	1.874921
		-0.20174	3.570414	1.874921	0.18368	-1.24012	-1.24012	-0.73981	-1.23582	0.226101	1.874921
		-1.00617	-1.24012	0.18368	-1.23582	-0.56057	-0.73981	-0.73981	-0.56057	0.515916	-1.03263
	mean	-0.01743	-0.12507	0.314992	-0.04504	0.159642	-0.2452	0.042009	0.216985	0.454527	0.564253
	variance	1.068388	1.745082	1.773052	2.02191	2.086722	1.586405	1.338851	2.066258	2.20643	2.224469

The Actual Within Differences (Seed Data)		Bootstrap Sample									
		31	32	33	34	35	36	37	38	39	40
-1.23582145		0.476458	-1.00617	1.565276	-1.03263	3.570414	0.515916	-1.03263	-1.24012	-1.00617	-1.23582
-1.647020556		0.515916	-1.00617	-1.03263	-0.35175	-0.16766	0.226101	-1.23582	-1.64702	-0.35175	-0.20174
-0.351750929		0.18368	-0.73981	-0.35175	2.448286	-0.73981	-0.56057	-0.16766	-0.73981	-1.64702	-0.38112
0.515916268		0.226101	0.476458	1.565276	0.476458	-1.24012	3.570414	-1.23582	1.565276	0.515916	-1.24012
-0.560572586		-1.24012	3.570414	-1.23582	-1.03263	-0.16766	0.226101	-0.19382	-0.35175	-0.19382	0.515916
0.183679795		-1.03263	-1.03263	3.570414	-0.19382	0.515916	1.874921	-1.03263	-1.03263	-1.03263	1.874921
-1.032627733		1.565276	0.476458	0.515916	-0.56057	0.18368	-1.00617	0.18368	-1.23582	-1.64702	-0.35175
-0.73981005		-0.20174	3.570414	1.874921	-0.73981	1.565276	-0.35175	1.565276	-0.20174	2.448286	-0.73981
-1.240118814		-1.00617	0.226101	-1.23582	-0.20174	0.18368	0.226101	0.226101	0.18368	0.18368	0.515916
-0.381123119		-1.23582	-1.00617	0.476458	-1.03263	3.570414	-0.38112	3.570414	-1.64702	-1.24012	-0.56057
-0.193823157		0.515916	2.448286	3.570414	-0.38112	-1.23582	-1.03263	-1.03263	-0.73981	1.874921	-0.19382
-1.006171272		-1.24012	1.565276	3.570414	0.476458	-0.19382	-0.35175	-0.73981	-1.00617	0.515916	2.448286
0.476458007		-0.16766	0.515916	1.874921	0.476458	-1.00617	0.18368	-1.03263	0.18368	0.226101	3.570414
-0.167657171		-1.23582	-0.19382	-1.23582	-1.64702	-0.56057	2.448286	3.570414	-0.73981	0.226101	-0.73981
-0.201743692		-0.35175	0.476458	-0.20174	-0.35175	1.565276	-1.03263	-0.16766	-0.38112	3.570414	-0.19382
3.570413842		-0.16766	0.18368	1.874921	-1.03263	0.18368	2.448286	-0.19382	-1.00617	0.476458	-0.38112
1.565275502		0.515916	-1.24012	0.476458	0.476458	-1.03263	-0.20174	0.515916	-0.38112	-0.20174	-0.73981
2.448286293		0.476458	3.570414	-0.73981	2.448286	0.476458	-0.16766	-1.00617	-1.23582	1.874921	-1.03263
0.226101071		-0.19382	-0.56057	0.476458	-0.19382	0.18368	-0.19382	-0.73981	-1.03263	-0.56057	0.515916
1.874921215		2.448286	-0.56057	1.874921	0.476458	0.18368	-0.35175	-0.35175	-0.35175	-0.73981	3.570414
	mean	-0.05747	0.486692	0.862669	-0.07365	0.291895	0.30441	-0.02654	-0.65188	0.164603	0.250991
	variance	0.956987	2.623009	2.612008	1.12436	1.865942	1.628076	1.998138	0.54812	1.906925	2.166393

	41	42	43	44	45	46	47	48	49	50
	0.476458	0.515916	0.515916	1.874921	-0.20174	-1.00617	-0.73981	-0.19382	-1.23582	2.448286
	0.515916	-0.16766	-1.03263	-1.00617	1.874921	3.570414	-1.64702	3.570414	-0.19382	0.515916
	1.874921	-0.35175	3.570414	-1.24012	-0.19382	-0.16766	-1.03263	-0.35175	0.476458	1.874921
	-0.19382	1.874921	-0.38112	-0.19382	0.226101	1.874921	-0.56057	1.565276	0.515916	-0.56057
	-0.16766	-1.23582	0.515916	0.226101	-0.16766	-0.73981	-1.03263	-0.16766	0.226101	-1.00617
	-1.03263	-0.38112	-1.00617	1.874921	-1.24012	-1.24012	-1.64702	0.476458	-0.16766	1.874921
	0.18368	-0.16766	-1.23582	-0.35175	-1.64702	0.515916	0.226101	-0.38112	-1.64702	-0.38112
	-1.23582	-1.23582	-1.03263	0.18368	-0.38112	-0.20174	-0.35175	0.226101	0.476458	-0.20174
	-0.16766	0.18368	-1.24012	-0.16766	-1.03263	-1.03263	-0.38112	1.565276	1.874921	0.226101
	-0.38112	2.448286	1.565276	-0.20174	-0.35175	-1.24012	0.476458	-0.16766	3.570414	-0.20174
	1.874921	2.448286	-1.23582	0.515916	-0.16766	0.476458	0.515916	1.565276	-1.03263	-0.56057
	0.476458	0.18368	0.515916	-0.20174	3.570414	-0.20174	-0.19382	2.448286	1.874921	3.570414
	-1.64702	-1.23582	-0.19382	-1.64702	1.874921	-1.24012	-1.24012	-1.00617	0.476458	0.226101
	-0.38112	0.226101	2.448286	-1.64702	2.448286	-0.35175	-0.19382	-0.73981	-1.03263	-0.16766
	-1.03263	-1.64702	0.18368	-1.64702	-0.35175	2.448286	-0.73981	0.226101	-1.64702	1.565276
	3.570414	-0.19382	-0.19382	0.515916	3.570414	-0.35175	0.18368	-0.38112	-1.23582	2.448286
	2.448286	-0.38112	0.476458	0.476458	-0.38112	-1.23582	-0.19382	-1.23582	-0.38112	-1.24012
	3.570414	2.448286	-0.38112	-1.03263	-0.38112	-1.24012	-1.23582	0.226101	3.570414	1.565276
	-0.20174	-1.03263	-0.73981	1.565276	-0.20174	1.565276	0.515916	-1.64702	0.226101	2.448286
	-0.16766	-1.24012	-1.23582	-0.20174	-1.24012	3.570414	-0.20174	-1.03263	-0.56057	1.874921
mean	0.419129	0.05294	-0.00584	-0.11526	0.281284	0.188607	-0.47367	0.228235	0.207702	0.81595
variance	2.241405	1.696476	1.706751	1.164494	2.352757	2.520989	0.463753	1.726566	2.307931	1.92962

	51	52	53	54	55	56	57	58	59	60
	-1.00617	1.874921	-0.16766	-0.35175	1.874921	1.565276	-0.16766	0.226101	1.565276	-0.16766
	0.226101	0.18368	-1.64702	-1.23582	2.448286	-1.23582	0.476458	0.515916	-0.19382	-0.56057
	-0.19382	-0.35175	0.226101	-1.23582	1.874921	-0.73981	-0.56057	0.476458	-1.00617	-0.38112
	-0.38112	3.570414	0.18368	-0.16766	-1.24012	0.476458	-0.38112	-0.56057	-0.38112	0.515916
	-0.19382	3.570414	-0.20174	2.448286	-1.23582	-0.35175	1.565276	3.570414	-0.16766	0.476458
	-0.73981	3.570414	-1.00617	-1.03263	-1.64702	-1.24012	-1.03263	3.570414	0.515916	0.226101
	-0.20174	-0.35175	-1.00617	-1.03263	-0.38112	0.226101	0.226101	-0.19382	-1.23582	-0.19382
	-0.16766	-0.19382	-0.38112	-1.00617	-1.24012	-0.56057	2.448286	-0.20174	-0.19382	2.448286
	-0.20174	-1.23582	0.226101	-0.16766	-0.16766	-1.03263	1.874921	1.874921	-0.19382	-1.23582
	1.874921	0.476458	0.476458	-0.16766	-0.16766	-0.19382	-0.19382	1.874921	0.476458	-0.20174
	-0.73981	-1.64702	-0.16766	-0.20174	0.226101	-1.03263	-0.38112	-0.56057	1.874921	-1.24012
	1.874921	-0.19382	3.570414	1.565276	0.515916	1.874921	-0.16766	0.18368	0.226101	-0.35175
	0.226101	-1.03263	-1.23582	0.226101	-0.20174	-0.35175	-0.20174	-1.23582	1.874921	1.874921
	-1.64702	1.565276	1.874921	-0.38112	-0.16766	2.448286	3.570414	3.570414	-1.03263	0.18368
	-0.16766	0.515916	2.448286	-1.00617	-1.64702	-1.24012	-1.00617	-1.24012	1.565276	-0.16766
	0.18368	0.476458	-1.00617	-0.38112	-0.16766	0.476458	-1.64702	-0.16766	-1.64702	0.18368
	1.565276	0.476458	2.448286	-1.64702	-1.64702	-1.23582	-1.23582	-1.03263	1.565276	0.515916
	2.448286	0.515916	-0.73981	0.226101	2.448286	2.448286	-1.00617	-1.64702	-1.00617	-0.56057
	1.874921	-0.56057	0.515916	0.476458	0.515916	1.874921	-1.24012	1.565276	-0.20174	1.874921
	-0.19382	-0.35175	-0.35175	0.476458	-1.24012	0.18368	0.226101	-1.24012	-1.24012	-1.00617
mean	0.222	0.543869	0.202953	-0.22981	-0.06232	0.117977	0.058296	0.467422	0.058211	0.111643
variance	1.22925	2.40037	1.90774	0.968843	1.794843	1.638894	1.819832	2.792084	1.265954	0.987522

The Actual Within		Bootstrap Sample									
Differences (Seed Data)		**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**
-1.23582145		-1.64702	-1.64702	-0.56057	2.448286	2.448286	-1.24012	-1.03263	-0.56057	2.448286	1.565276
-1.647020556		-0.73981	-0.16766	-1.03263	0.476458	-1.23582	-0.38112	0.18368	-0.16766	2.448286	-0.19382
-0.351750929		1.565276	-1.03263	3.570414	1.874921	-0.20174	0.476458	-0.20174	0.18368	0.515916	-0.19382
0.515916268		-0.35175	-0.38112	1.874921	0.226101	-0.19382	2.448286	-0.38112	-1.64702	-1.00617	0.226101
-0.560572586		3.570414	0.18368	-0.20174	1.874921	-1.03263	0.18368	-1.23582	-1.24012	-0.38112	-1.00617
0.183679795		-1.00617	-0.73981	-1.64702	-0.73981	-0.19382	-0.16766	-0.56057	0.226101	-1.00617	-0.35175
-1.032627733		-1.24012	1.565276	0.226101	0.515916	0.18368	1.565276	0.476458	0.476458	-0.16766	2.448286
-0.73981005		0.226101	-1.00617	-1.03263	-0.73981	1.874921	-1.03263	-0.56057	0.226101	0.226101	-0.38112
-1.240118814		2.448286	-1.03263	-1.64702	-0.73981	-0.35175	2.448286	-0.16766	0.18368	-0.56057	0.515916
-0.381123119		-0.38112	1.874921	0.476458	-0.16766	-1.23582	-1.24012	-1.23582	3.570414	-1.03263	0.476458
-0.193823157		-1.00617	-1.03263	-0.38112	-0.20174	-1.23582	1.565276	-1.23582	1.874921	-1.64702	-0.35175
-1.006171272		-1.03263	-1.24012	-0.56057	-1.00617	0.515916	0.226101	0.515916	-0.56057	0.515916	-1.64702
0.476458007		-0.35175	-1.00617	-0.16766	-1.64702	-0.56057	1.565276	-1.64702	2.448286	-0.16766	1.565276
-0.167657171		-0.38112	-1.03263	-0.35175	-0.35175	1.874921	-1.00617	-0.35175	0.226101	0.226101	-1.64702
-0.201743692		-0.38112	-1.00617	-0.56057	1.565276	0.476458	1.874921	1.874921	-0.38112	1.874921	1.874921
3.570413842		-1.64702	-0.35175	0.226101	-0.20174	-0.73981	0.515916	-0.56057	-0.19382	2.448286	0.18368
1.565275502		-1.24012	-1.24012	-0.56057	-1.64702	-0.16766	0.515916	-1.03263	-1.03263	-0.38112	-0.19382
2.448286293		-1.03263	-0.35175	0.476458	1.874921	-0.35175	-0.20174	-1.24012	-0.56057	-1.24012	-0.35175
0.226101071		0.515916	0.18368	-1.64702	-0.35175	0.476458	-0.19382	1.565276	-0.20174	0.226101	1.565276
1.874921215		0.18368	-0.38112	0.515916	-0.56057	-0.35175	1.565276	1.874921	-0.20174	3.570414	3.570414
	mean	-0.19644	-0.4921	-0.14923	0.125097	-0.00011	0.474364	-0.24763	0.133408	0.345504	0.383677
	variance	1.824229	0.81021	1.500299	1.472232	1.09492	1.423884	1.106669	1.521112	2.134019	1.8057

		71	72	73	74	75	76	77	78	79	80
		-1.24012	0.18368	-0.38112	-1.64702	0.18368	-0.73981	-0.73981	-1.23582	-0.20174	-1.64702
		-1.24012	0.226101	1.874921	1.874921	0.515916	3.570414	3.570414	-1.00617	-0.38112	-1.00617
		-0.20174	-1.03263	-0.56057	-1.03263	-0.19382	2.448286	-1.03263	2.448286	-0.56057	-0.19382
		-0.19382	-1.03263	-1.23582	-0.38112	-1.03263	-1.64702	0.226101	1.565276	3.570414	-0.56057
		0.226101	-0.16766	-0.20174	0.18368	-1.00617	1.565276	-0.16766	-1.64702	-0.56057	-1.03263
		-1.64702	-1.23582	1.874921	0.18368	1.874921	0.515916	0.476458	0.226101	2.448286	0.515916
		1.565276	1.565276	-1.03263	-0.19382	3.570414	-1.23582	-0.35175	-0.16766	1.874921	-0.35175
		-1.00617	-0.35175	2.448286	-0.38112	0.515916	-1.24012	-1.23582	-0.19382	-0.56057	0.18368
		0.18368	-1.03263	-1.23582	-0.35175	-0.38112	1.565276	-0.38112	-1.64702	-1.64702	-0.20174
		0.226101	0.515916	-0.16766	-0.56057	-1.24012	-0.35175	-1.23582	0.18368	1.874921	-1.00617
		1.565276	0.476458	0.226101	1.874921	-1.64702	-0.73981	-0.35175	-1.23582	-1.00617	-1.24012
		-0.38112	0.226101	-1.24012	-0.73981	0.476458	-1.64702	0.515916	1.874921	-1.23582	3.570414
		-1.03263	-1.00617	1.874921	-0.56057	-1.64702	-0.38112	-0.16766	-1.24012	-1.64702	-1.03263
		-1.24012	0.515916	-1.24012	-1.64702	-1.64702	3.570414	-1.64702	-0.73981	1.565276	1.565276
		-0.20174	1.874921	-0.35175	-0.38112	-0.38112	-0.19382	-0.19382	0.226101	0.18368	2.448286
		-1.64702	0.515916	-0.56057	0.226101	-1.24012	-1.03263	3.570414	0.515916	-1.24012	-1.00617
		0.515916	0.18368	-0.19382	-1.03263	-1.23582	0.18368	-1.00617	-0.38112	-0.19382	-1.23582
		0.476458	0.226101	1.565276	0.18368	0.18368	0.515916	2.448286	1.874921	-0.19382	-0.20174
		1.565276	3.570414	2.448286	-0.19382	2.448286	0.515916	-0.35175	-1.23582	2.448286	-1.00617
		-0.38112	0.515916	2.448286	-0.56057	-0.16766	-1.03263	2.448286	-0.73981	-1.64702	-1.64702
	mean	-0.20443	0.236856	0.317962	-0.25683	-0.10252	0.210477	0.219654	-0.12774	0.144519	-0.2543
	variance	1.035304	1.315486	1.958315	0.818233	2.002625	2.545293	2.424563	1.548085	2.486959	1.864642

		81	82	83	84	85	86	87	88	89	90
		-1.23582	0.18368	-0.38112	0.476458	-0.16766	-0.56057	0.226101	-0.19382	-1.03263	2.448286
		-0.16766	-1.64702	-0.20174	-0.19382	-1.64702	0.515916	1.565276	-0.16766	-1.03263	0.226101
		0.18368	2.448286	-1.24012	0.226101	-0.35175	-0.56057	-1.00617	0.226101	0.18368	0.476458
		-0.16766	3.570414	-1.23582	-1.24012	0.515916	-0.38112	-1.00617	-0.20174	-1.23582	0.18368
		-0.73981	-1.24012	-1.24012	-0.56057	-1.03263	0.476458	1.565276	-1.23582	-0.38112	0.18368
		0.476458	-1.23582	-0.16766	0.476458	1.565276	-0.73981	-0.16766	-0.19382	-1.64702	-0.38112
		1.874921	-0.35175	-0.35175	1.565276	-0.35175	-0.56057	-1.24012	-0.73981	1.874921	-0.20174
		0.515916	-1.00617	3.570414	0.476458	-0.73981	-0.35175	-0.19382	-0.19382	-0.16766	1.565276
		0.18368	-1.00617	2.448286	-0.73981	2.448286	-0.20174	-0.73981	0.18368	0.226101	-0.19382
		0.226101	-1.03263	0.476458	0.476458	0.18368	-0.35175	-0.38112	-1.03263	-1.64702	2.448286
		-1.24012	0.18368	-1.64702	0.18368	-1.24012	-1.24012	-0.35175	-0.38112	-0.73981	-1.24012
		0.476458	0.226101	-0.16766	-0.20174	-0.35175	-1.24012	-1.24012	-1.64702	-1.24012	-0.73981
		-0.73981	-1.00617	-0.16766	-1.64702	-0.38112	-0.19382	-1.64702	0.226101	0.476458	0.476458
		-1.00617	0.515916	-0.16766	-1.24012	1.565276	-0.38112	0.18368	-0.19382	-0.38112	1.565276
		-0.38112	-0.16766	-1.64702	-1.64702	-1.23582	-0.56057	1.565276	-1.03263	-1.24012	0.18368
		0.18368	1.565276	-0.19382	-0.56057	0.18368	-0.38112	2.448286	-0.73981	-0.16766	-0.19382
		-0.38112	-0.56057	-1.23582	-1.64702	2.448286	-1.64702	-0.35175	-0.16766	0.476458	-0.35175
		1.874921	2.448286	-0.38112	2.448286	0.515916	0.226101	-0.20174	-0.35175	-0.16766	-0.20174
		0.18368	-0.19382	0.226101	-0.35175	3.570414	-0.20174	-0.73981	0.226101	-0.20174	-0.38112
		0.515916	-1.03263	-0.16766	-0.73981	-1.23582	-0.16766	-0.20174	-0.35175	-1.64702	-1.03263
	mean	0.031806	0.033055	-0.19363	-0.22201	0.213074	-0.42514	-0.09575	-0.39814	-0.48458	0.241975
	variance	0.721145	2.052649	1.603104	1.13633	2.041648	0.281713	1.194397	0.269683	0.79971	1.055054

The Actual Within	**Bootstrap Sample**										
Differences (Seed Data)		**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**
-1.23582145		0.18368	0.18368	1.565276	1.874921	-0.16766	0.476458	-0.35175	-1.03263	-0.20174	-0.56057
-1.647020556		-1.23582	-1.23582	-0.35175	0.226101	-0.73981	2.448286	2.448286	-0.35175	-1.64702	2.448286
-0.351750929		1.565276	-1.23582	-0.35175	-0.73981	0.515916	-1.64702	-0.19382	-0.35175	-0.35175	-0.35175
0.515916268		0.18368	0.515916	2.448286	0.226101	3.570414	1.565276	-1.23582	-1.23582	-0.35175	-0.38112
-0.560572586		-0.35175	-0.16766	-1.00617	-0.16766	-0.35175	-0.16766	-0.38112	-1.23582	-0.56057	-1.64702
0.183679795		-0.20174	-1.64702	-0.56057	-1.00617	0.18368	-0.38112	-0.56057	-0.38112	0.18368	-0.20174
-1.032627733		0.476458	-1.24012	3.570414	-0.16766	-1.23582	-0.38112	-0.19382	1.874921	2.448286	1.565276
-0.73981005		1.874921	-0.16766	-0.20174	0.226101	2.448286	-1.64702	1.565276	0.18368	-1.64702	-1.23582
-1.240118814		-1.03263	-0.73981	-1.03263	-1.24012	-0.56057	-1.00617	-0.56057	-0.73981	-1.03263	-0.35175
-0.381123119		-0.73981	0.515916	-0.56057	-1.24012	0.476458	-0.35175	-0.20174	-0.56057	-0.56057	-0.19382
-0.193823157		-0.56057	-0.73981	-1.03263	0.476458	-0.20174	-0.16766	-0.38112	-0.16766	-1.03263	-0.73981
-1.006171272		2.448286	-0.35175	-0.19382	3.570414	1.874921	3.570414	1.874921	-1.64702	-0.19382	-1.03263
0.476458007		-1.00617	-1.00617	-1.00617	3.570414	-0.38112	-1.64702	-0.38112	-0.56057	-0.56057	-0.73981
-0.167657171		1.874921	3.570414	-1.03263	-0.56057	-1.64702	0.515916	-1.24012	-0.56057	-0.19382	1.874921
-0.201743692		-0.20174	-0.73981	-1.64702	2.448286	-0.56057	0.18368	-0.19382	-0.35175	-0.19382	-0.35175
3.570413842		-0.35175	-0.20174	0.515916	0.476458	-0.19382	-0.35175	1.874921	-0.56057	0.18368	-0.35175
1.565275502		-1.24012	0.515916	-1.24012	-0.16766	-0.20174	-0.20174	-0.19382	-0.35175	-0.56057	-0.73981
2.448286293		1.565276	-1.00617	-1.03263	-0.16766	0.226101	-0.56057	-1.23582	-0.73981	-1.64702	-0.56057
0.226101071		-1.64702	0.476458	1.874921	-0.73981	-0.73981	3.570414	-0.16766	-1.64702	-1.64702	-0.35175
1.874921215		0.226101	-0.35175	3.570414	-0.73981	1.565276	0.18368	-0.56057	-1.64702	0.476458	-1.64702
	mean	0.091473	-0.25264	0.114751	0.307911	0.19398	0.200176	-0.01349	-0.60322	-0.45451	-0.2775
	variance	1.428955	1.255092	2.576467	2.098587	1.626946	2.305194	1.146574	0.60791	0.884113	1.134259
Mean of 100 Bootstrap Sample Means:	**0.0583**										
Mean Variance of 100 Bootstrap Samples:	**1.6356**										

APPENDIX 8
"BETWEEN" BOOTSTRAP DATA"

The Actual Between Differences (Seed Data)		Bootstrap Sample									
		1	2	3	4	5	6	7	8	9	10
-2.575302308		0.096352	1.342703	-2.4944	1.075882	-1.20164	1.213169	-2.5753	0.731935	1.342703	0.436328
-2.498058383		0.393647	-2.4944	1.075882	1.342703	1.342703	-1.44098	1.075882	1.567686	-1.44098	-1.74614
-2.494399823		1.567686	0.436328	1.075882	0.096352	-0.7477	-2.4944	1.567686	1.567686	-1.33088	-2.4944
-1.746136787		-2.4944	-1.20164	-2.5753	1.075882	1.342703	-1.33088	-0.79181	1.213169	-1.74614	-1.44098
-1.473886444		-2.4944	0.393647	0.096352	-0.79181	-1.33088	-2.4944	-0.7477	-2.49806	1.928733	-1.74614
-1.440979236		-2.49806	-0.79181	-0.79181	-1.47389	-2.5753	-2.5753	0.436328	0.731935	-0.79181	-1.74614
-1.330881548		0.436328	-2.5753	-1.47389	-2.5753	-1.03727	1.075882	0.096352	1.213169	0.731935	1.075882
-1.201643376		0.436328	-2.4944	0.436328	-0.7477	-1.74614	0.436328	-1.20164	-2.4944	1.213169	0.393647
-1.037270045		1.213169	0.731935	-1.03727	-1.33088	0.436328	-2.5753	0.096352	0.393647	1.567686	0.393647
-0.791810326		0.731935	1.213169	1.075882	0.731935	-0.7477	1.928733	-1.03727	1.567686	1.213169	-0.79181
-0.74769637		-1.03727	-1.74614	1.567686	-1.33088	0.436328	-1.74614	-1.74614	-1.47389	0.393647	0.436328
0.096351785		1.075882	-2.49806	-1.03727	1.213169	0.096352	-2.5753	0.731935	-1.03727	-0.79181	-2.49806
0.393646966		-1.44098	-2.4944	0.096352	0.731935	-0.79181	1.342703	-1.20164	-1.44098	0.393647	0.436328
0.436328416		1.567686	-1.20164	-1.44098	0.393647	-1.33088	1.213169	1.928733	0.436328	1.928733	0.096352
0.731934905		-1.74614	-0.79181	1.928733	-1.03727	0.436328	-1.47389	-2.5753	1.075882	1.342703	1.075882
1.075882095		-1.20164	-0.7477	-1.44098	-2.49806	1.567686	1.342703	0.393647	-1.47389	1.928733	1.342703
1.213168948		-2.49806	1.075882	-1.20164	-1.74614	1.928733	1.928733	-1.20164	0.393647	1.342703	-2.49806
1.342703247		-1.74614	-1.74614	-1.44098	1.075882	-1.74614	-2.49806	-1.20164	1.928733	-2.4944	1.213169
1.567686138		1.213169	-0.79181	-1.47389	-1.03727	1.342703	-1.44098	0.393647	-1.44098	-1.20164	0.096352
1.928732533		-2.49806	-0.79181	1.213169	1.928733	-2.49806	0.096352	0.393647	1.928733	-0.79181	0.436328
	mean	-0.54615	-0.85867	-0.39211	-0.24515	-0.34118	-0.60339	-0.35829	0.144539	0.236904	-0.37644
	variance	2.420567	1.797805	1.889838	1.867109	1.92718	3.041639	1.596227	2.215986	2.007183	1.81045
		11	12	13	14	15	16	17	18	19	20
		-1.33088	1.075882	-0.79181	0.731935	1.213169	-1.20164	1.567686	1.928733	0.731935	0.731935
		-0.7477	0.393647	0.436328	-1.33088	0.731935	-1.74614	1.342703	1.567686	1.567686	1.928733
		-2.4944	-2.49806	0.436328	1.342703	-1.47389	0.436328	1.213169	1.567686	0.436328	-2.5753
		1.075882	-0.7477	-2.5753	-1.74614	-1.33088	1.075882	-1.47389	1.213169	1.567686	-2.4944
		0.393647	-1.47389	-2.4944	1.342703	0.096352	-1.03727	1.075882	-1.47389	-1.20164	-1.20164
		-2.4944	1.075882	-1.20164	0.436328	0.436328	-0.7477	0.393647	1.567686	0.731935	-1.03727
		-1.47389	-1.33088	-1.03727	-1.20164	1.928733	-1.33088	-0.7477	1.342703	0.731935	-1.47389
		-0.79181	0.096352	-2.5753	-1.74614	-2.49806	-1.47389	-1.03727	1.075882	-1.33088	-0.79181
		-2.5753	1.928733	-1.33088	-2.49806	1.075882	0.393647	1.567686	-2.49806	-1.47389	-1.44098
		-1.03727	0.096352	-2.49806	1.567686	1.928733	-1.44098	0.436328	1.342703	1.075882	-2.4944
		-1.47389	-1.47389	0.436328	0.393647	-1.74614	1.213169	-0.79181	-2.5753	1.342703	-1.74614
		-0.7477	0.731935	-1.20164	1.928733	-1.44098	-0.7477	1.567686	0.731935	1.075882	0.731935
		1.342703	0.731935	0.436328	-1.33088	1.567686	-0.79181	-2.5753	1.567686	1.342703	-1.03727
		-1.03727	1.342703	-1.20164	-2.49806	1.075882	-2.49806	-0.79181	-2.4944	-0.7477	0.393647
		1.213169	-1.47389	-1.74614	-1.47389	1.342703	-1.33088	-1.33088	-1.44098	-2.5753	-1.47389
		-1.33088	1.567686	0.096352	1.213169	1.928733	1.928733	-1.33088	-2.5753	1.342703	-1.47389
		0.393647	1.075882	1.342703	-1.74614	-2.49806	1.567686	1.342703	-1.20164	1.567686	-1.03727
		-2.49806	1.075882	1.342703	0.096352	-1.74614	0.393647	1.342703	-1.33088	1.213169	-1.74614
		1.213169	-1.44098	-1.44098	-1.33088	1.213169	-1.44098	-1.47389	1.213169	0.096352	1.342703
		-0.79181	1.075882	0.436328	0.731935	-1.47389	1.075882	-2.5753	-2.4944	0.436328	1.567686
	mean	-0.75965	0.091474	-0.75658	-0.35588	0.016564	-0.38515	-0.11393	-0.14829	0.396575	-0.76638
	variance	1.705265	1.684725	1.672453	2.142414	2.535787	1.627363	2.080893	3.198208	1.473624	1.922445

	21	22	23	24	25	26	27	28	29	30
	-1.33088	1.075882	-0.7477	0.731935	0.731935	1.928733	-1.44098	0.436328	1.928733	0.436328
	1.075882	-1.33088	-1.33088	0.436328	1.342703	-2.5753	0.436328	1.342703	1.342703	-2.5753
	1.075882	-1.20164	1.567686	-2.5753	0.393647	-0.79181	-2.5753	0.096352	-2.5753	-1.20164
	-0.7477	1.928733	1.075882	1.342703	-2.49806	-1.74614	0.096352	1.567686	1.567686	-0.7477
	-1.03727	1.213169	1.567686	0.436328	-0.7477	0.731935	-2.49806	-2.5753	-1.03727	0.731935
	0.096352	-1.47389	1.213169	-2.49806	-2.5753	1.342703	0.393647	-2.4944	-0.79181	1.342703
	1.928733	-1.03727	1.075882	-1.33088	-0.7477	1.342703	1.213169	0.096352	0.393647	-2.4944
	1.213169	-1.44098	-1.74614	1.567686	-1.33088	0.731935	1.213169	-1.20164	-1.74614	-0.79181
	0.731935	1.075882	-1.47389	0.436328	-1.03727	-2.5753	1.342703	0.731935	1.213169	-1.20164
	0.436328	0.731935	-1.74614	-2.5753	-1.33088	-1.03727	-1.20164	-2.4944	0.393647	-1.33088
	0.096352	-2.5753	-1.44098	1.928733	1.213169	1.928733	-2.5753	-1.47389	0.096352	-2.5753
	-1.47389	1.567686	-2.4944	-1.47389	1.213169	-1.33088	-2.49806	-1.74614	-1.03727	-2.49806
	0.096352	-1.20164	-1.33088	-2.4944	-1.33088	-2.49806	1.567686	1.213169	1.567686	1.075882
	-1.47389	0.731935	-1.44098	1.928733	0.393647	0.096352	1.213169	0.096352	0.436328	1.342703
	0.393647	-1.74614	0.436328	1.213169	1.075882	0.731935	1.075882	1.075882	1.567686	-1.47389
	0.393647	-1.03727	-1.47389	0.096352	-2.49806	1.928733	1.928733	-1.20164	-0.7477	-0.79181
	0.096352	-2.49806	-2.5753	0.436328	-2.49806	1.075882	-1.20164	0.731935	-0.7477	-1.33088
	0.393647	0.096352	1.567686	-0.7477	0.096352	0.731935	-2.5753	-1.33088	1.928733	-2.49806
	-2.5753	-2.49806	1.567686	-2.49806	-1.47389	1.213169	-2.5753	-1.74614	0.393647	1.342703
	-2.5753	1.342703	0.096352	-2.4944	-1.74614	0.096352	-1.74614	-1.20164	-0.79181	-1.03727
mean	-0.1593	-0.41384	-0.38164	-0.40667	-0.66772	0.066317	-0.52034	-0.50387	0.167751	-0.81382
variance	1.53909	2.244436	2.234491	2.83489	1.890745	2.394545	2.921865	1.923761	1.704966	1.973935

	31	32	33	34	35	36	37	38	39	40
	1.567686	-1.33088	0.096352	-0.7477	-1.33088	0.436328	-2.5753	0.096352	0.436328	0.731935
	1.213169	1.213169	1.928733	-1.20164	-1.74614	-2.49806	-1.47389	1.928733	1.342703	0.096352
	-1.47389	1.213169	1.075882	-1.03727	0.393647	-1.44098	1.928733	-1.47389	-1.03727	1.928733
	-2.4944	-1.20164	1.213169	1.928733	-1.74614	-1.74614	-1.03727	0.393647	1.075882	0.393647
	0.393647	0.393647	1.213169	0.436328	-0.79181	1.342703	-1.20164	1.213169	-1.20164	1.075882
	-1.44098	-0.79181	1.213169	1.075882	-1.33088	1.342703	-2.5753	-1.03727	1.075882	-0.79181
	1.567686	-1.03727	-2.5753	1.213169	-0.7477	0.436328	0.731935	1.928733	-1.20164	1.928733
	-1.20164	-0.7477	-2.4944	1.567686	1.342703	0.436328	-2.4944	1.342703	1.342703	-1.74614
	-1.33088	-1.03727	0.436328	-2.4944	0.096352	1.928733	-1.33088	0.096352	-0.79181	-1.44098
	-1.47389	-1.74614	0.731935	1.928733	-0.7477	1.928733	-1.33088	-1.74614	-0.79181	-1.47389
	1.075882	-0.79181	-1.44098	-2.4944	0.393647	1.075882	-2.4944	-2.49806	-1.74614	1.342703
	-2.49806	-1.47389	-1.03727	-1.03727	1.075882	1.928733	0.393647	-1.20164	-2.49806	-2.4944
	-1.03727	0.731935	-1.20164	0.393647	0.393647	1.567686	-1.47389	0.096352	0.731935	-1.74614
	1.075882	1.213169	-1.20164	-0.79181	-1.33088	-1.44098	1.928733	1.213169	-0.7477	0.436328
	1.075882	-1.74614	-1.20164	1.928733	0.731935	1.928733	0.436328	-0.79181	-2.4944	-2.49806
	0.436328	-1.47389	1.342703	-1.33088	-2.5753	-1.44098	1.213169	1.567686	-0.7477	1.567686
	1.213169	0.731935	1.075882	-1.20164	0.393647	-1.03727	0.096352	-0.7477	0.731935	1.213169
	-1.33088	1.213169	-1.20164	1.928733	-1.33088	1.567686	-1.33088	1.213169	1.213169	0.096352
	1.928733	0.436328	1.567686	1.342703	-2.49806	-0.79181	1.075882	-1.20164	-2.49806	-1.03727
	-2.5753	-2.49806	0.731935	-0.79181	-0.7477	-2.4944	0.731935	-2.49806	-1.20164	-2.49806
mean	-0.26546	-0.4365	0.013621	0.030776	-0.60513	0.151498	-0.5391	-0.10531	-0.45037	-0.24576
variance	2.398179	1.439805	1.987402	2.271803	1.32427	2.532323	2.293133	2.048875	1.796273	2.356513

		41	42	43	44	45	46	47	48	49	50
		-1.33088	-1.47389	-2.49806	-1.03727	-1.74614	-2.49806	-2.49806	0.731935	-0.7477	-2.4944
		-1.33088	1.342703	-2.49806	-0.7477	-2.5753	0.436328	0.731935	-2.4944	0.393647	-1.20164
		0.731935	-1.20164	0.393647	-0.79181	0.096352	-0.79181	1.342703	-1.33088	1.213169	-2.49806
		1.213169	-1.44098	-0.7477	1.928733	-1.33088	-2.5753	-0.7477	-1.20164	1.567686	1.342703
		0.436328	0.096352	-2.4944	0.393647	1.928733	-1.44098	-0.79181	-1.20164	-1.74614	0.393647
		-1.47389	-0.79181	1.213169	0.436328	-2.49806	-2.49806	0.096352	1.567686	0.393647	-0.79181
		0.096352	1.567686	-1.03727	-1.03727	-1.33088	1.342703	-1.33088	-2.4944	-2.5753	1.075882
		-0.79181	-2.49806	-0.7477	-1.33088	-1.03727	-1.47389	1.567686	-2.5753	-0.7477	-2.5753
		-1.47389	1.567686	-1.20164	-1.74614	0.436328	1.567686	-1.74614	-0.79181	-1.20164	-1.33088
		0.096352	1.342703	-1.20164	1.213169	0.731935	0.393647	-0.79181	-1.47389	-1.74614	-2.49806
		-1.47389	-2.4944	1.928733	0.436328	-1.47389	-2.4944	-1.03727	-1.03727	1.342703	-2.4944
		-0.79181	1.075882	1.342703	-1.74614	0.731935	1.342703	-1.74614	0.436328	-0.79181	-2.49806
		1.928733	0.731935	-1.44098	-2.5753	-2.4944	1.567686	-0.7477	-1.47389	1.213169	0.436328
		0.393647	-2.5753	-1.47389	0.096352	0.096352	0.436328	1.567686	-1.33088	-2.49806	-2.5753
		-1.44098	1.567686	-0.7477	-2.49806	-1.74614	-1.47389	1.928733	-1.20164	1.213169	-1.44098
		0.731935	0.436328	-1.03727	0.393647	-1.44098	0.731935	-1.20164	1.075882	-2.49806	-2.5753
		1.567686	-1.03727	-1.44098	0.436328	-1.74614	0.731935	1.075882	0.436328	-1.03727	1.342703
		-0.7477	-2.4944	-1.74614	0.096352	1.342703	-1.47389	0.393647	-0.7477	1.075882	-2.4944
		-1.33088	1.567686	1.567686	1.075882	1.928733	-1.33088	0.393647	1.213169	-0.79181	-1.44098
		-0.79181	-2.4944	1.075882	-0.79181	0.096352	1.928733	0.436328	0.096352	-1.33088	-1.74614
	mean	-0.28911	-0.36028	-0.63958	-0.38978	-0.60153	-0.37857	-0.15523	-0.68988	-0.46497	-1.30322
	variance	1.250536	2.719336	1.967222	1.521943	2.126548	2.489909	1.640026	1.581639	1.983853	2.07728
The Actual Between		**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
Differences (Seed Data)		0.393647	-1.33088	0.436328	-2.49806	-0.79181	-1.44098	-1.20164	-0.79181	-2.49806	0.731935
-1.746136787		-1.74614	-1.20164	1.213169	0.436328	-1.20164	-0.7477	-2.5753	0.436328	-2.4944	0.731935
-2.498058383		1.213169	0.436328	-0.7477	-1.20164	-1.44098	-1.74614	-1.47389	-1.44098	-2.4944	0.436328
0.096351785		-0.7477	-1.20164	-0.79181	0.096352	-0.79181	1.213169	-1.74614	-2.49806	0.436328	1.567686
-2.494399823		-2.4944	-1.33088	1.075882	1.928733	-1.47389	0.731935	0.096352	-1.47389	0.096352	-0.79181
-0.791810326		1.075882	-1.20164	1.567686	0.436328	-0.79181	-2.4944	-1.20164	1.928733	-2.5753	0.393647
-1.330881548		-2.5753	-2.5753	-0.79181	-2.4944	0.731935	-1.44098	0.096352	-2.49806	0.096352	-0.79181
1.342703247		0.436328	-1.33088	1.928733	1.075882	1.928733	1.342703	-0.7477	-1.44098	-1.33088	-1.33088
-1.201643376		1.213169	-1.47389	0.393647	-0.79181	-0.79181	-1.03727	1.928733	-0.79181	1.213169	1.213169
1.567686138		-0.7477	1.928733	-0.7477	-1.44098	-1.74614	0.393647	-0.7477	-1.47389	1.213169	-1.47389
-1.473886444		-2.5753	1.928733	0.436328	-1.33088	-1.44098	1.213169	1.342703	-2.4944	1.213169	-1.20164
-2.575302308		1.075882	0.731935	-1.33088	0.393647	-1.33088	1.928733	1.075882	-1.20164	-1.47389	-0.7477
1.213168948		-2.5753	-2.49806	0.731935	0.731935	-1.20164	-1.47389	1.567686	-1.44098	-1.20164	0.731935
1.075882095		1.213169	-1.33088	0.731935	-1.33088	-2.49806	-2.49806	-1.33088	-1.20164	-0.79181	-1.44098
-1.440979236		-1.20164	-1.44098	-1.33088	-2.4944	-0.7477	-2.49806	-1.74614	-1.47389	-1.03727	-2.4944
-1.037270045		-1.47389	-2.4944	0.393647	-0.79181	1.075882	-0.7477	1.928733	-2.5753	-1.47389	-1.20164
0.436328416		1.928733	1.342703	1.075882	-1.33088	-1.03727	-1.33088	-1.74614	-2.5753	1.075882	-2.49806
-0.74769637		-1.33088	1.075882	0.393647	-0.79181	-1.74614	0.096352	-1.03727	-0.7477	0.436328	-1.20164
1.928732533		-1.33088	0.731935	1.213169	0.393647	0.393647	-2.4944	1.928733	1.342703	-1.47389	-0.79181
0.731934905		-1.03727	0.436328	0.096352	0.096352	1.075882	-1.47389	0.393647	0.436328	0.731935	-2.49806
0.393646966											
	mean	-0.56432	-0.53993	0.297378	-0.54542	-0.69132	-0.72523	-0.25978	-1.09881	-0.61664	-0.63288
	variance	2.260366	2.146438	0.921499	1.556434	1.296453	2.057033	2.116133	1.640528	1.876565	1.545553

		61	62	63	64	65	66	67	68	69	70
		-0.7477	1.075882	-0.79181	-1.33088	1.075882	1.213169	-2.4944	-2.4944	-2.49806	0.731935
		-0.79181	1.075882	-0.7477	-2.49806	0.436328	-1.44098	0.096352	-0.79181	-1.74614	-1.33088
		0.393647	-1.44098	-1.47389	1.213169	-0.7477	-1.33088	0.436328	-2.49806	-1.33088	1.075882
		0.393647	0.731935	1.075882	1.928733	-2.49806	0.436328	1.342703	-1.74614	0.393647	-1.20164
		-1.20164	-0.7477	1.928733	-1.47389	-0.79181	-0.7477	-2.49806	1.342703	-1.47389	-1.03727
		0.096352	-2.4944	0.436328	1.342703	1.567686	0.731935	0.393647	0.393647	-2.5753	0.436328
		-1.47389	0.436328	-2.5753	0.731935	-1.47389	-0.7477	1.928733	1.342703	1.928733	-2.5753
		0.731935	-1.44098	-2.5753	-1.33088	-1.20164	1.928733	1.567686	-2.4944	0.393647	1.342703
		0.096352	-1.44098	-0.7477	1.567686	0.731935	-0.7477	-1.47389	1.928733	-1.03727	-1.74614
		1.075882	-2.4944	1.213169	-1.03727	1.928733	1.342703	1.928733	0.393647	-0.79181	0.436328
		-2.4944	1.928733	1.075882	1.342703	0.393647	-1.33088	-2.49806	-1.74614	1.928733	-1.47389
		-1.20164	-0.7477	0.096352	-1.44098	-1.33088	-1.74614	1.075882	0.436328	0.393647	-1.20164
		-2.49806	1.075882	1.342703	0.731935	-1.03727	-1.44098	1.075882	-0.7477	-0.7477	0.096352
		0.393647	-2.5753	0.096352	-1.20164	1.075882	0.436328	0.731935	-2.5753	-0.7477	-1.03727
		1.342703	-2.4944	-1.03727	-2.4944	-1.03727	1.075882	-1.44098	-2.49806	1.075882	-1.20164
		-0.7477	0.731935	-1.44098	0.436328	0.731935	-1.33088	1.567686	-2.49806	1.213169	-2.4944
		0.393647	-2.4944	0.731935	1.567686	-0.7477	1.342703	1.567686	1.213169	-2.4944	-1.03727
		-0.7477	-1.44098	0.731935	-2.4944	-1.47389	-2.5753	-1.20164	-0.79181	-2.4944	0.393647
		-1.74614	1.928733	-1.44098	-1.20164	-1.20164	-1.33088	-1.74614	-1.33088	1.928733	1.075882
		-1.33088	0.436328	-1.03727	-1.74614	-1.03727	-2.49806	-1.47389	1.342703	-2.4944	0.731935
	mean	-0.50319	-0.51953	-0.25695	-0.36937	-0.33185	-0.43801	-0.05569	-0.69096	-0.55879	-0.50082
	variance	1.248288	2.521616	1.724007	2.407075	1.469683	1.887938	2.598728	2.58061	2.597972	1.480232
		71	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**
		0.096352	-0.79181	1.342703	-1.20164	-1.33088	1.928733	-0.79181	-2.5753	-0.7477	1.213169
		0.096352	-1.03727	0.096352	0.096352	1.342703	-2.49806	-1.44098	0.436328	0.096352	1.342703
		1.213169	-1.33088	0.096352	-1.47389	1.342703	-2.4944	0.436328	-2.4944	-2.49806	-1.20164
		-1.03727	-0.7477	1.342703	-2.5753	0.436328	-0.79181	0.436328	-2.5753	-2.49806	-2.4944
		-1.33088	-0.79181	0.393647	-2.5753	0.731935	-2.5753	-1.44098	0.436328	1.928733	-0.79181
		1.342703	-2.4944	-1.74614	1.342703	0.731935	-1.20164	-0.7477	-0.7477	0.096352	0.731935
		-1.47389	1.213169	-0.7477	-0.7477	-1.74614	0.096352	1.928733	-1.47389	1.342703	1.567686
		-0.79181	-2.49806	-1.44098	-1.20164	-2.4944	-0.7477	-2.4944	0.436328	1.075882	-1.44098
		1.213169	0.436328	0.436328	0.393647	-1.47389	-1.33088	1.342703	-2.5753	1.567686	-2.5753
		-1.03727	-1.44098	-1.03727	-1.74614	-2.49806	1.075882	-0.7477	-1.47389	0.393647	-2.4944
		1.075882	-1.47389	-2.4944	-2.4944	-1.44098	-2.5753	-1.74614	0.436328	0.096352	1.075882
		1.075882	-2.5753	0.393647	1.567686	0.096352	1.567686	-1.33088	-2.5753	0.436328	-2.5753
		-1.74614	0.393647	-1.47389	-0.79181	-1.33088	-1.47389	0.731935	-2.5753	0.436328	-1.03727
		-0.79181	0.436328	-1.74614	1.567686	1.075882	0.096352	1.928733	-1.20164	-2.4944	1.342703
		-0.7477	0.096352	-2.5753	1.342703	-1.44098	-1.74614	-1.33088	1.928733	1.342703	-1.74614
		-0.7477	0.436328	-2.5753	-1.03727	0.096352	1.342703	-0.7477	-1.47389	0.393647	-2.5753
		-2.49806	1.213169	1.342703	1.567686	-1.44098	0.096352	-1.33088	0.731935	0.096352	-1.20164
		1.075882	1.213169	0.731935	1.213169	-2.49806	1.567686	0.096352	-2.49806	1.342703	-1.33088
		-1.20164	0.436328	-1.44098	-2.49806	-1.33088	-0.79181	-1.44098	0.436328	1.928733	-1.44098
		-2.49806	-1.33088	-1.47389	1.928733	-1.20164	0.393647	-2.4944	0.096352	-1.33088	-2.49806
	mean	-0.43564	-0.53191	-0.62878	-0.36614	-0.71868	-0.50308	-0.55922	-0.96507	0.15027	-0.9065
	variance	1.572783	1.550382	1.803829	2.618492	1.717082	2.246997	1.750231	2.143851	1.988045	2.365171

		81	82	83	84	85	86	87	88	89	90
		0.731935	1.213169	1.213169	1.213169	1.075882	-2.5753	1.342703	-2.4944	1.075882	-1.03727
		1.213169	0.393647	-2.5753	0.436328	-0.79181	-1.03727	-1.44098	-1.74614	0.436328	1.342703
		1.567686	0.393647	-2.5753	-1.20164	-1.20164	-2.4944	-2.4944	-1.74614	-1.20164	0.731935
		-1.74614	1.213169	-1.03727	1.213169	-1.03727	1.213169	0.436328	-1.20164	0.393647	0.393647
		-0.79181	1.342703	0.096352	-0.79181	0.731935	-1.74614	-2.5753	-1.20164	-1.20164	-2.4944
		-1.33088	-0.7477	1.213169	0.096352	-0.7477	-2.5753	-0.79181	1.928733	-1.20164	0.096352
		-2.4944	-2.49806	1.342703	-1.74614	-1.74614	-1.47389	-1.20164	1.342703	-1.33088	1.213169
		1.567686	1.928733	0.731935	0.393647	-2.49806	0.436328	0.731935	1.075882	0.393647	0.436328
		1.213169	1.342703	0.731935	1.928733	-1.44098	-1.44098	-2.4944	1.928733	-2.4944	-0.7477
		1.213169	1.567686	-2.49806	-1.03727	0.436328	1.213169	-2.5753	-1.03727	0.731935	-1.44098
		1.928733	-1.33088	0.096352	-1.33088	1.075882	1.342703	-2.5753	1.075882	-1.44098	0.096352
		-1.33088	-0.79181	-2.4944	0.436328	1.567686	1.213169	0.096352	1.075882	0.393647	1.928733
		-2.5753	-1.47389	-1.74614	-2.4944	-2.49806	-0.79181	-0.79181	-2.5753	-0.7477	-1.20164
		-1.47389	0.731935	-1.03727	-0.7477	1.075882	1.567686	-0.7477	0.436328	-1.20164	-1.44098
		1.928733	0.436328	1.213169	-2.49806	-2.49806	1.928733	-1.44098	-1.47389	-0.79181	-1.03727
		1.075882	-0.7477	-0.79181	-2.49806	-1.20164	1.075882	-1.44098	-0.7477	0.393647	-1.74614
		-0.79181	-2.5753	-2.5753	-1.74614	1.928733	1.928733	0.436328	1.075882	0.096352	-2.4944
		0.096352	0.393647	-0.7477	-0.7477	0.096352	-1.74614	-0.7477	-1.44098	-1.74614	-1.33088
		1.928733	-0.7477	1.928733	-1.33088	-0.7477	1.567686	-1.74614	-1.33088	-1.33088	-2.4944
		1.928733	0.731935	1.928733	-0.7477	1.342703	1.075882	-1.03727	-1.47389	-1.44098	0.731935
	mean	0.192943	0.038814	-0.37912	-0.66003	-0.35388	-0.0659	-1.0529	-0.42649	-0.61076	-0.52475
	variance	2.528453	1.765456	2.664179	1.666464	2.06521	2.764636	1.424595	2.215414	0.998962	1.827204
		91	92	93	94	95	96	97	98	99	100
		0.393647	0.393647	-0.7477	-2.5753	-2.5753	0.393647	0.436328	-1.20164	-1.20164	0.731935
		1.342703	0.393647	0.731935	-1.44098	-0.79181	1.928733	1.342703	-1.20164	-2.5753	-0.79181
		-1.47389	-2.4944	-1.47389	1.928733	0.096352	1.075882	1.075882	-2.5753	-2.49806	-2.49806
		1.567686	1.567686	-1.20164	-2.5753	-0.79181	-1.44098	1.567686	1.075882	0.436328	-0.7477
		-2.4944	-1.20164	-1.33088	1.928733	-2.4944	-0.79181	-1.44098	-1.47389	-2.4944	-2.4944
		-0.7477	0.393647	-2.4944	0.436328	-1.74614	-1.47389	0.096352	-1.20164	-1.44098	-1.74614
		1.075882	0.731935	-1.03727	-2.5753	-1.20164	-1.47389	-1.74614	-2.49806	1.928733	1.213169
		-1.74614	-1.74614	1.928733	-1.20164	-1.33088	0.096352	0.393647	0.393647	0.096352	1.213169
		-1.33088	1.213169	-1.44098	-0.7477	0.393647	-2.49806	0.096352	0.393647	0.731935	-2.5753
		1.567686	-0.79181	0.096352	-1.44098	-1.33088	1.213169	-1.03727	0.436328	1.928733	0.436328
		-1.20164	-1.20164	-1.74614	-2.49806	-0.7477	1.928733	1.928733	1.928733	1.213169	-1.33088
		0.436328	1.567686	0.731935	1.075882	0.436328	1.075882	-1.44098	-2.4944	-1.44098	1.567686
		-1.74614	1.075882	0.731935	-1.44098	-2.4944	1.567686	-2.49806	1.342703	1.075882	1.213169
		0.096352	-1.03727	-1.20164	-1.33088	-0.7477	-1.33088	-1.47389	-1.20164	-1.74614	1.213169
		-2.49806	-1.47389	-0.79181	1.567686	-2.5753	-2.4944	-2.4944	-1.47389	1.928733	1.928733
		-0.79181	1.928733	-2.5753	1.075882	1.928733	-1.44098	1.342703	-1.47389	0.096352	-1.44098
		1.213169	-2.4944	-1.74614	-1.03727	-2.4944	-1.44098	-1.20164	-0.79181	-1.74614	-1.03727
		1.075882	0.096352	-2.5753	1.213169	1.075882	-1.44098	-1.20164	1.928733	-1.44098	0.731935
		-1.20164	1.342703	1.928733	-1.03727	-1.47389	1.567686	-1.44098	1.075882	-2.5753	-1.03727
		1.213169	1.567686	0.436328	1.075882	-2.49806	1.567686	1.928733	-1.33088	1.928733	-1.74614
	mean	-0.26249	-0.00842	-0.68886	-0.47997	-1.06817	-0.17057	-0.28834	-0.51716	-0.38975	-0.35983
	variance	1.975324	2.041565	1.921612	2.564063	1.745423	2.404896	2.170458	2.131301	2.879675	2.269213
Mean of 100 Bootstrap Sample Means:	-0.40621										
Mean Variance of 100 Bootstrap Samples:	2.018009										

APPENDIX 9

CRUSH COEFFICIENTS FOR 1998 FORD CONTOUR

Vehicle Crush Stiffness Coefficients

Neptune Engineering, Inc.

REF NO.	YR	MAKE	MODEL	BODY	TRAN	VIN	WB	WT	V-EFF	PDOF	%OL	#C's	X_C	b0	b1	K_v	A	B	TEST#
Contou06	98	FORD	CONTOUR	4S	AF	3FAFP6533WH118227	106.5	3310	35.0	0	100%	6	14.0	4.2	2.20	240	354	186	A:2708
							Stnd Weight	2859						4.50	Default Value For "b0"				

Liability Disclaimer

The data supplied with this publication is based upon the measurements as reported by the respective source of said measurements. Neptune Engineering, Inc. makes no warranties, either expressed or implied, with respect to the accuracy of said measurements.

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The proper use of the data contained in this publication requires a thorough understanding of vehicle dynamics. The user should recognize that there is a degree of variance in the level of damages sustained by "identical" vehicles during controlled barrier collisions. This variance can be seen in the scatter of data points in the CRASH plots and SMAC plots. The user also should recognize that the potential variance in the level of damages sustained during a "real-world" collision is even greater. Sound engineering judgment, therefore, should be used when applying the enclosed data in the reconstruction of "real-world" accidents. The user must accept full responsibility for any decisions that are based, in whole or in part, upon information obtained by using this data.

APPENDIX 10

REVIEWERS' COMMENTS
SAE PAPER 2004-01-1208

REVIEW #1

I believe the topic of this paper is worthwhile and would make a good SAE paper if modified. Basically the authors need to add a lot of detail concerning the methodologies and equipment used in the study. A lot of new text and new sections have been added to remedy this.

The tables and figures need to be titled, labeled and referenced in the body of the text. The NHTSA numbers need to be added to the two main tables to reference the tests used. Done. The test number for the Ford Contour (the "within" subjects subject) was included also.

A detailed description of the Photomodeler program needs to be included. It should describe how to obtain the software, the principles of its operation, how to use it, define key terms and define precisely the equipment it was used with. The new sections entitled "Description of the Software" and "Description of a Generic PhotoModeler Procedure" have been added.

For instance, how was the Olympus C-5050 calibrated? Why was it chosen for use? More detail has been added to the "Camera Calibration" section. Why is "overlap" necessary? The "Exemplar Modeling" section has been expanded to explain this. What measurements were made to scale the photos? Why were those particular measurements used? This also was clarified in the "Exemplar Modeling" section. How was the dxf file exported? This is answered in the very last sentence of "Exemplar Modeling."Were the photos digitized and saved in photomodeler? How was this done? This is explained better in the last part of paragraph 1 of "Exemplar Modeling" and in "Crushed Vehicle Modeling."What is a screenshot? This is explained in the middle of the "Camera Calibration" paragraph.What is EBS? Why was the research based on Cooper's work? How do you know Cooper's work is correct? Need a short discussion of Cooper's work and discussion of the tables in Appendix 2. The "EBS Determination" section has been revamped.What is bootstrapping? How do you do it? Discuss the two main tables, explain the data. Substantial additions have been made to the bootstrapping section.Why was a study of "between subjects" vehicles undertaken? This is answered in paragraph 4 in the "Introduction."

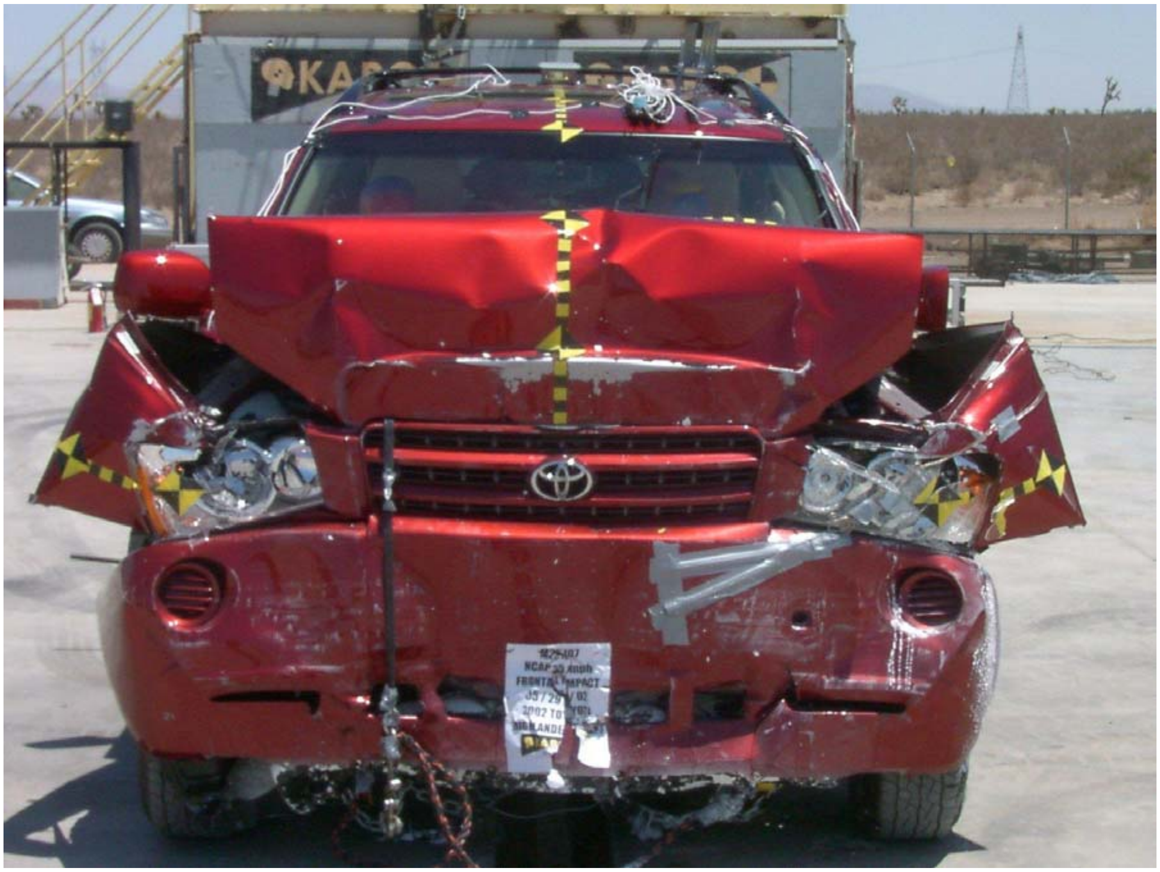
How are these results applicable to accident reconstruction? This paper could be very helpful if fleshed out. It's obvious the authors know their subject matter, it just needs to be presented so others can understand and use it. Remember the scientific method; the results need to be repeatable by others.

REVIEW #2

Crush coefficients (presumably 'A' and 'B' can be easily calculated using the elemental physics inherent in the Crash3 equations used to calculate EBS. If one is not an engineer, one could purchase these from a source such as Neptune but why anybody with even a remote scientific education would do so is beyond me. The authors should clearly state how they determined 'A' and 'B'. I sincerely hope they calculated them based on the actual crash test data (measured crush, measured speed, measured weight, etc.). I would hope that authors of an SAE paper do not purchase them from someone who uses unknown methods to calculate them (remember that Neptune does that idiotic 'airgap' adjustment and therefore has highly suspect 'A' and 'B' values). A whole new section has been devoted to this—it is entitled "Crush Coefficient Determination."

This paper is actually two studies. First of all, Photomodeler determined measurements so this is actually a study of how well Photomodeler can model measurements made on crash tested vehicles. A statistical study should have been done on how well these crush measurements were determined. The second part of the study is really a sensitivity study on using those measurements from photomodeler and a Crash3 model, how well can EBS be determined based on these errors in crush measurements. These two aspects of the paper should have been much more clearly presented. I would like to see a percent error in crush measurements using Photomodeler before showing EBS conclusions. This is an excellent suggestion, however; it is not feasible due to the intrinsic features of PhotoModeler. There is a way this could work, but it would require that I work closely with the folks at Veridian, TRC, and Karco Engineering---there's no way I could do this before the paper deadline. Let me explain. Look at the following figure. Veridian clearly took this picture after the crash test—you can see c1 thru c6 very clearly indicated with little crosses. We know exactly where the CMM measured.

Now look at the next picture from Karco:



Where exactly are c1-c6? Your guess is as good as mine. I would imagine that it's somewhere in the vicinity of the bumper area. With PhotoModeler, I didn't always measure the bumper (unless it had a distinct feature on it.) Hence, my measurements would most likely be totally different than theirs; but I think they are suitable, because a resultant speed around 35 mph is almost always achieved. Bumpers are rounded and smooth; PhotoModeler needs distinct points for modeling. A curve is not acceptable for measurement extraction. I typically used the badging, edges of the hood, parts of the headlight, and other clear features that are easily seen on the crushed vehicle as well as the exemplar. What you are suggesting would require three things: 1. Prior to testing, the test vehicle would have to be marked with c1—c6 across the bumper. 2. Photos of the exemplar test vehicle (with the "c" marks clearly visible in a lot of the photos) would need to be taken. 3. Photos of the crushed test vehicle need to be taken, again with the "c" marks easily seen. If Veridian (or Karco) and I could agree where we would both measure, your proposition would work. It would be a dandy at that. But this study took a somewhat different direction, and got reasonable results. If I had the time and resources, I certainly would like to do it your way---it is a more comprehensive approach, and would make a better paper, but not very feasible at this juncture, considering the deadline is in a couple of days.

Since part 1 of the suggestion is unresolved, part 2 of the suggestion can't be pursued, but is a good idea nonetheless.

In all of the NHTSA tests I have examined, measured impact speed is given to one or two decimal places yet the authors seem to be reporting much more precise values than that. How did they get these very precise values from test reports. I assumed they used the speed trap data reported in the reports which is the only accurate way of doing this. I assume they didn't use integrated accelerometer data over speed trap data. Reporting actual test velocity to 8 decimal places is ridiculous and needs to be removed from any SAE paper. Please clarify this. Done. The values were initially just pasted from the spreadsheet, which explains the excessive digits. You are not the first to say this. It should have been resolved previously.

In conclusions, remove the statement, "Both of these CI's would be acceptable to an accident reconstructionist." This is editorializing. It may be correct. It may be wrong. But there is no analytical basis in this paper to state what would or would not be acceptable to an accident reconstructionist. Done.

Remove all references in the abstract and elsewhere to what is acceptable or not. Report your data as a scientist. Do not editorialize about what is acceptable or not in accident reconstruction. You may do that in a courtroom if you want but not in a scientific paper. You are not the judgeof what is acceptable or not. Done.

Remove the entire last paragraph. The results speak or themselves. The authors are not the judge by which accident reconstruction tools are divined to be acceptable or not. The authors did a study and presented the results.It may be acceptable. It may not. There is no analytical basis with which to say Photomodeler is or is not "an appropriate crush measurement tool." Done.

Describe the bootstrapping method a bit more fully. It is not in wide use in accident reconstruction. Substantial additions have been made to the bootstrapping section.

Overall, evaluate your significant figures (decimal places) used in the paper. It seems to be an exercise by someone who has lots of digits on their calculator but doesn't know when to cut them off. Done.

Not a bad paper but these changes will make it acceptable for publication.

REVIEW #3

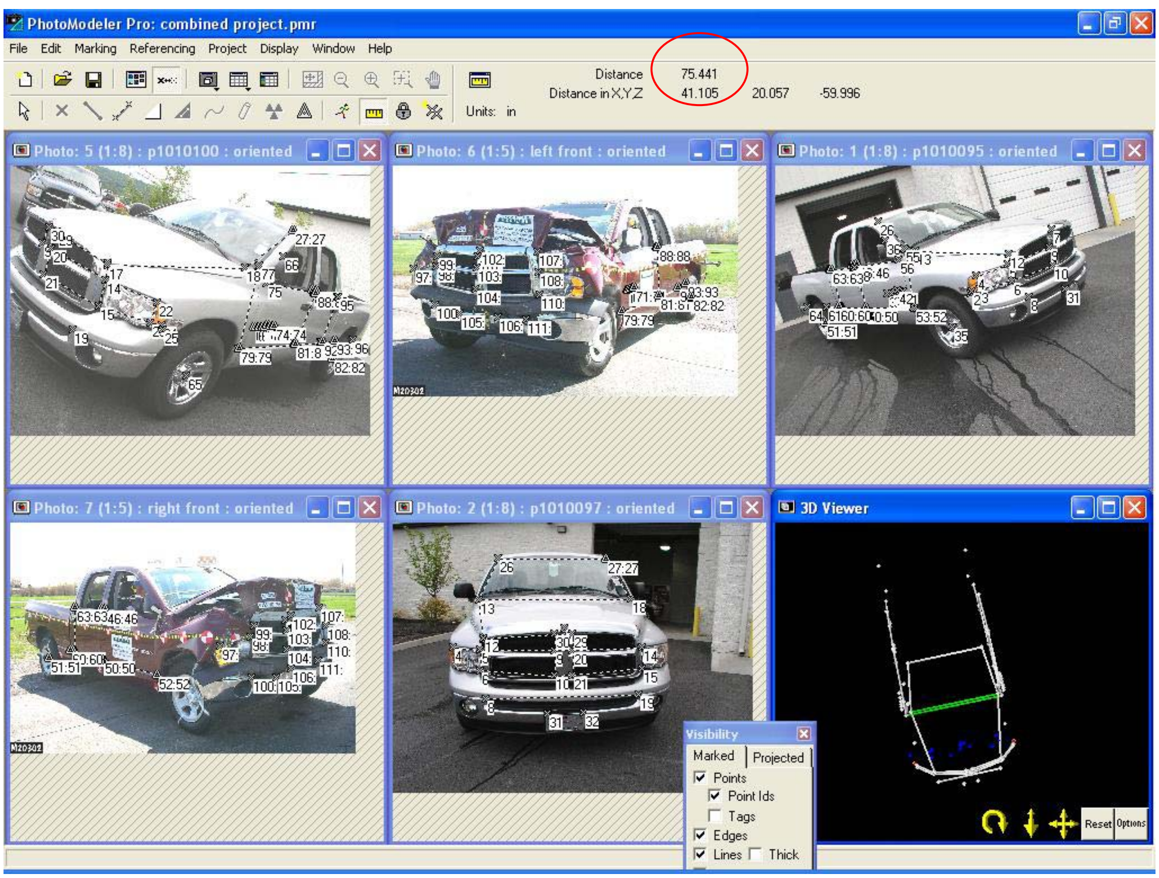
I recommend the paper be accepted if modified.
The paper is well done however, I believe the data used in the paper (study-analysis) is not a true indicator of "real world data." The damage measurements of crush both in "c"

measurements and total damage width and vehicle weight is not representative of real world data due to the level of precision that was used. I would suggest that values of crush and weight be taken to the tenth or whole number. Taking this data to the hundred or thousand is unrealistic and any outcomes derived from this type of data is not indicative of the real world, making this papers' analysis and findings not as valuable as they can be for study.

The vehicle's weight "precision" is due to a conversion from kilograms (from the NHTSA test report) to lbs. (see Figure 4.) This was done in a spreadsheet, and I just left the extra digits where they were. This wasn't an attempt to be overly super-accurate; I just intended to round off the numbers in the end of the analysis. Now on the "c" measurements and the width of crush measurements, those numbers were directly copied from PhotoModeler—no joke. Let me illustrate with a screenshot:

Note that for the Dodge Ram that the width of crush is 75.441 inches, which is indicated with a red circle. This is what PhotoModeler gives me, and that's what I used in the analysis. The computations themselves for this vehicle are shown in Appendix B, second page, second row. I can't illustrate for all of the "c" measurements, but they are the same way also.

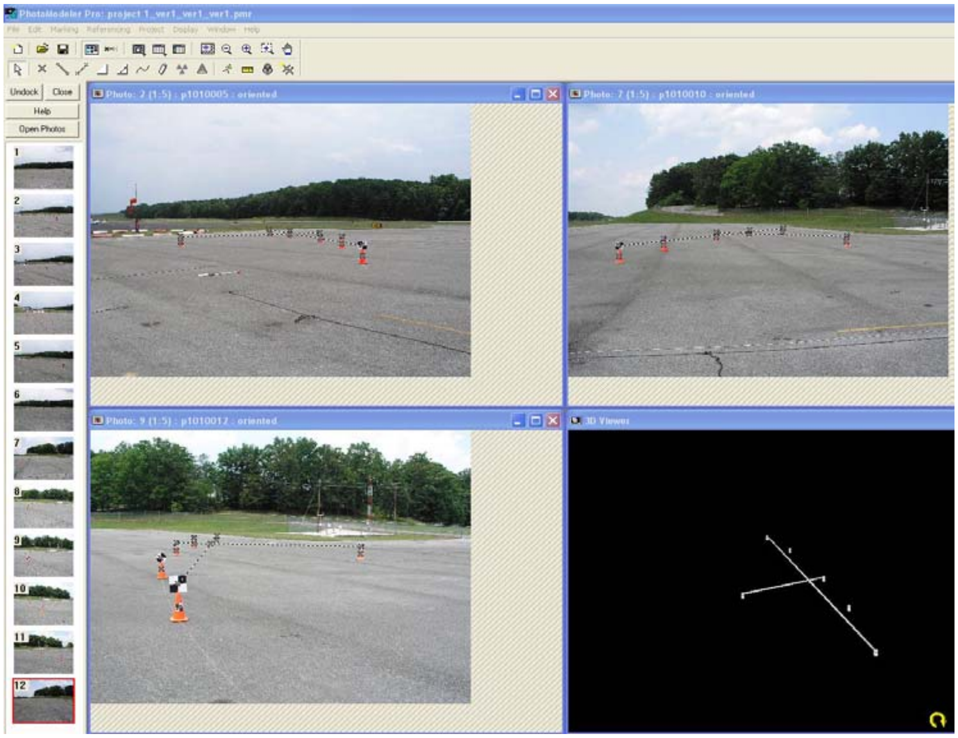
You are not the first to bring this subject up. I did allow the numbers to get to a ridiculous amount of precision in the spreadsheet, but I did, in this revision, modify the EBS's to a more agreeable accuracy.



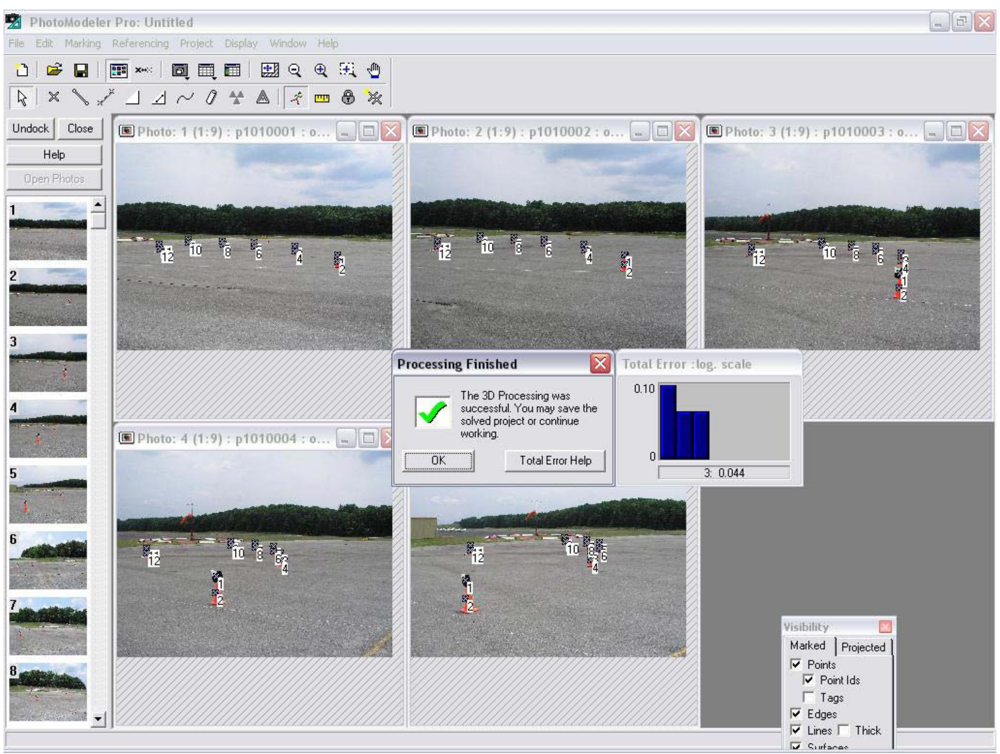
APPENDIX 11

SCREENSHOTS FOR PART TWO

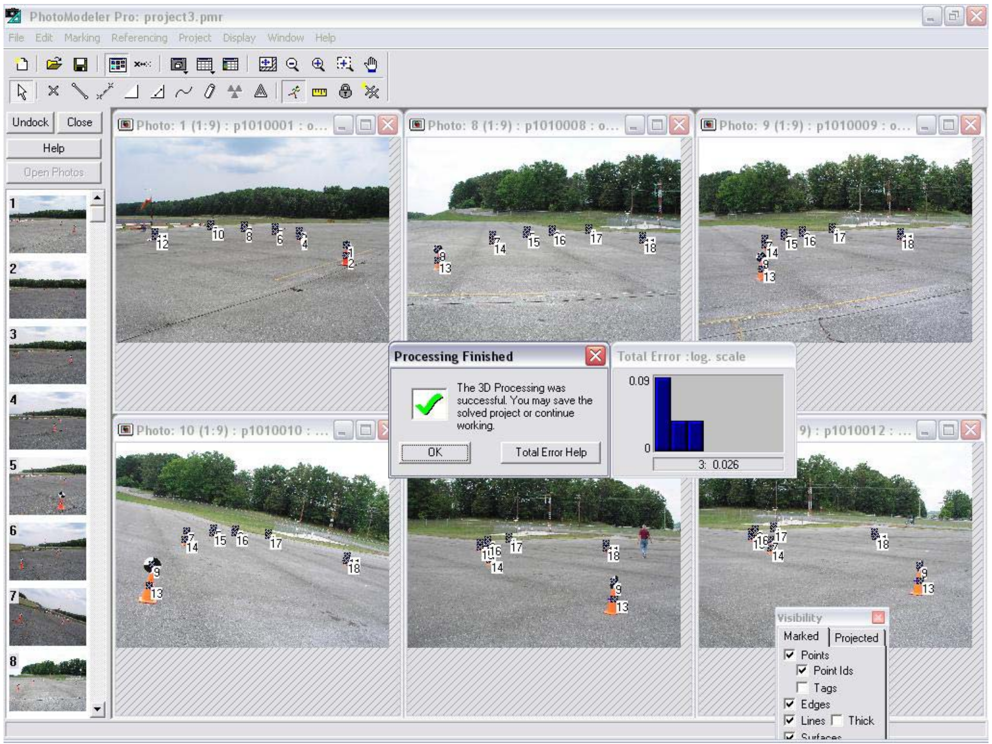
Case 1



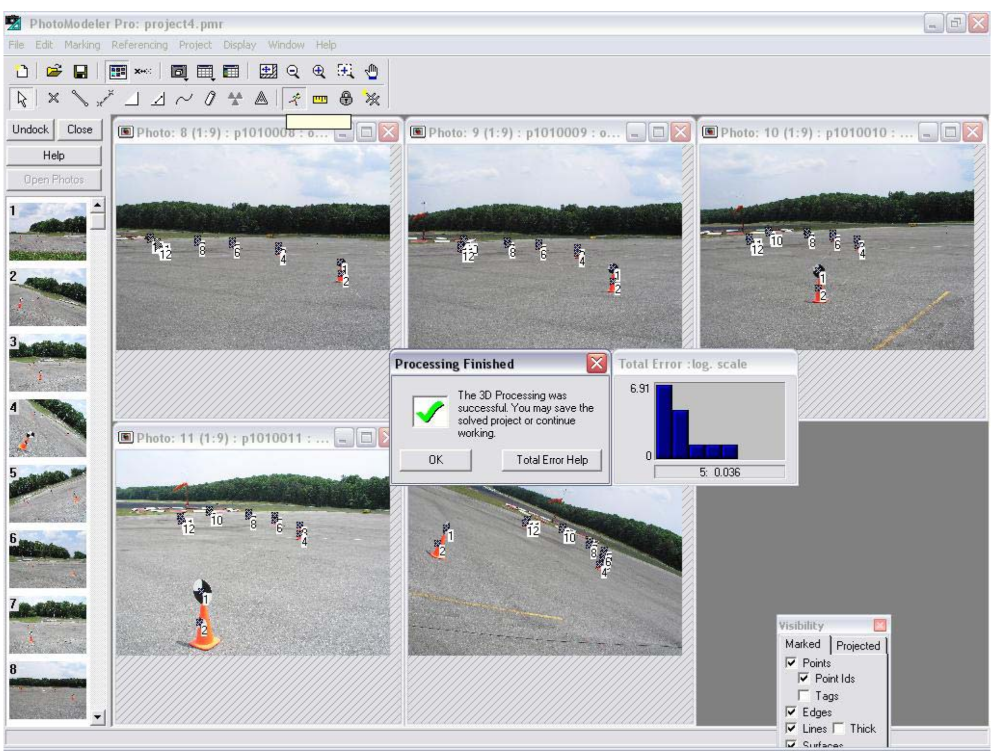
Case 2


PhotoModeler Pro: Untitled
File Edit Marking Referencing Project Display Window Help
Undock Close
Help
Open Photos
Photo: 1 (1:9) : p1010001 : o...
Photo: 2 (1:9) : p1010002 : o...
Photo: 3 (1:9) : p1010003 : o...
Photo: 4 (1:9) : p1010004 : o...
Processing Finished
The 3D Processing was successful. You may save the solved project or continue working.
OK
Total Error Help
Total Error :log. scale
0.10
0
3: 0.044
Visibility
Marked
Projected
Points
Point Ids
Tags
Edges
Lines
Thick

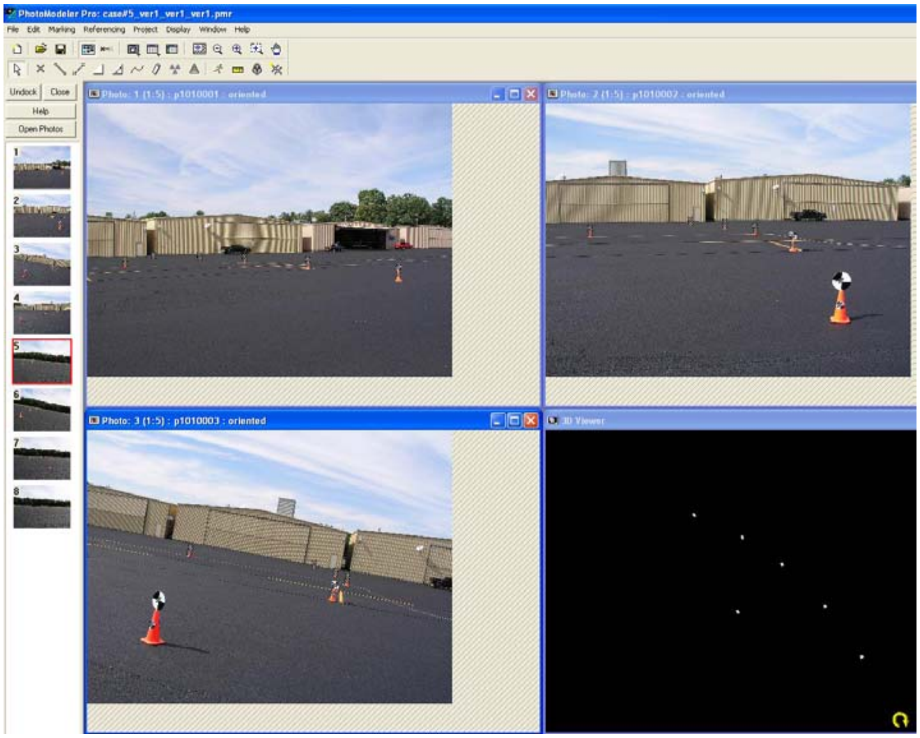
Case 3


PhotoModeler Pro: project3.pmr
File Edit Marking Referencing Project Display Window Help
Undock
Close
Help
Open Photos
Photo: 1 (1:9) : p1010001 : o...
Photo: 8 (1:9) : p1010008 : o...
Photo: 9 (1:9) : p1010009 : o...
Photo: 10 (1:9) : p1010010 : ...
9) : p1010012 : ...
Processing Finished
The 3D Processing was successful. You may save the solved project or continue working.
OK
Total Error Help
Total Error :log. scale
0.09
0
3: 0.026
Visibility
Marked
Projected
Points
Point Ids
Tags
Edges
Lines
Thick

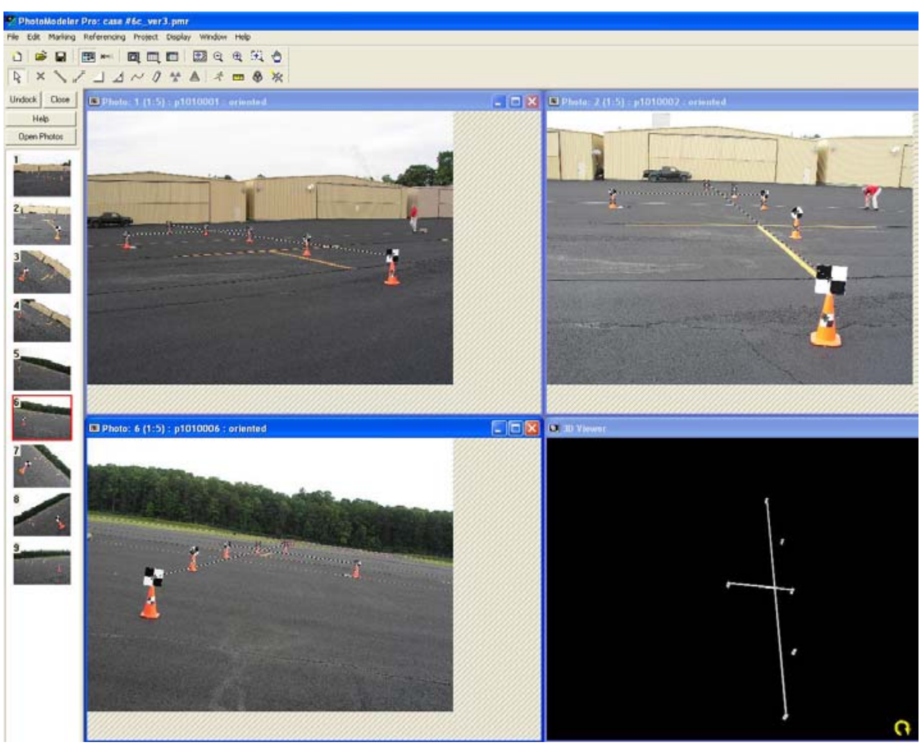
Case 4


PhotoModeler Pro: project4.pmr
File Edit Marking Referencing Project Display Window Help
Undock
Close
Help
Open Photos
Photo: 8 (1:9) : p1010008 : o...
Photo: 9 (1:9) : p1010009 : o...
Photo: 10 (1:9) : p1010010 : ...
Photo: 11 (1:9) : p1010011 : ...
Processing Finished
The 3D Processing was successful. You may save the solved project or continue working.
OK
Total Error Help
Total Error :log. scale
6.91
0
5: 0.036
Visibility
Marked
Projected
Points
Point Ids
Tags
Edges
Lines
Thick

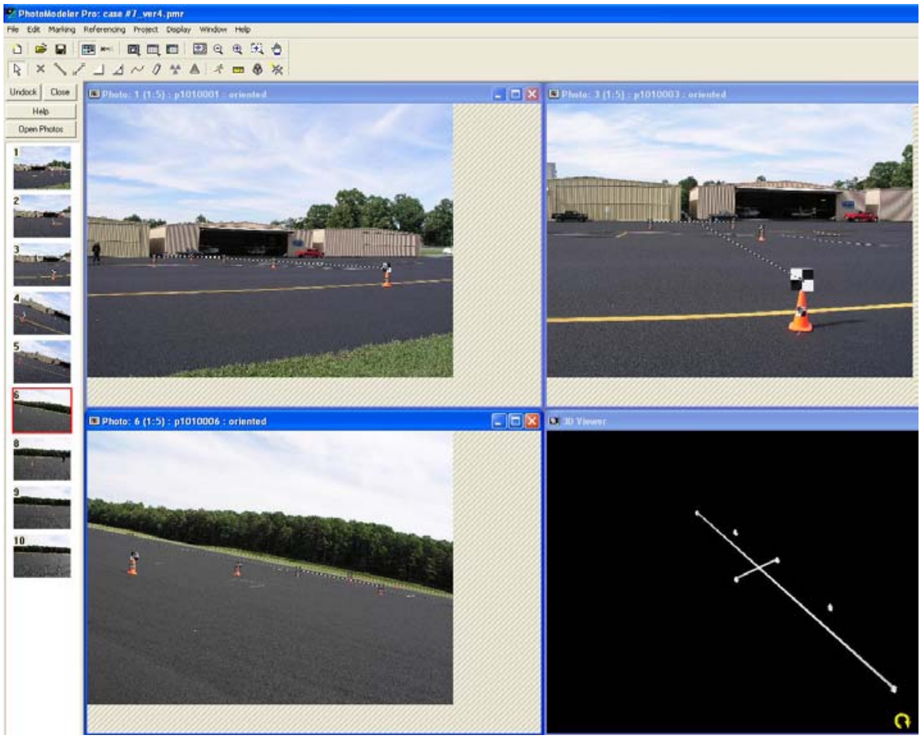
Case 5


PhotoModeler Pro: case#5_ver1_ver1_ver1.pmr
File Edit Marking Referencing Project Display Window Help
Undock Close
Help
Open Photos
Photo: 1 (1:5) : p1010001 : oriented
Photo: 2 (1:5) : p1010002 : oriented
Photo: 3 (1:5) : p1010003 : oriented
3D Viewer

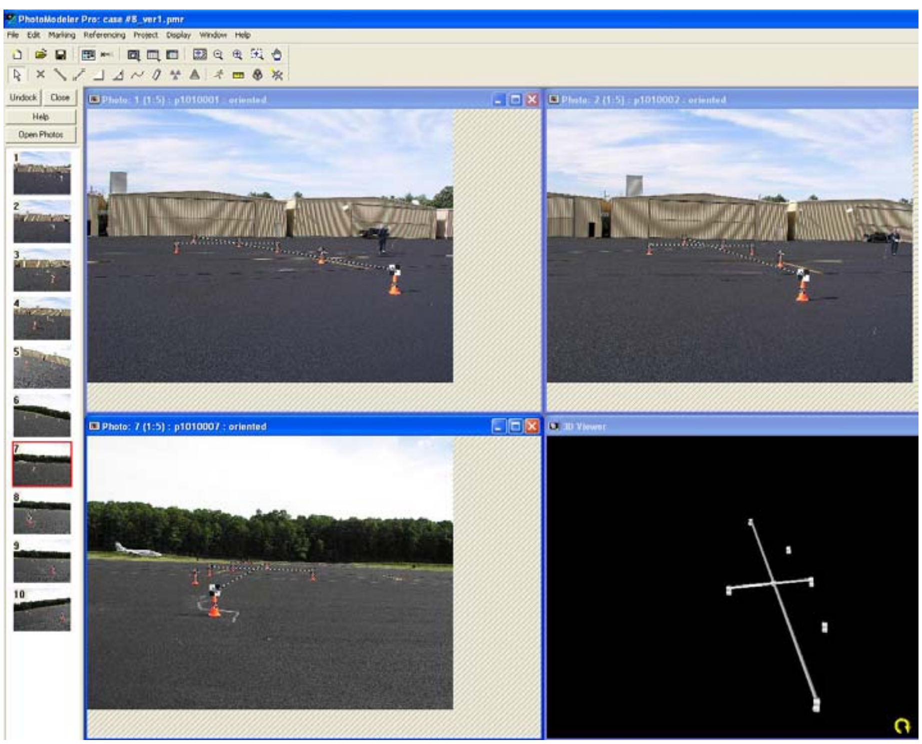
Case 6


PhotoModeler Pro: case #6c_ver3.pmr
File Edit Marking Referencing Project Display Window Help
Undock Close
Help
Open Photos
Photo: 1 (1:5) : p1010001 : oriented
Photo: 2 (1:5) : p1010002 : oriented
Photo: 6 (1:5) : p1010006 : oriented
3D Viewer

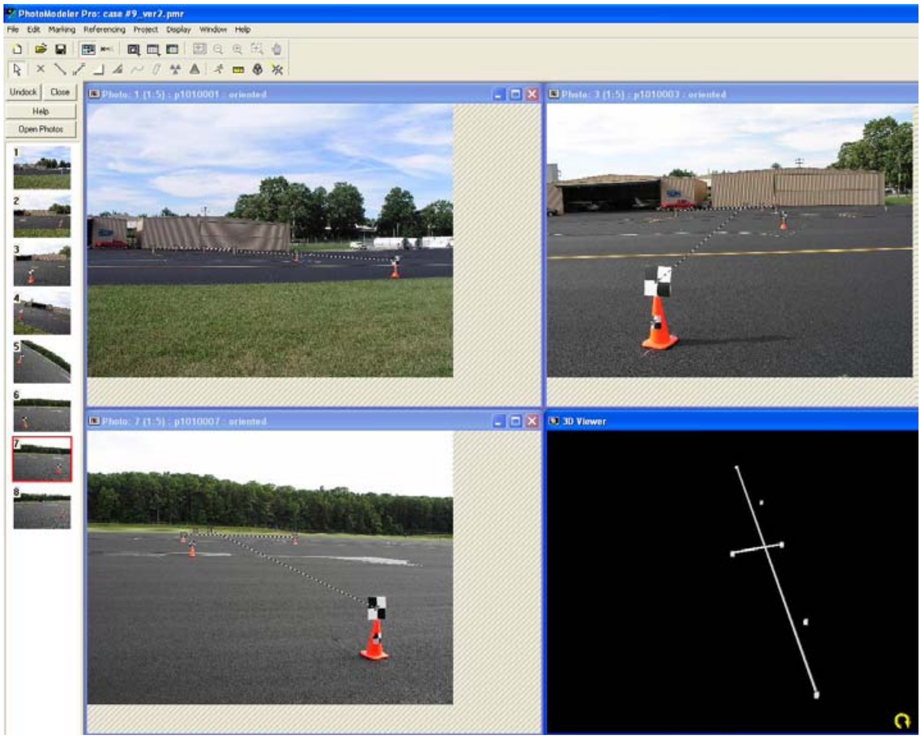
Case 7


PhotoModeler Pro: case #7_ver4.pmr
File Edit Marking Referencing Project Display Window Help
Undock Close
Help
Open Photos
Photo: 1 (1:5) : p1010001 : oriented
Photo: 3 (1:5) : p1010003 : oriented
Photo: 6 (1:5) : p1010006 : oriented
3D Viewer

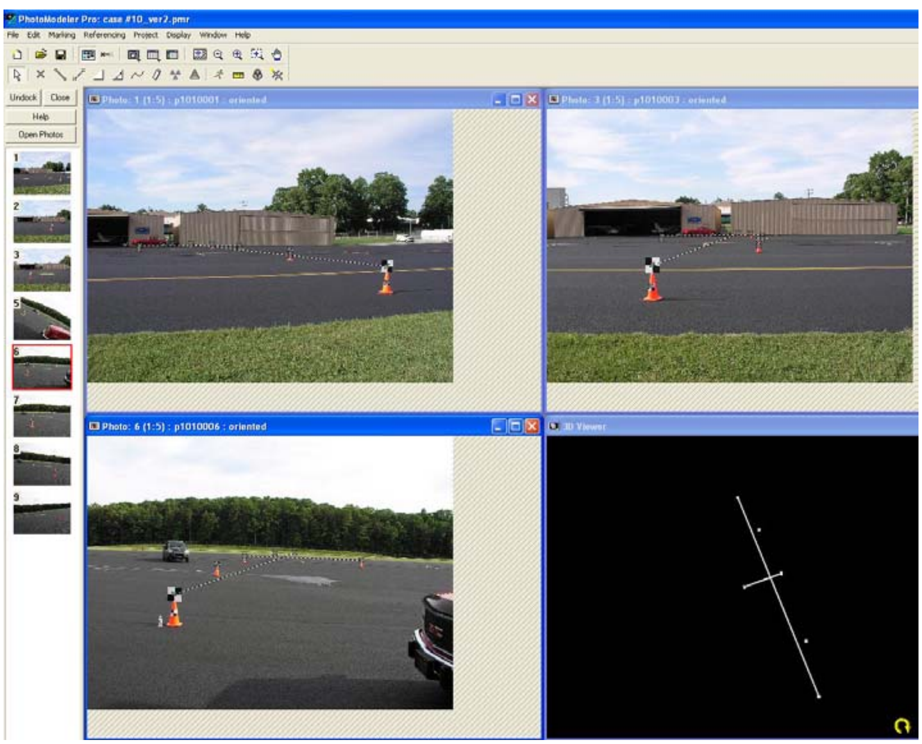
Case 8


PhotoModeler Pro: case #8_ver1.pmr
File Edit Marking Referencing Project Display Window Help
Undock Close
Help
Open Photos
Photo: 1 (1:5) : p1010001 : oriented
Photo: 2 (1:5) : p1010002 : oriented
Photo: 7 (1:5) : p1010007 : oriented
3D Viewer

Case 9



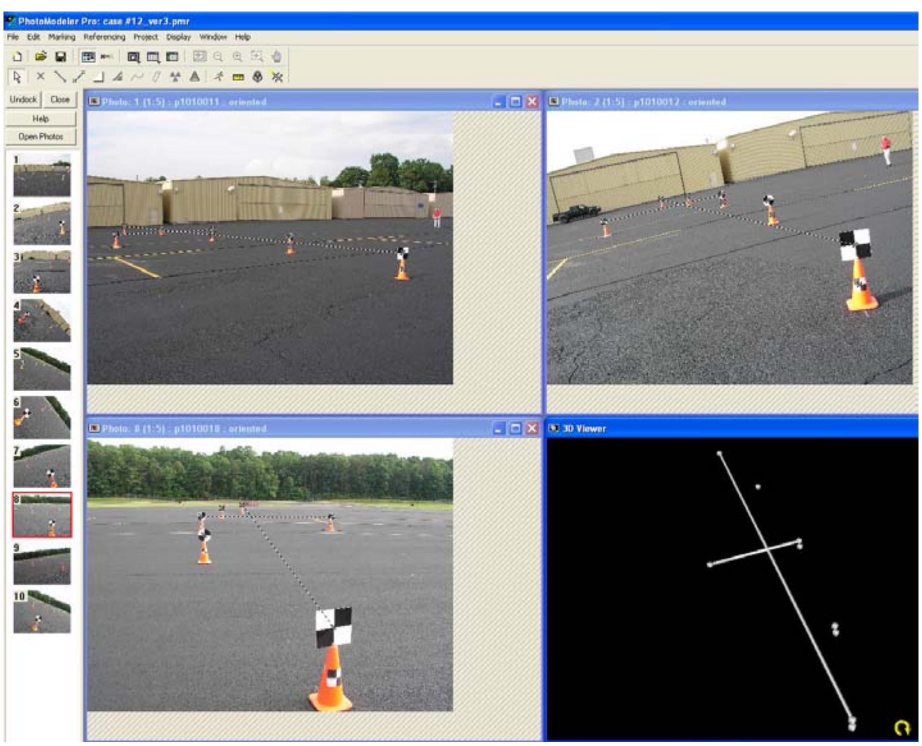
Case 10



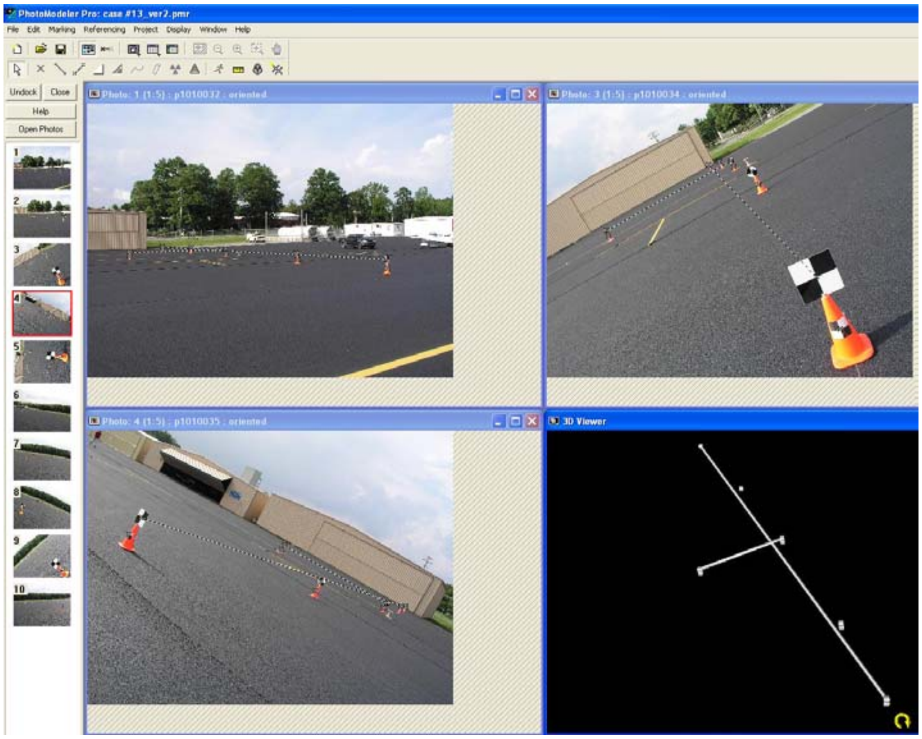
Case 11

Missing Due To Hard Disk Crash

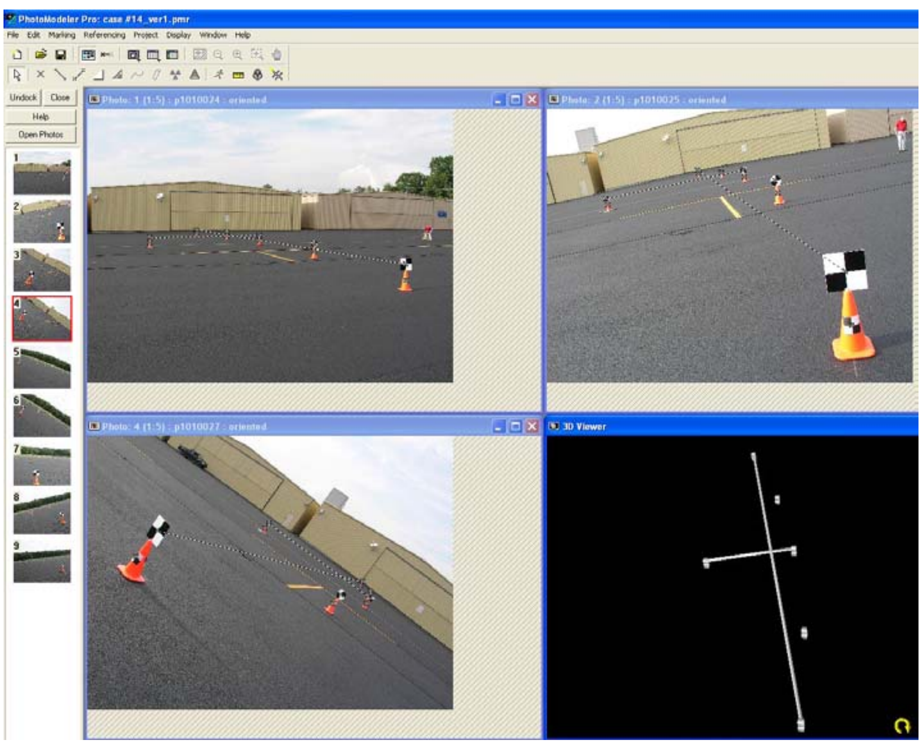
Case 12



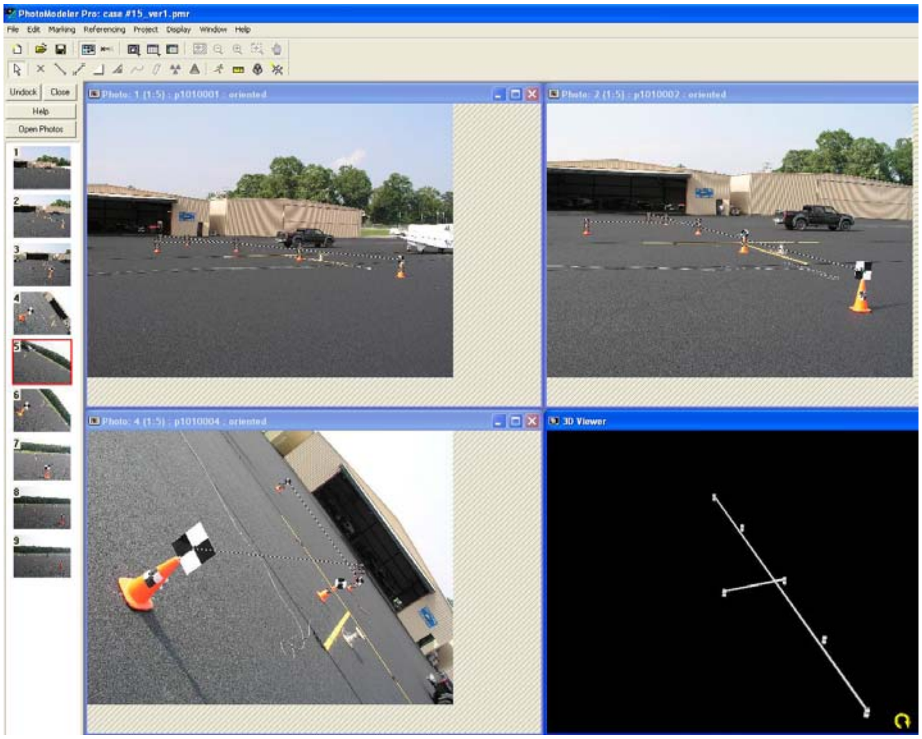
Case 13



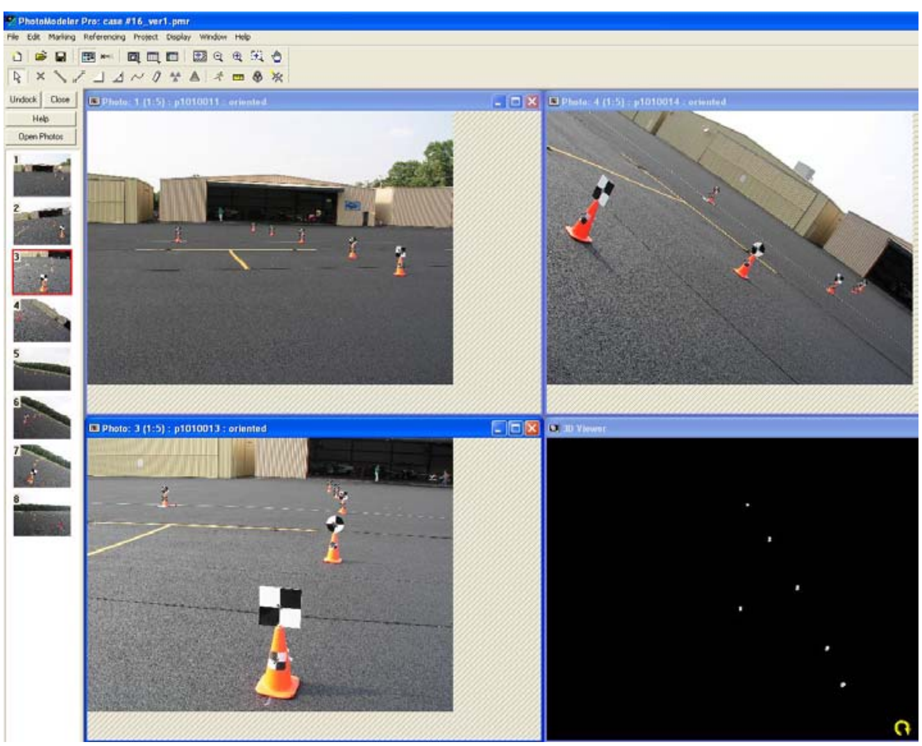
Case 14



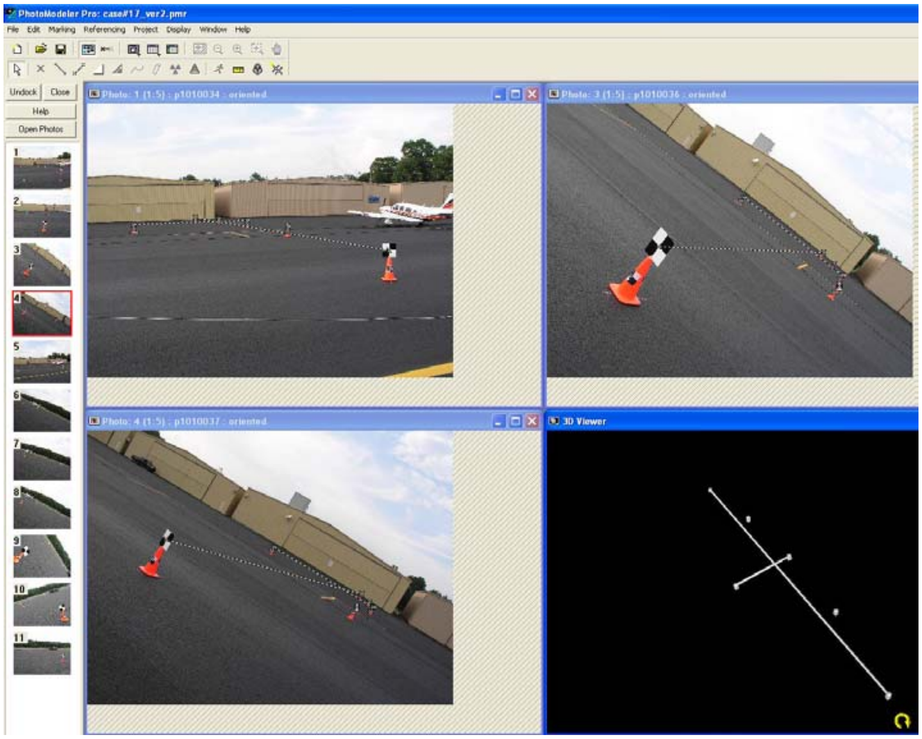
Case 15



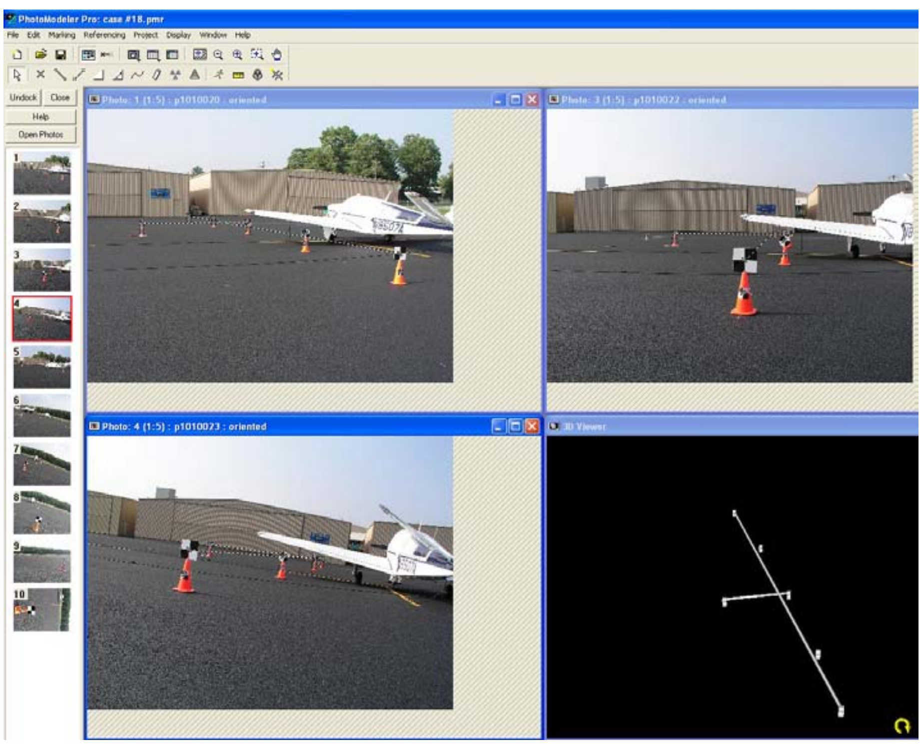
Case 16



Case 17



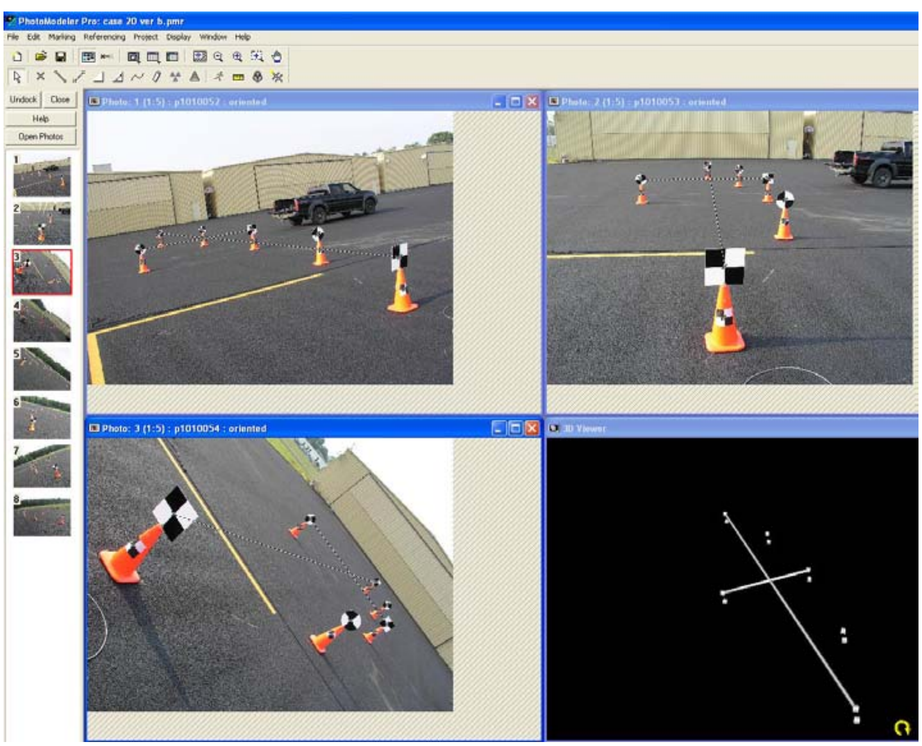
Case 18



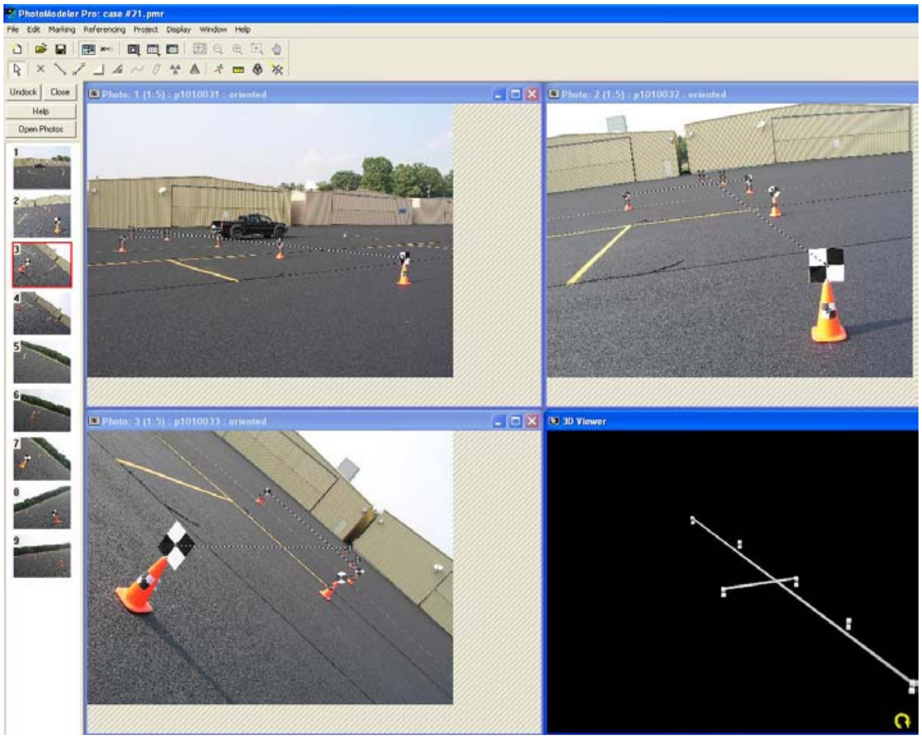
Case 19

Missing Due To Hard Disk Crash

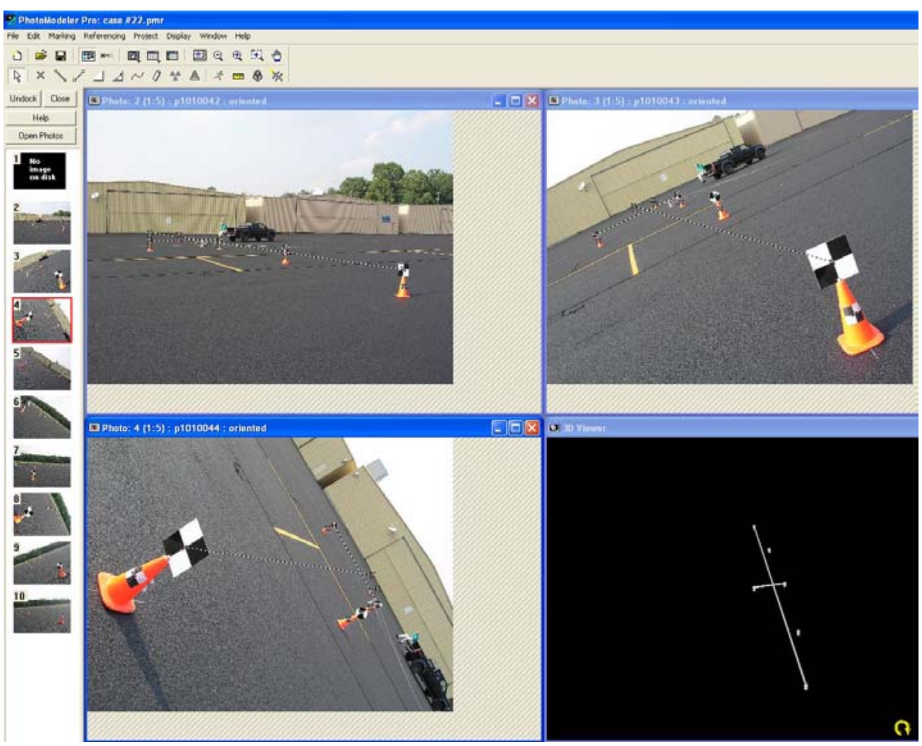
Case 20



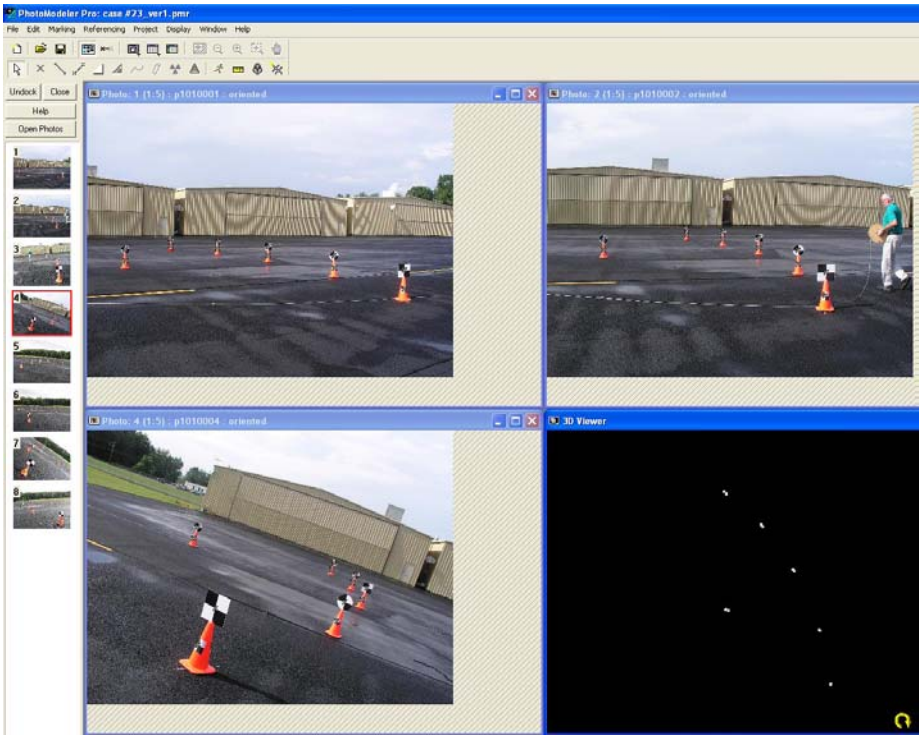
Case 21



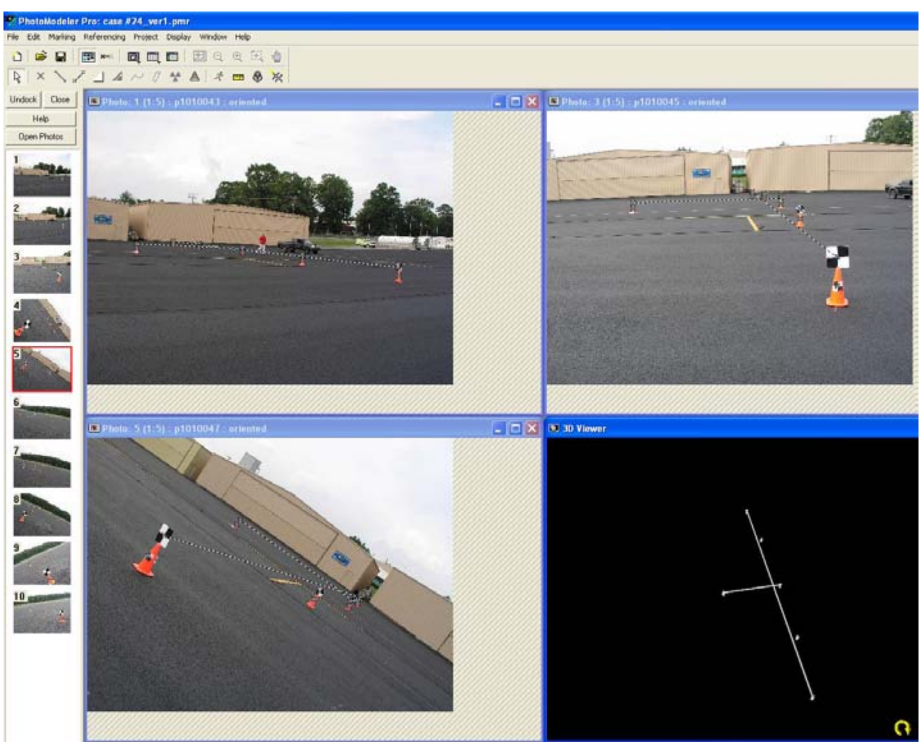
Case 22



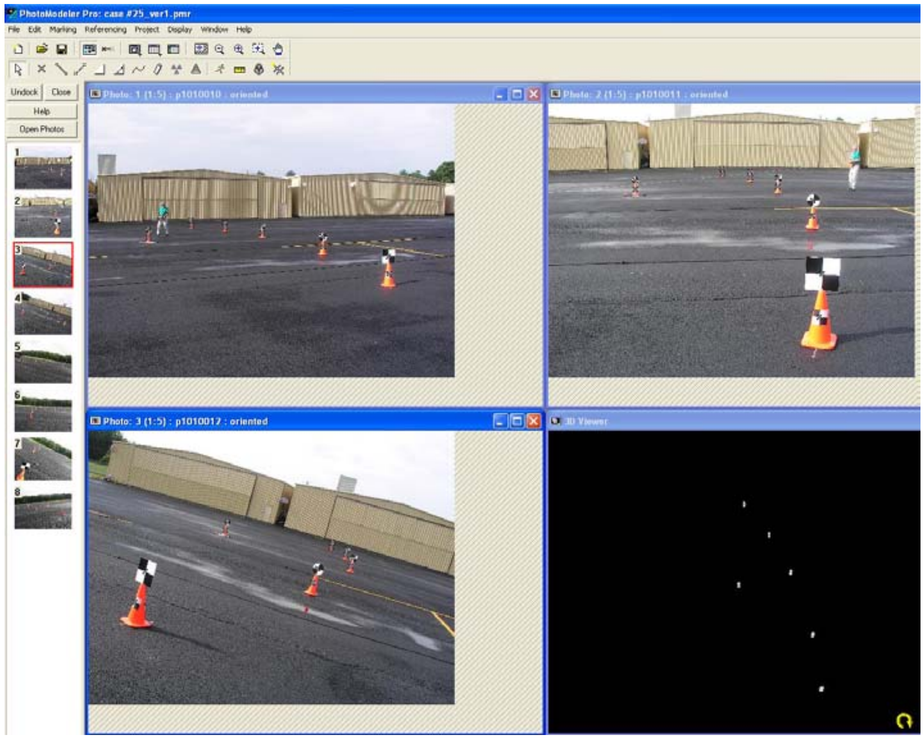
Case 23



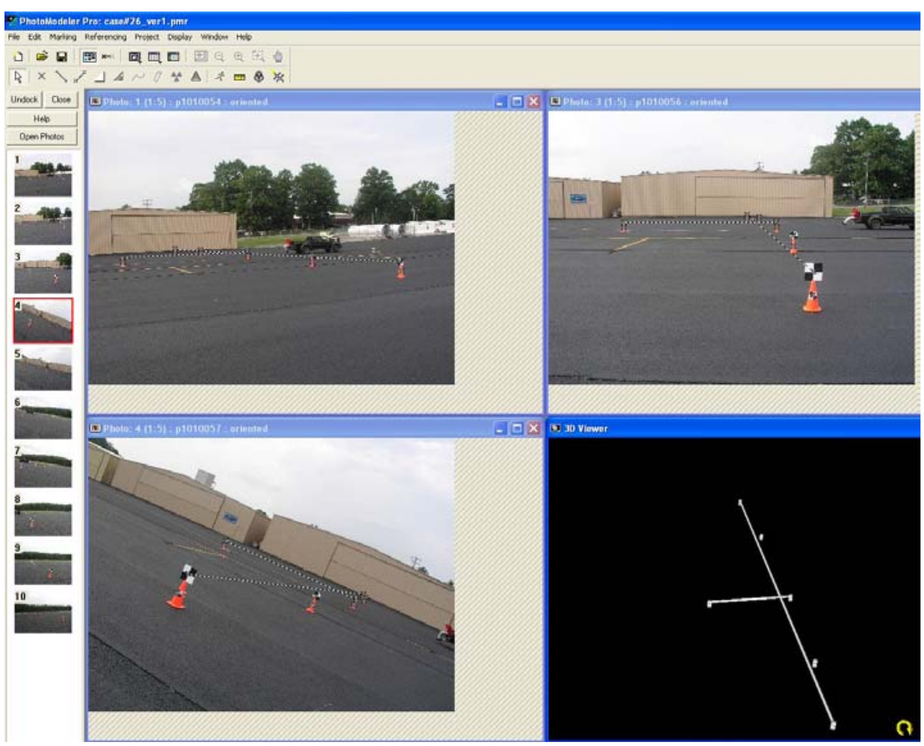
Case 24



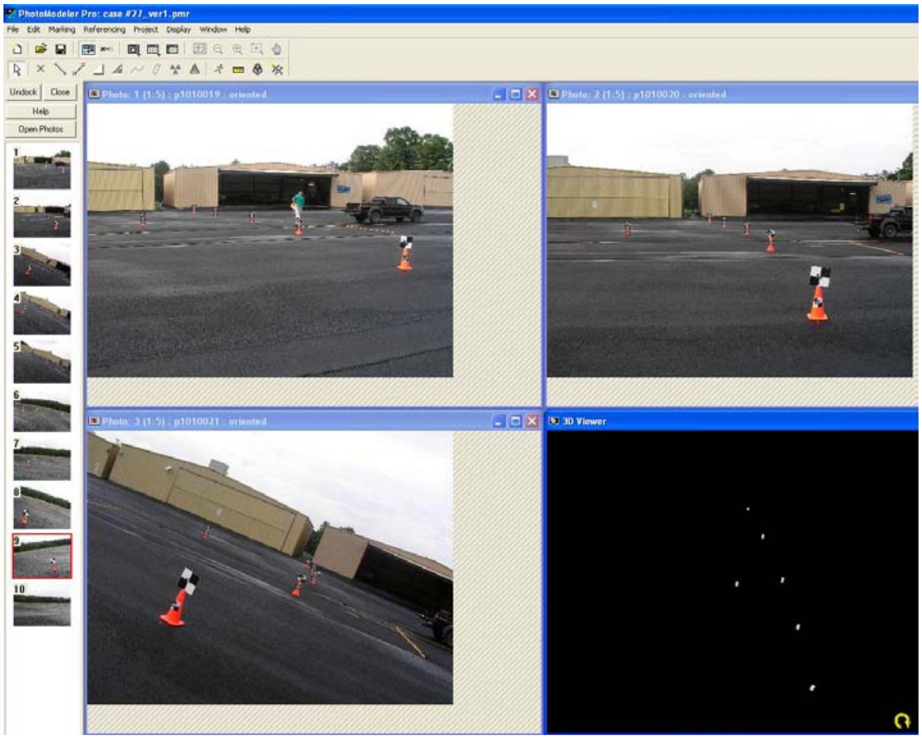
Case 25



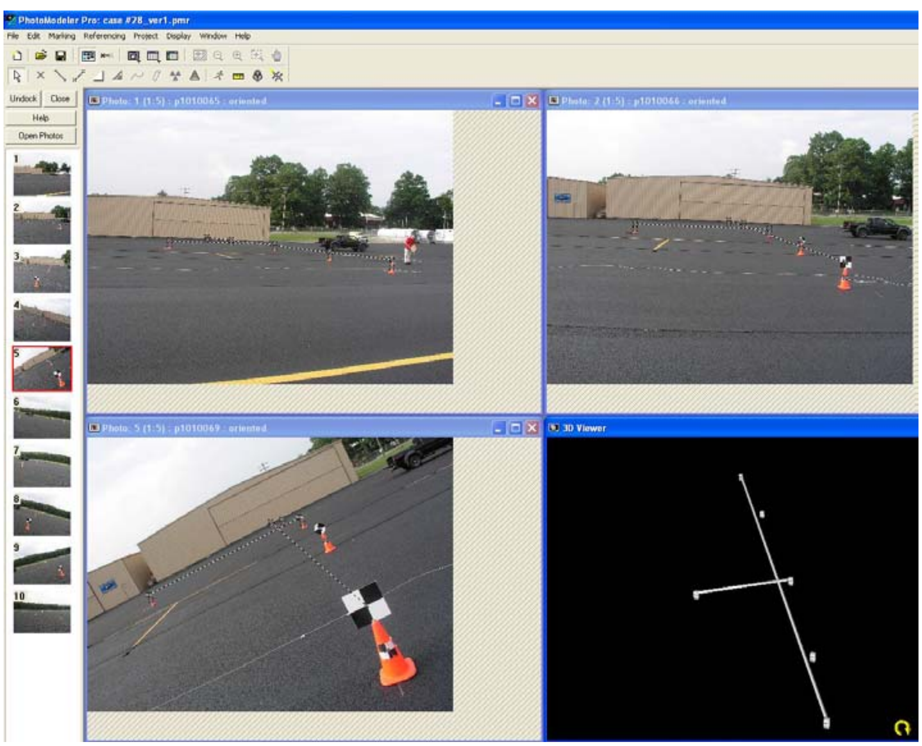
Case 26



Case 27



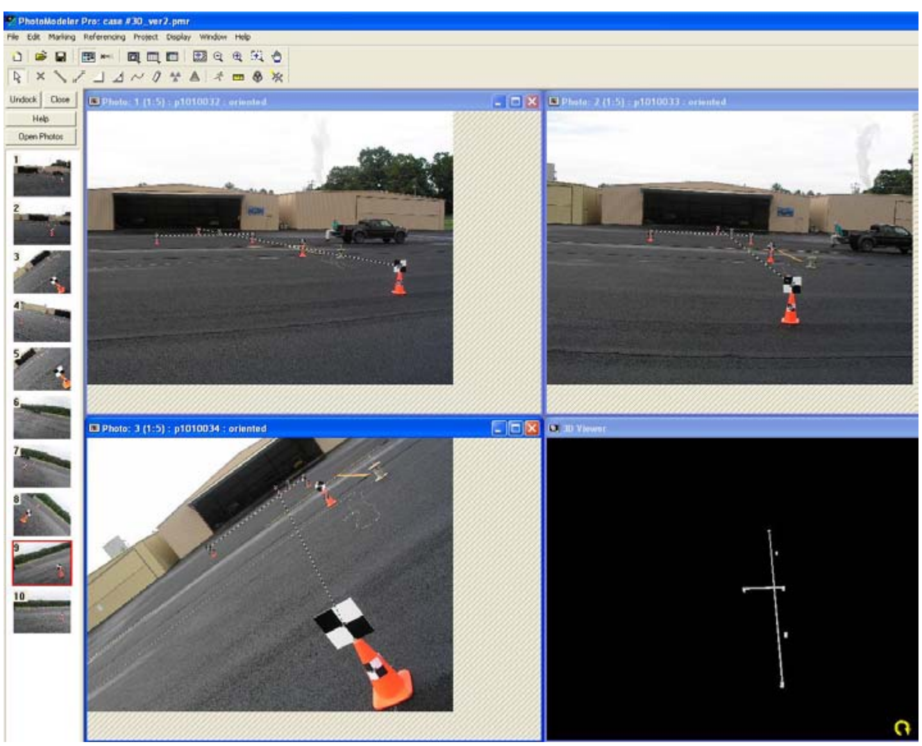
Case 28



Case 29

Missing Due To Hard Disk Crash

Case 30



APPENDIX 12

REVIEWERS' COMMENTS
PART TWO

Your SAE Paper is not approved for publication this year. Please see comments below. If after reviewing these comments, signifiant changes are made, we would invite you to resubmit for next year (2006). Thank you for the submission.

Michael Varat
co organizer

Reviewer:
Professional Experience Well Qualified
Previously Published Yes
Status Disapproved

5 Quality
3 Reference
4 Innovative
7 Integrity
6 Presentation
5 Conclusions

Comments:

The accuracy of photogrammetry has been well established in the literature already and the accuracy of PhotoModler has similarly been established. As the authors point out the CSF analysis has similarly been well published. This current work does nothing to further the knowledge or understanding of these 2 separate topics.

Reviewer:
Professional Experience Well Qualified
Previously Published No
Status Disapproved

6 Quality
3 Reference
3 Innovative
8 Integrity
5 Presentation
8 Conclusions

Comments:

This paper reports on the application of the PhotoModeler program to the measurements of road curvature. The authors report on this facet being an import portion of accident reconstruction, insofar as the application of the critical speed formula is concerned. As these authors are aware the PhotoModeler application has been validated in a number of publications for photographic measurement value. This paper appears to be consistent with the general research that the PhotoModeler software is useful for many different applications within Accident Reconstruction. In reviewing the research it was unclear to this reviewer it's direct application to the field. In many new applications of different software packages in the field, it is useful and required that actual field application be performed to demonstrate it's usefulness. It seems that this methodology demonstrates its usefulness on a flat curved roadway (such as an airport), and at least to this reviewer it is unclear how reliable it would be on a curved hilly roadway with a superelevation. Obviously the latter represents a more realistic need for critical speed calculations.

Reviewer:
Professional Experience Moderately Qualified
Previously Published No
Status Disapproved

3	Quality
3	Reference
3	Innovative
6	Integrity
8	Presentation
3	Conclusions

Comments:

The authors should be commended for conducting a well organized set of tests and describing the results clearly. That said, the study does not significantly expand on prior photogrammetry studies and the usefulness of the method is not established in the paper. Due to the limited scope and reference value of the study I cannot approve the paper for publication as it is. The following specific issues would need to be addresses:

The goal of the study, "to show that the measurement of l and h can be accomplished with photogrammetry", does not expand on prior studies (SAE 930662, 940925 and many others). Photogrammetry has been studied for some time by accident investigators and its ability to produce measurements with an acceptable level of accuracy has been established. A more ambitous, focused study is required to provide a contribution to the research. For example: a comparison of the accuracy of curve radii based on l and h from the photogrammetry method and the traditional tape measure method.

The usefullness of the specific method studied in the paper is not established. Since it relies on numerous photographs taken by a calibrated camera and a known measurement in the scene, improvements over the traditional tape measure or survey equipment methods for measuring chord and mid-ordinate are unclear.

The limitations of the method are not clearly explained. The study tested the best case scenario; a flat scene, known camera and a large number of photographs. The authors need to discuss the consequences of an unknown camera, only a few photographs, and a 3d scene - a common reconstruction scenario.

The method described in the paper requires a known dimension in the scene and the accuracy of the results are directly related to this dimension. The authors need to expand on how their scaling measurement was made, its accuracy, and how its accuracy effects the accuracy of their results.

In summary, this paper does not describe significant or useful results. It does however; summarize well-conducted tests that could be a first step towards a useful contribution for the application of photogrammetry in accident investigation.

APPENDIX 13

CAMERA CALIBRATION OF OLYMPUS C-5050
LOW RESOLUTION

Overview

As stated in Appendix 1, camera calibration involves the projection of a special grid pattern (the slide is provided by PhotoModeler with the software CD) onto a flat wall, and in this case, was done with a slide projector. The photos are taken of eight (8) different positions: upper, middle, lower, and middle vertical on both the left and the right sides. Next is the transfer of the digital photos to the computer. Points are marked and calibration begins by selecting “Calibrate” under the Calibration menu. After successful processing, the camera can be used as a measurement device with PhotoModeler.

Prepare for Picture Day

The process for calibrating a camera at high resolution is the exact same procedure for calibrating at low resolution. Interested readers can consult Appendix 1 for the fine details. A short, abbreviated documentation of the calibration will be shown here. Table 1 shows the Squareness Verification Data for low resolution.

Squareness Verification Data	
A=62.1875	C= 41.125 inches
B= 61.25	D= 40.875 inches
|A-B| < A/40	|C-D| < C/40
|.9375| < 62.1875/40	|.25| < 45.625/40
|.9375| < 1.555 ✓	|.25| < 1.028 ✓
Scaling distance between control points 1 & 4: **42.25 inches**	

Table 1. Squareness Verification Data

The following photos Figures 1-8 were the photos used in the low resolution calibration.

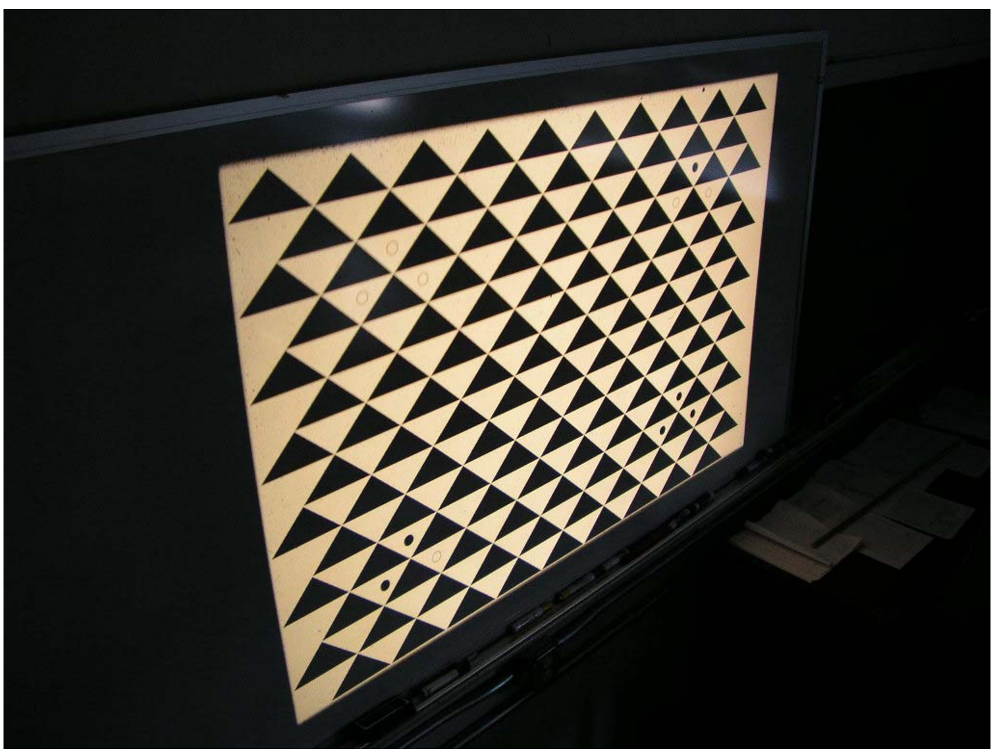


Figure 1. Upper Left Calibration Photo

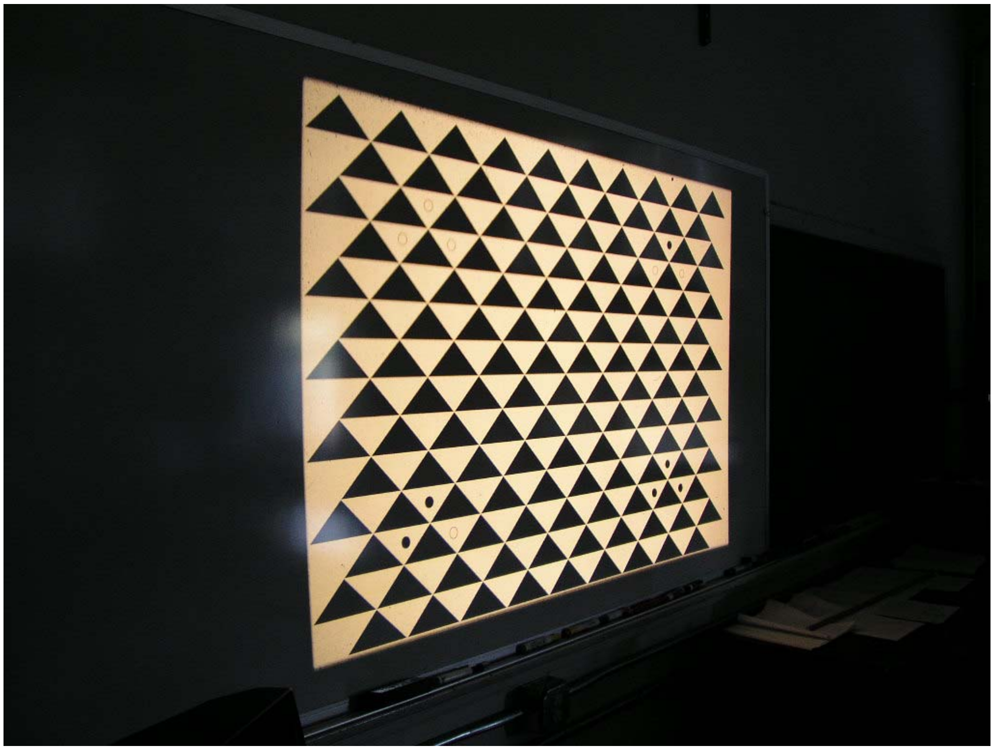


Figure 2. Middle Left Calibration Photo

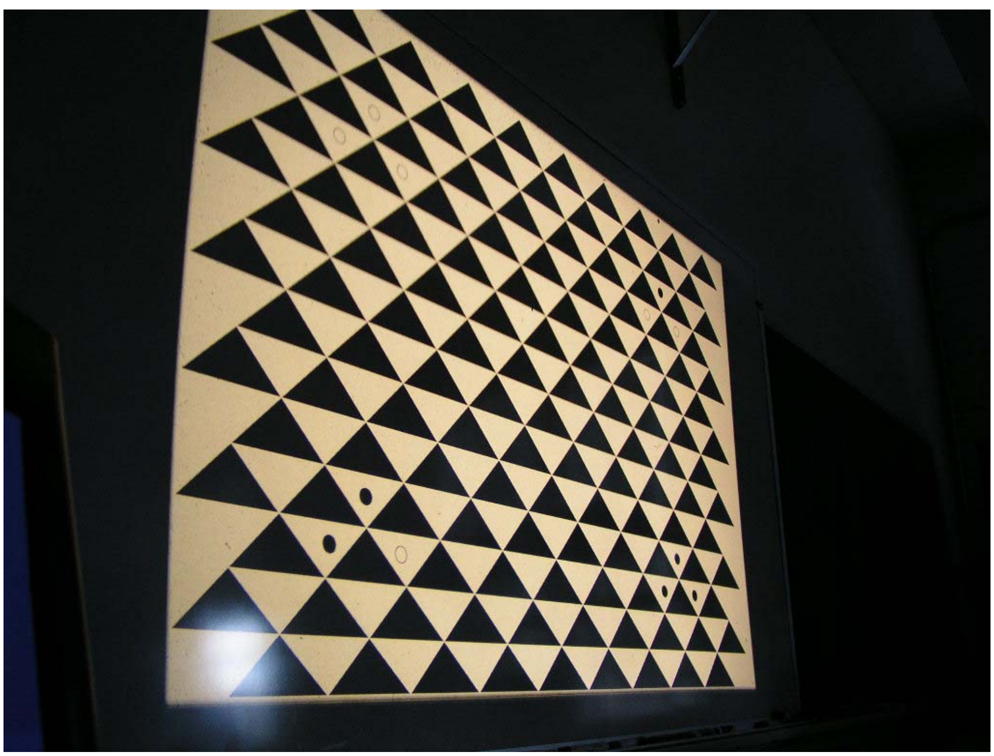


Figure 3. Lower Left Calibration Photo

Figure 4. Middle Vertical Left Calibration Photo

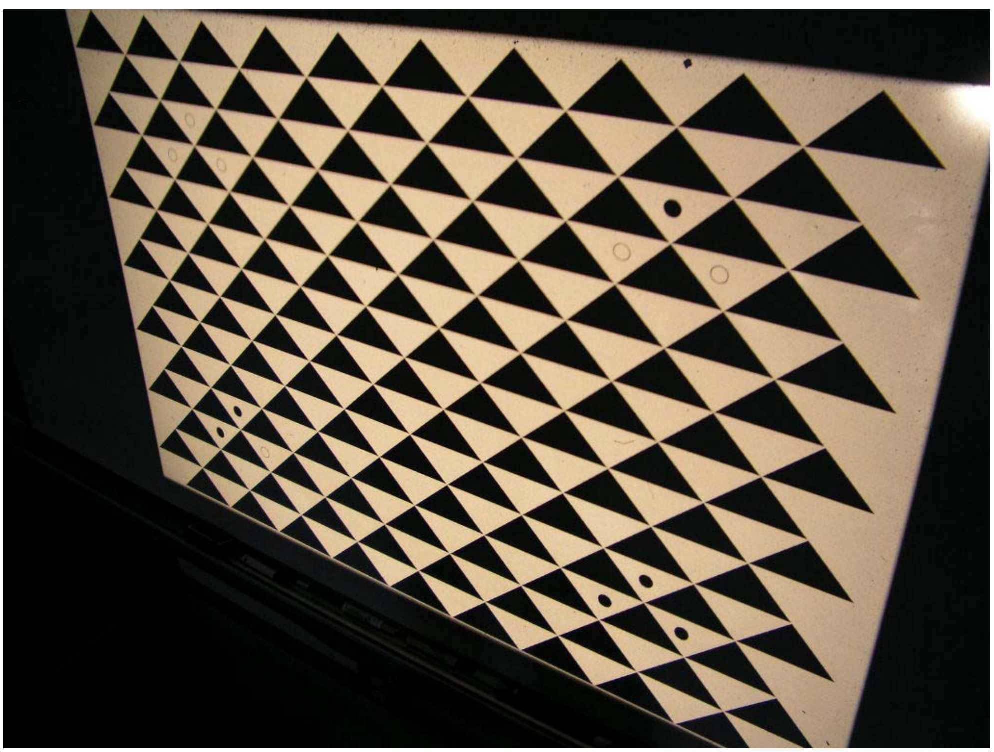


Figure 5. Upper Right Calibration Photo

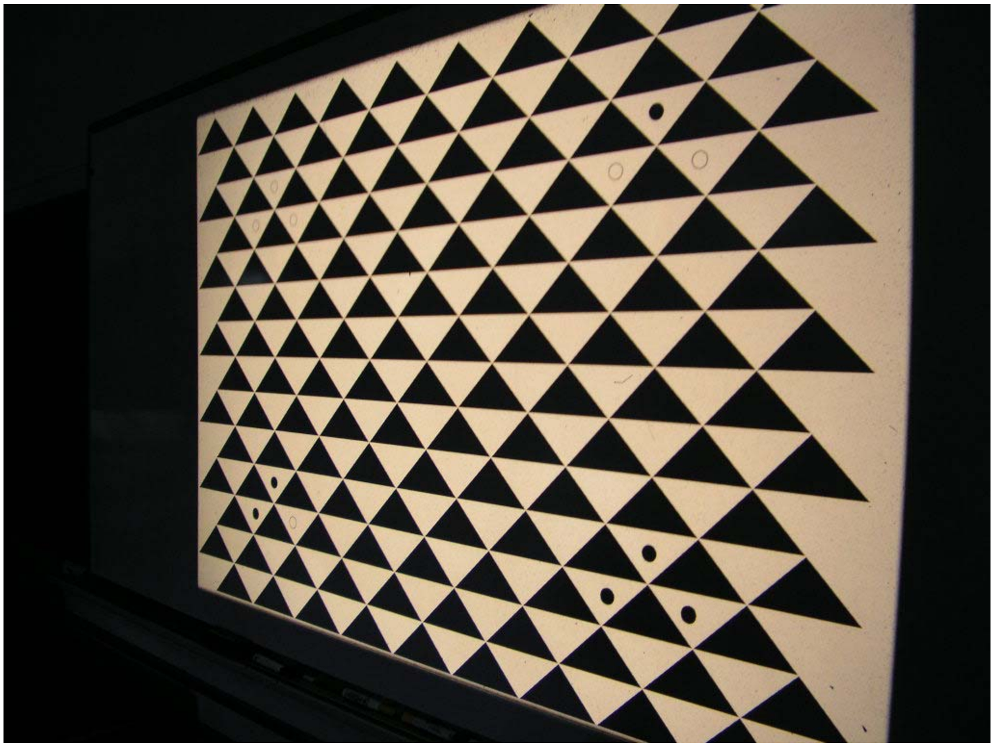


Figure 6. Middle Left Calibration Photo

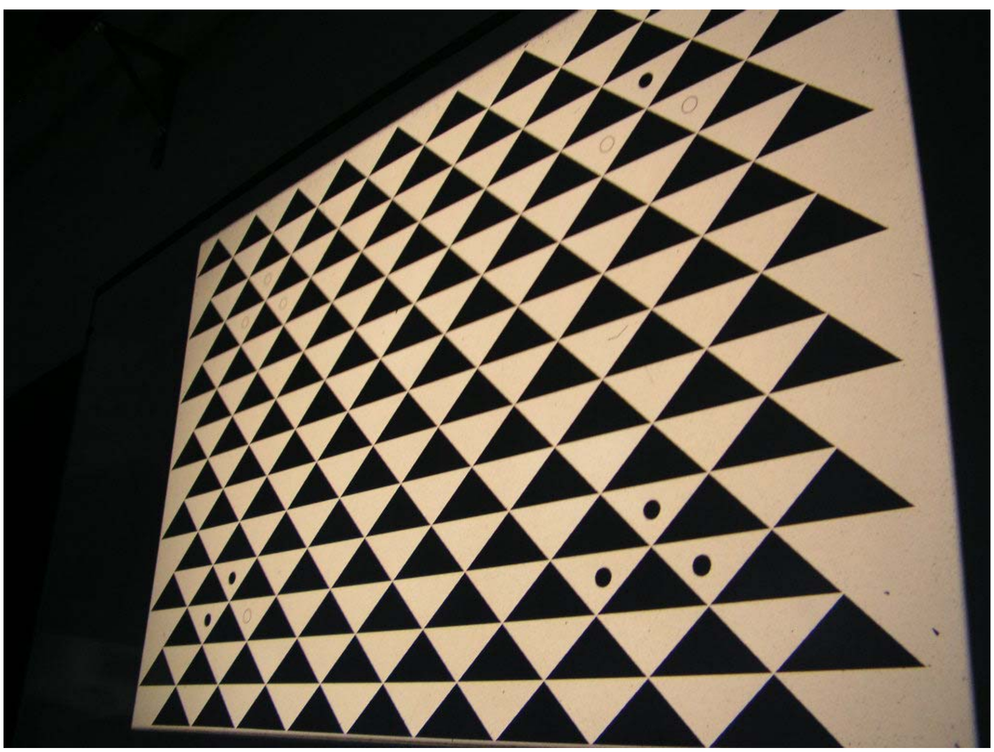


Figure 7. Lower Left Calibration Photo

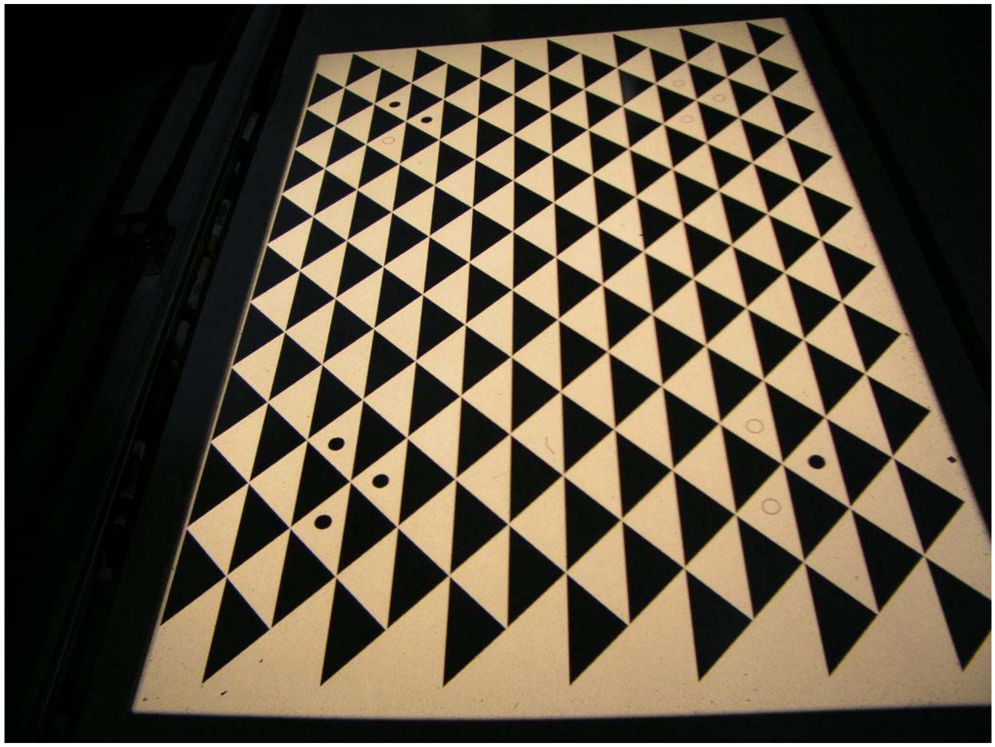


Figure 8. Left Middle Vertical Calibration Photo

After the user marks control points (using the special control point buttons at the top) and the Camera Calibrator's marking of the all visible triangle intersections, processing will follow. Figure 9 shows the error dialog which happens after successful processing. Figure 10 shows the camera parameters for the low resolution calibration of the Olympus C-5050

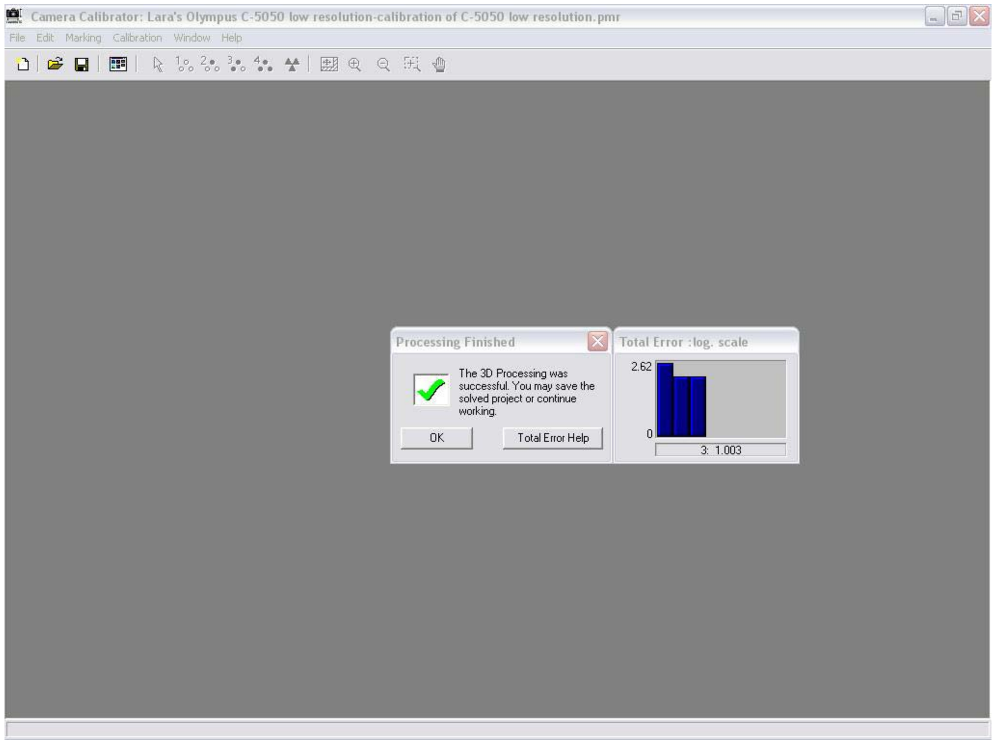


Figure 9. Error Dialog for Low Resolution Calibration Project

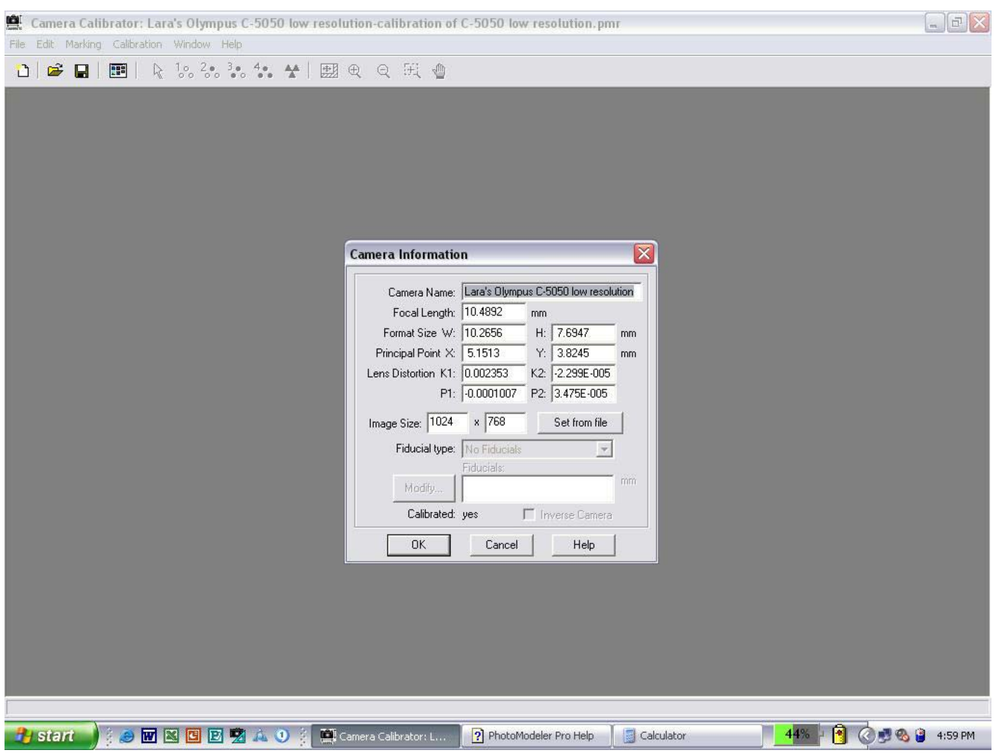


Figure 10. Solved Camera Information Low Resolution

APPENDIX 14

PICTURES FROM BENCHMARK MEASUREMENT DAY


Nikon
DTM-450

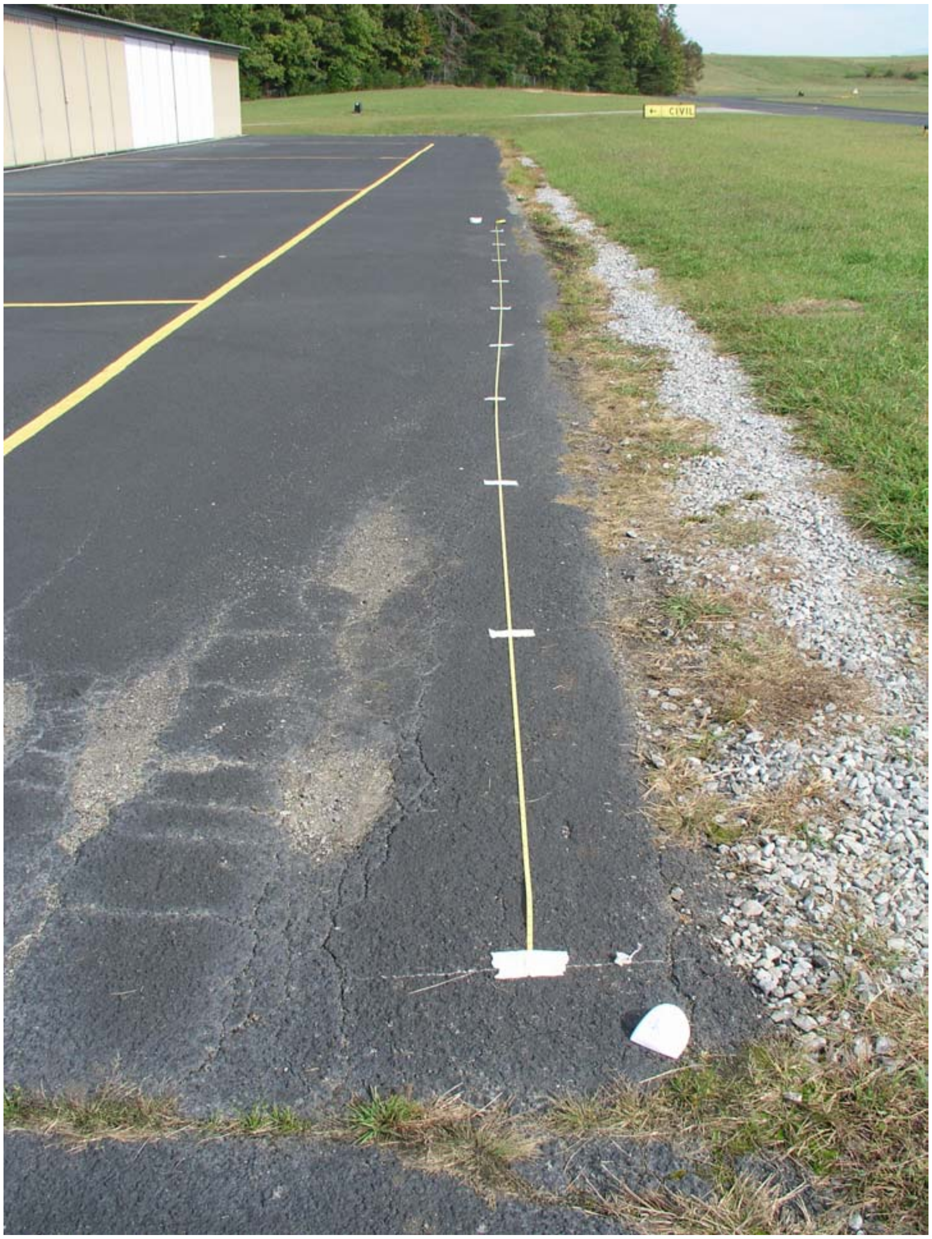

Nikon


111083
Nikon
HA# 351°35'23"
VD# -69.752 f
HD# 288.718 f
PWR
FNC
ESC
MSR
DSP
TRK
ANG
XYZ
REC
RDM
REM
STN
S-O
ENT

APPENDIX 15

SELECTED PHOTOS FROM TAPE MEASUREMENT EXPERIMENT

Low Tape—4 pieces



High Tape—8 pieces

Beginning measurement

Ending measurement

APPENDIX 16

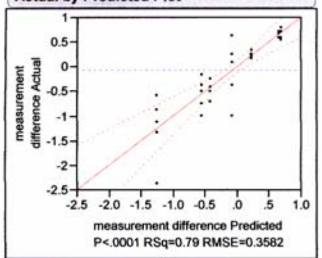
JMP PRINTOUTS WITH HANDWRITTEN NOTES

Measuring Wheel

~~Response~~ measurement difference

Whole Model

Actual by Predicted Plot



Even though this experiment truly has categorical (or discrete) factors (smooth/rough; small/large; rush/take time), I ran the experiment as continuous as per the suggestion of the Statistical Consulting Ctr at UT. (I actually ran the experiment both ways & the results were nearly identical) The SCC suggested this b/c JMP computes more accurately in a continuous setting than categorical. JMP simply assigns -1 or +1 to each level; the experimenter has to keep each setting straight as to avoid confusion. Also, using the prediction profiler is much easier to use in a continuous setting, however; keep in mind that desirabilities anywhere but on the edges do not have any meaning in model interpretations. the red dashed line must be moved all the way to the left or right. {Describe desirability at some point}

Summary of Fit

RSquare	0.786894
RSquare Adj	0.740277
Root Mean Square Error	0.358155
Mean of Response	-0.06901 = -.88818 in
Observations (or Sum Wgts)	40

78% of the variation is due to the model

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	15.156958	2.16528	16.8800
Error	32	4.104801	0.12828	Prob > F
C. Total	39	19.261759		<.0001*

Parameter Estimates

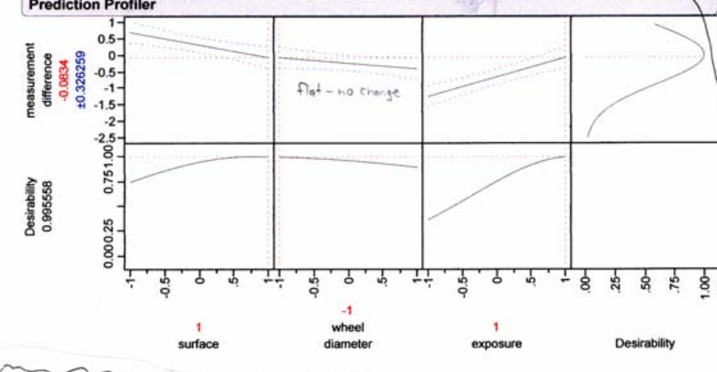
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.06901	0.056629	-1.22	0.2319
surface	-0.51236	0.056629	-9.05	<.0001*
wheel diameter	-0.066745	0.056629	-1.18	0.2472
exposure	0.166795	0.056629	2.95	0.0060*
surface*wheel diameter	0.156375	0.056629	2.76	0.0095*
surface*exposure	0.160335	0.056629	2.83	0.0079*
wheel diameter*exposure	-0.13538	0.056629	-2.39	0.0229*
surface*wheel diameter*exposure	-0.12509	0.056629	-2.21	0.0345*

all but wheel diameter have significance at $\alpha = .05$

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
surface	1	1	10.500511	81.8594	<.0001*
wheel diameter	1	1	0.178196	1.3892	0.2472
exposure	1	1	1.112823	8.6753	0.0060*
surface*wheel diameter	1	1	0.978126	7.6252	0.0095*
surface*exposure	1	1	1.028292	8.0163	0.0079*
wheel diameter*exposure	1	1	0.733110	5.7151	0.0229*
surface*wheel diameter*exposure	1	1	0.625900	4.8794	0.0345*

Prediction Profiler



Main Effects

these interpretations were achieved with the help of the prediction profiler

Surface — smooth is better

- smooth surface gives you results that are long of the target (target = 0) [this is possible due to wavy behavior or bad tracking]

+ rough surface gives you short of target results [possibly due to lack of rotation of the wheel]

wheel diameter — neither is better (insignificant)

- small has a desirability of 99.99%
+ large 98.78% ← basically the same

main effect plot is basically flat

exposure — take time is better

- rushing gives a short of target result (neg.) [wheel possibly skips]

+ taking your time gives a long of target result (pos.) [wheel possibly waves about]

Cross Effects

the following yields the lowest errors:

a*b : surface * wheel dia.

a smooth surface plus a large wheel diameter will yield a lower error

a*c: surface * exposure

if you have a rough surface, it is best to take your time

b*c : wheel diameter * exposure

if you have a large diameter wheel, it is best to take your time

a*b*c : surface * wheel diameter * exposure

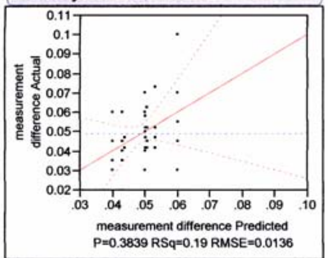
if you have a rough surface plus a small diameter wheel, it is best to take your time

Measuring tape

Response measurement difference

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.194641
RSquare Adj	0.018469
Root Mean Square Error	0.013628
Mean of Response	0.048818
Observations (or Sum Wgts)	40

19% of variation is due to this model

= 0.586 in

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.00143628	0.000205	1.1048
Error	32	0.00594284	0.000186	Prob > F
C. Total	39	0.00737912		0.3839

Parameter Estimates

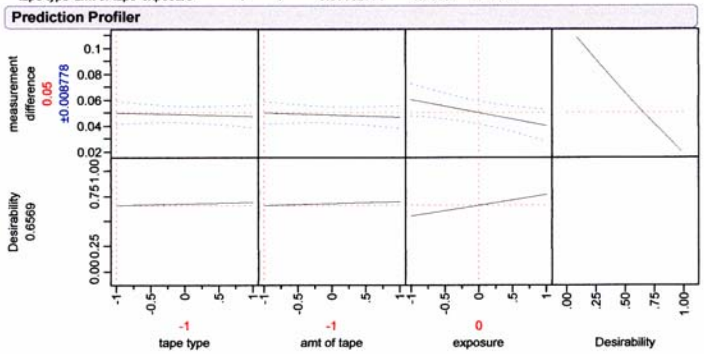
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0488175	0.002155	22.66	<.0001*
tape type	0.0005675	0.002155	0.26	0.7940
amt of tape	0.0002325	0.002155	0.11	0.9147
exposure	-0.002887	0.002155	-1.34	0.1897
tape type*amt of tape	0.0019825	0.002155	0.92	0.3644
tape type*exposure	0.0038625	0.002155	1.79	0.0825
amt of tape*exposure	0.0003875	0.002155	0.18	0.8584
tape type*amt of tape*exposure	-0.002862	0.002155	-1.33	0.1934

none are significant at $\alpha = 0.05$

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
tape type	1	1	0.00001288	0.0694	0.7940
amt of tape	1	1	0.00000216	0.0116	0.9147
exposure	1	1	0.00033351	1.7958	0.1897
tape type*amt of tape	1	1	0.00015721	0.8465	0.3644
tape type*exposure	1	1	0.00059676	3.2133	0.0825
amt of tape*exposure	1	1	0.00000601	0.0323	0.8584
tape type*amt of tape*exposure	1	1	0.00032776	1.7648	0.1934

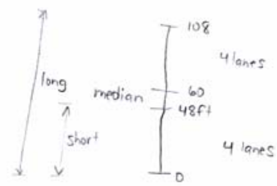
Prediction Profiler



I would hate to make any sort of predictions based on this model ($R^2 = 19\%$)

The factors that I thought that would have an impact on the response turned out to have no impact at all. In retrospect, I would do the experiment differently. I'm thinking that length of measurement would have an impact; shorter measurements would be more accurate than longer measurements because the tape could become more twisted with long measurements than short ones.

Here's a simulated 8 lane highway



Length of measurement could also potentially affect the measuring wheel experiment (more opportunities for skips and wavy motion) but probably not all that much on PM experiment

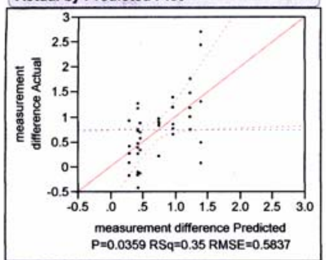
2x2x2 Factorial PhotoModeler- Fit Least Squares

PhotoModeler

Response measurement difference

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.353999
RSquare Adj	0.212686
Root Mean Square Error	0.583684
Mean of Response	0.7395 => 8.874 in
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	5.974119	0.853446	2.5051
Error	32	10.901993	0.340687	Prob > F
C. Total	39	16.876112		0.0359*

Parameter Estimates

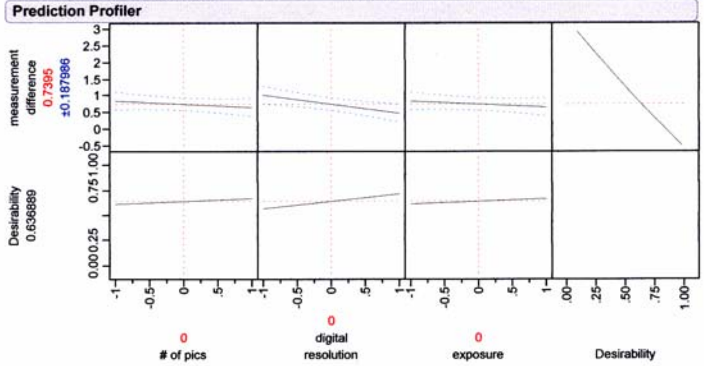
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.7395	0.092289	8.01	<.0001*
# of pics	-0.0998	0.092289	-1.08	0.2876
digital resolution	-0.26975	0.092289	-2.92	0.0063*
exposure	-0.0933	0.092289	-1.01	0.3196
# of pics*digital resolution	-0.01505	0.092289	-0.16	0.8715
# of pics*exposure	-0.1077	0.092289	-1.17	0.2518
digital resolution*exposure	0.20625	0.092289	2.23	0.0325*
# of pics*digital resolution*exposure	0.05965	0.092289	0.65	0.5227

These 2 are significant at $\alpha = 0.05$

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
# of pics	1	1	0.3984016	1.1694	0.2876
digital resolution	1	1	2.9106025	8.5433	0.0063*
exposure	1	1	0.3481956	1.0220	0.3196
# of pics*digital resolution	1	1	0.0090601	0.0266	0.8715
# of pics*exposure	1	1	0.4639716	1.3619	0.2518
digital resolution*exposure	1	1	1.7015625	4.9945	0.0325*
# of pics*digital resolution*exposure	1	1	0.1423249	0.4178	0.5227

Prediction Profiler



based on this model (R^2 only 35%):

Main Effects

higher resolution is better

only resolution is significant

Cross Effects

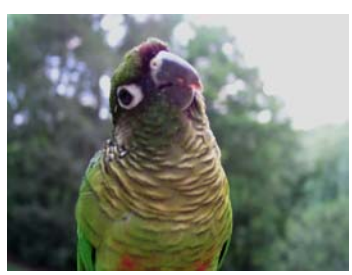
To get a smaller error, use high resolution while rushing.
[? — I don't know — can't explain it]

VITA

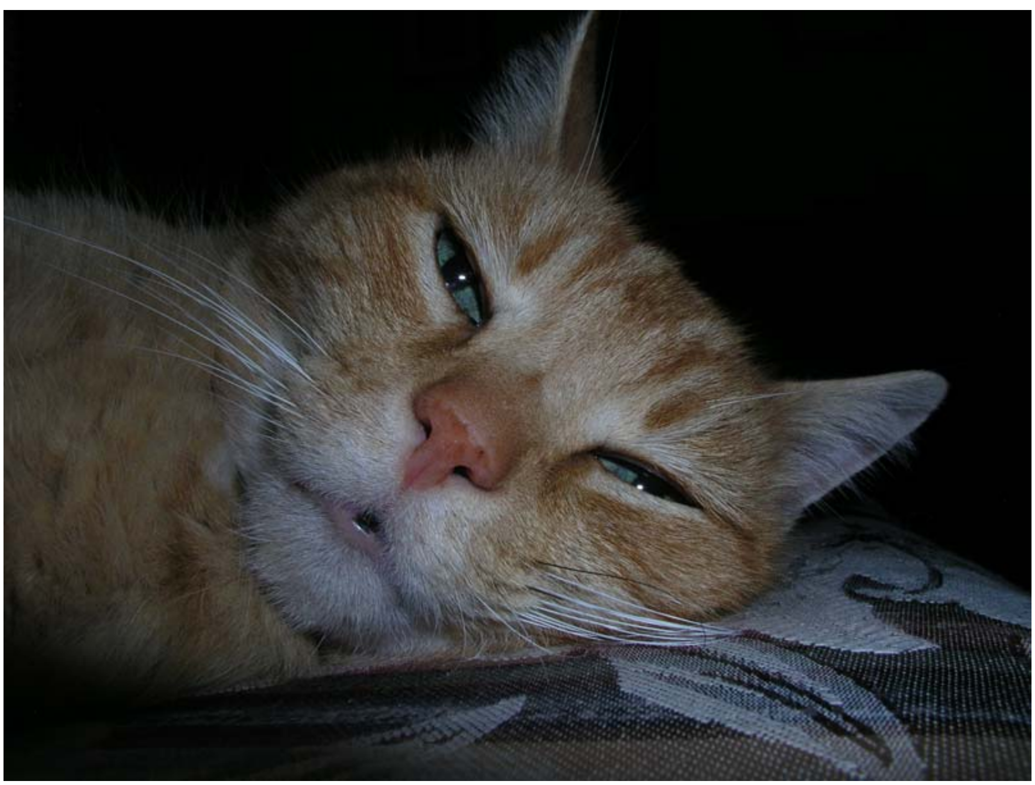
Lara Lynn O'Shields was born on February 14, 1972 in Sevierville, TN. She is the daughter of David O'Shields and Alesia O'Shields (father and stepmother) and Susan and Wayne Gourley (mother and stepfather) and has a half-brother Seth O'Shields and two stepbrothers, Todd and Seth Gourley, and a stepsister Samantha Gourley Angelopolous. She received a Bachelor of Science in Industrial Engineering in December 1995 and a Master of Science in Industrial Engineering in August 2000. Her Doctor of Philosophy in Industrial Engineering was awarded in August 2007.

For the past 4 years, Lara has enjoyed being a member of the Walters State Sevier Jazz Band playing baritone saxophone. Additionally, she plays piano and sings at Millican Grove Baptist Church in Sevierville. Flying locally and cross-country in her dad's airplane is also a fun pastime of Lara. Lara *especially* enjoys riding motorcycles, whenever a friend will loan her one to ride. For the past 10 years, Lara has taken pleasure in growing orchids, especially the genus Phalaenopsis. Photography with medium format folder cameras from the post-WWII era is another one of her passions.

Lara currently resides in Sevierville with her pets: cat Pete, bird Cookie, and dog Bart and four angelfish.


Bart at airport helping out with Part III



Pete taking it easy

Photo of Bart taken with a 1951 Voigtlander Perkeo I