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I am submitting a thesis written by Lara O'Shields entitled "The Determination of Pre-Impact Speeds and Accident Scene Information Using PhotoModeler as a Measurement Tool." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

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THE DETERMINATION OF PRE-IMPACT SPEEDS AND ACCIDENT SCENE INFORMATION USING PHOTOMODELER AS A MEASUREMENT TOOL

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Lara Lynn O'Shields
August 2000

DEDICATION

This thesis is dedicated to my family and friends

who have continually supported me financially,

emotionally, and otherwise.

Despite many futile endeavors in life,

you never lost faith in me, and

I never could

have done this without you.

This thesis is also especially dedicated to

Mama Kerr,

my grandmother,

who passed away last October. Your presence

and love will be truly missed.

ACKNOWLEDGMENTS

I would like to thank many people for their time, effort, and money, which have made this thesis possible. First and foremost, I thank Dr. John Hungerford for his stupendous support by introducing me to the profession of traffic accident reconstruction and to PhotoModeler, the basis of this thesis. Dr. Tyler Kress has provided me with a host of useful ideas that I have utilized with great appreciation. And Dr. Wayne Claycombe is an inspiration and a super kind of guy.

Someone who really needs special recognition is Mr. Steve Flach of EOS Systems (PhotoModeler's company.) In addition to sending me necessary materials to complete this thesis, Steve quickly answered any questions I had about PhotoModeler, no matter how dumb. Thank you so much!

Lastly, I would like to thank the National Crash Analysis Center, who provided me with the NHTSA photos needed for this thesis. Without those photos, this thesis would have never materialized.

ABSTRACT

This thesis investigates the role of PhotoModeler, a photogrammetry technique, in traffic accident reconstruction. More specifically, important elements to the reconstructionist such as vehicle crush and accident scene details are measured with PhotoModeler. The extracted measurements are utilized further to establish pre-impact speeds and vehicle placement in terms of the centerline.

To verify that PhotoModeler is a suitable measurement technique, its results are compared against NTSHA controlled crash data and a pre-measured accident scene.

The data are convincing. NTSHA's crash tests are performed at 35 mph and this study's results came up with 36.88 mph, which is quite good. In the accident scene diagram, the average measurement deviation was 1.480 inches, which is also a good result.

PhotoModeler is accurate as well as convenient for generating measurements when applied to traffic accident reconstruction situations.

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CHAPTER I

INTRODUCTION

General Introduction

This thesis will focus on the role of PhotoModeler, a photogrammetry technique, in two important facets of traffic accident reconstruction—vehicle crush and accident scene measurement procurement. By examining the amount of deformation or crush in a wrecked vehicle, one can approximate its speed before impact, for speed is proportional to the amount of deformation. It is also imperative to accurately diagram the accident scene itself, so that the resting positions of vehicles in terms of a common reference point can be documented properly. PhotoModeler has many advantages, such as accuracy and convenience, which can make it superior to other measurement techniques used.

Terminology

Photogrammetry – The science and art of making measurements from photographs.

Normal PhotoModeler Project – A project using PhotoModeler created with the intent of making measurements. Requires that camera information be known so

that data can be processed to create an accurate 3-D model. Important features are marked with reference points.

Inverse Camera Project – PhotoModeler's method of developing a project when camera information is not known. PhotoModeler will "create" a camera for each unknown photograph. Important features are marked with reference and control points.

Reference Points – Points marked by the user on one photograph that are identified as the same physical locations in space on other photographs. They give the 3-D model shape.

Control Points – A special type of reference point used in Inverse Camera projects, which allows for the establishment of critical camera information. These are known X, Y, and Z values. In a vehicle crush project, control points are placed on the exemplar vehicle and only on the undamaged portions of the damaged vehicle.

Fiducials – Marks on photographs or on negatives (usually the four corners) created by a camera insert or by the user which gives PhotoModeler an idea of camera position at the time of photograph exposure. Designed to counteract the harmful effects of cropping or rotation that may occur with ordinary photograph reproduction and/or scanning.

Calibrated Camera – A camera that can accurately be used as a measurement device. Important camera information such as focal length, principal point, and format size has been determined.

Focal Length – The length of the lens, or how far the lens is zoomed out.

Principal Point -- Where the principal ray intersects the film plane undefracted; the dead center of the film plane, denoted by x, y coordinates in PhotoModeler.

Format Size – Refers to the size of film or camera being used. 35 mm is a common smaller format, whereas professional photographers use larger formats.

Background

In traffic accidents, legal issues arise frequently. Many times it is necessary to determine if laws were broken, especially if a fatality occurred. Therefore it is imperative to determine exactly who was at fault. Speed can be considered a factor in almost every accident, for without motion, there would be very few traffic accidents. Also, another concern is vehicle placement relative to the centerline. It is essential to approximate the speed and vehicle placement as accurately as possible to establish fault. Because of the impending legal

implications present, this thesis will examine speed's influence on traffic accidents (in the form of crush) and vehicle placement through the application of PhotoModeler.

Traditionally, accident reconstructionists would physically measure crushes themselves using conventional measuring devices such as tape measures or rulers. Measurements made by hand are many times quite varied, and the measurement technique itself may be questionable. When making crush measurements using conventional methods, it is hard to establish where the undamaged part of the vehicle would have been on a damaged portion. Sometimes a reconstructionist is armed with wheelbase and width dimensions to aid in this approximation, but sometimes it is nothing more than an educated guess. Therefore, accurate approximations of measurements are in great need. This thesis will demonstrate that PhotoModeler, a software package from EOS Systems, Inc., is able, with very suitable accuracy, to generate needed measurements from photographs alone.

Since photographs are the principal media in PhotoModeler, vital pieces of evidence (such as crushed vehicles or roadway markings) that would have since been repaired or destroyed are captured on film. This allows the reconstructionist to work on a particular case perhaps many years after the accident took place. In addition, taking photographs at an accident scene in lieu of making the physical measurements yourself tends to be less time consuming for the reconstructionist and any police officers trying to restore traffic flow.

Also, revisiting an old accident can be a safer experience for the reconstructionist if photographs are taken, especially if the scene is a busy highway or intersection.

Problem Statement

In the area of traffic accident reconstruction, there is a need for a reliable measurement technique when measuring crush and objects in an accident scene diagram. The technique must be quite accurate because the results it produces needs to be upheld in a court of law.

General Approach to the Problem

This thesis will apply controlled crash data (in the form of photographs and information) generated by the National Highway Traffic Safety Administration (NHTSA) to PhotoModeler. In these crash tests, vehicles intentionally collide into a very hard, immovable fixture (with an aluminum honeycomb attached to mock the existence of another car) at a predetermined speed of 35 mph. Then, knowing the speed of the vehicle already, NHTSA's photographs of the crushed vehicle will be processed by PhotoModeler, measurements will be extracted, and a pre-impact speed will be determined by

using traditional conservation of energy equations. If a result close to 35 mph is obtained, then the technique is suitable for examining crush.

This thesis will also compare the application of hand measurement techniques to PhotoModeler's measurement technique when applied to vehicle placement position in an accident scene. If results are similar, then the technique is suitable.

Organization Of The Project

This project will contain the following sections:

- Introduction – General Introduction, Terminology, Background, Problem Statement, General Approach To The Problem, and Organization Of The Project
- Literature Review – Current Methodologies And Techniques As Discussed In Literature
- Research Methods – Research Design, Selection Of Sample, Instrument Used, and Procedures
- Results – Analysis Of Data
- Conclusions and Recommendations

CHAPTER II

LITERATURE REVIEW

Introduction

Sources used to create the Literature Review range from old Photogrammetry books and texts (circa 1951 and later) to SAE papers presented in 1999. This chapter is sectioned in the following manner:

- History of Photogrammetry
- Photogrammetry In Traffic Accident Reconstruction
- Photogrammetry With PhotoModeler In Traffic Accident Reconstruction

History of Photogrammetry

Photogrammetry, which is the science and art of making measurements from photographs, soon got its start after photography was invented, around 1840 (Sharp [1]). Initially, Photogrammetry was used for map making purposes. Colonel Aime' Laussedat of the French Army Corps was the first engineer to use photographs for topographical map making. His dedication and hard work in the subject earned him the title, "Father of Photogrammetry" (Wolf [2]).

Photogrammetry is made possible by a collection of math equations, aptly named photogrammetric equations. These equations are rather complex; some are linear while others are nonlinear; some iterations may involve large numbers of equations with an equal number of unknowns (e.g. 30 equations and 30 unknowns.) In the past, photogrammetrists had to arrive at these solutions by hand (!), which took a great deal of time and effort, and run the risk of being saturated with errors. Luckily today, these equations are executed via computers and software which undoubtedly makes the process a whole lot easier. The interested reader can find these equations in Appendix A, which were taken from The Manual of Photogrammetry, Fourth Edition [3].

Photogrammetry in Traffic Accident Reconstruction

As the first trained users of Photogrammetry measured distances with their photographically inspired maps, Photogrammetry users of today can apply the same principles to traffic accident reconstruction.

In the past, photogrammetrists in traffic accident reconstruction who were armed with photographs, drafting equipment, and calculators could produce acceptable results, but this method was limited to the accuracy of the geometry of the photography (Townes and Williamson [4]). However, with the increase in the development of the personal computer, software programs, and new techniques, photogrammetry used today in accident reconstruction has become

more accurate, convenient, cost effective, and less time consuming (Townes and Williamson [4]).

Also according to Townes and Williamson [4], there are three commercially available photogrammetric software packages appropriate for accident reconstruction:

- PhotoWin35
- PC Giant
- PhotoModeler

All of the above software packages have 3-D capabilities, which are suitable for crush and skid mark analysis. Skid mark analysis requires only a photogrammetric program with 2-D capabilities; 2-D analysis of crush will not yield reliable results.

Rentschler and Uffenkamp [5] maintain that digital photogrammetry is an advantageous technique at Porsche's Crash Test Facility. With equipment such as digital cameras, image processing, and photogrammetric algorithms, the authors are able to measure the amount of deformation for a given crash test that is superior in terms of accuracy (+/- 1 mm), cost (50% lower), and time consumption (only if > 50 targets are to be processed) to conventional measurement techniques. Also, they find this technique quite flexible in terms of time management. They can crash one vehicle, take the appropriate photographs, and progress on with the next vehicle. This is cost effective too, for personnel's time and effort are reduced to a minimum.

Photogrammetry With PhotoModeler In Traffic Accident Reconstruction

In the SAE Technical Paper "Factors Affecting the Accuracy of Non-Metric Analytical 3-D Photogrammetry, Using PhotoModeler", the authors do a superb job of checking out PhotoModeler's accuracy. According to Switzer and Candrlic [6] there are 57 possible ways to use PhotoModeler. They mixed and matched several different combinations of cameras, fiducials, scanners, image cropping techniques, number of control points, and plotted out their corresponding accuracies. Table 1 summarizes the following:

Table 1. Summary of Varied Factors on Accuracy

FACTOR VARIED	MOST ACCURATE	LEAST ACCURATE
CONTROL POINTS	Many	Few
IMAGE CROPPING	Not Present	Present
CAMERA	Calibrated	Not Calibrated
PHOTO IMAGES	Kodak Photo CD	Scanned
FIDUCIALS	Present	Not Present

Given various situations in terms of equipment, time, and money, one can estimate how accurate the results might be, however; individual results will vary. Perhaps the "Least Accurate" situation is suitable enough for current needs. Or perhaps some parameters are simply out of the photogrammetrist's control, such as a case where a third party presented the photographs and nothing is known about the camera or where the images were possibly cropped. The results may not be as accurate, but they certainly are acceptable.

Fenton et al. [7] in the Paper "Using Digital Photogrammetry to Determine Vehicle Crush and Equivalent Barrier Speed" use PhotoModeler to determine vehicle crush. With those crush measurement results, they use the software program EDCRASH to determine EBS (Equivalent Barrier Speed). Included in this paper is a good discussion of how to go about executing a PhotoModeler project. Steps included in this portion are scan photographs, input camera characteristics, process the information, add points to increase model detail, and repeat steps with exemplar (undamaged) vehicle.

They maintain that PhotoModeler's accuracy is quite acceptable, and their results yielded accuracy within $1/8^{th}$ of an inch (within 1%), but accuracy within one inch is sufficient for EDCRASH.

Also included in this paper is a section dedicated to the dimensions of a passenger compartment of a Peterbuilt tractor. They explain that the passenger compartment's dimensions can be measured using PhotoModeler, possibly

assisting engineers in a more safety effective design, however; this has little relevance to the topic at hand. This is quite useful, but I don't know why they included it in this paper.

Fenton and Kerr [8] maintain that suitable results are achievable with PhotoModeler by using just one photograph in their analysis of skid marks. As mentioned earlier, PhotoModeler is capable of analyzing 2-D (skid marks) or 3-D (vehicle crush) situations. 3-D is more complex and requires more photographs.

The general procedure followed by Fenton and Kerr is to take one "old" photograph of the accident scene and compare it to several "new" photographs taken by the reconstructionist. Under normal circumstances, several "old" photographs are made available to the reconstructionist, but Fenton and Kerr maintain that all that is needed is one, since this is a 2-D situation. The "new" photographs must contain vital "landmarks" in the accident scene, such as trees or light poles, that are visible in the "old" photograph, so control points can be made. The skid marks themselves are not required to be visible in the "new" photographs; the situation may be that they aren't visible anyway (since they sometimes degrade quickly with time.) The paper goes on to tell how tracing of the skid marks using PhotoModeler assists in the clarity of the diagram.

The purpose of analyzing these photographs is to accurately diagram the accident scene, not to make an estimate of pre-impact speed. It would have been nice if a pre-impact speed was determined in this paper, but perhaps that wasn't the authors' objective. The measurements in this case study were quite

accurate; they were well within 1 percent, which is suitable for an EDCRASH analysis.

CHAPTER III

RESEARCH METHODS

Introduction

This chapter will include an explanation of how the research was conducted. The following sections will be included:

- Research Design – Description Of Steps Involved In The Research
- Selection of Sample – How Sample Was Selected
- Instrument Used – Description Of Instrument
- Procedures – How Instrument Was Applied To Sample

Research Design

The core of the project will contain two portions:

- Establish that PhotoModeler, coupled with classical motion equations and vehicle specifications, is a suitable tool to determine pre-impact speeds of vehicles.

- Establish that PhotoModeler is a suitable tool for accident scene diagramming.

The procedure that will be used to validate the proposed method is a direct comparison of its results verses controlled crash data generated by NHTSA. NHTSA performs crash tests on all new vehicles sold in the United States, at a predetermined speed of 35 mph, to test the vehicles' safety integrity. In other words, the pre-impact speed generated by the proposed method should match or be very close to NHTSA's predetermined speed.

The second portion of the procedure involves comparing an accident scene measured by hand to the same scene measured by PhotoModeler. The results should also match or be very close to the pre-measured values. In Table 2, the research design is summarized.

There is one segment of the project that was initiated before the two above research procedures were carried out. This is calibration of the camera. Calibrating your camera assures that it is an accurate measurement device. During this procedure, the internal geometry of the camera is precisely determined, such as focal length, principal point, and format size. Refer to Appendix B for the complete camera calibration procedure.

Table 2. Summary of Research Design

PERFORMED PRIOR TO ANY RESEARCH	
❖ Camera Calibration	
CRUSH MEASUREMENT RESEARCH STEPS	**ACCIDENT SCENE MEASUREMENT RESEARCH STEPS**
❖ Obtain NTSHA Photos (Damaged Vehicle)	❖ Take measurements of accident scene
❖ Take pictures (& a few measurements) of exemplar vehicle with calibrated camera	❖ Take pictures of accident scene with calibrated camera
❖ Use PhotoModeler to get measurements	❖ Use PhotoModeler to get measurements
❖ Obtain crush coefficients	
❖ Use measurements, crush coefficients, weight, and width of crush in equations to get speed	

Selection of Sample

Photographs of a 1998 Ford Contour were obtained from NHTSA. NHTSA's photos were selected because it is known that their tests are conducted at 35 mph.

Also obtained were photographs of an accident scene which was measured by hand via measuring tapes.

Instrument Used

The primary instrument used is the photogrammetry software package called PhotoModeler. It can successfully, with an accurate degree of precision, measure crush and distances in an accident scene.

To convert PhotoModeler's measurements into a speed, "secondary" instruments are used. These are equations are taken from Northwestern University's Traffic Accident Reconstruction Vol. II by ed. Lynn B. Fricke [9]. Appendix C contains the subsequent equations and appropriate information. They are as follows:

$$E=\frac{W}{5}\left[5G+\frac{A}{2}(C_1+2C_2+2C_3+2C_4+2C_5+C_6)+\frac{B}{6}\left(C_1^2+2C_2^2+2C_3^2+2C_4^2+2C_5^2+C_6^2+C_1C_2+C_2C_3+C_3C_4+C_4C_5+C_5C_6\right)\right]\left(1+Tan^2\vartheta\right)$$

which computes the amount of energy dissipated by crush damage, and

$$EBS = v = \sqrt{2g\frac{E}{w}}$$

which computes the velocity of the vehicle.

Procedures

Table 3 summarizes the steps in applying the instrument to the sample. In the following pages, this thesis will illustrate, in great detail, how this is done.

Table 3. Summary of Procedures

MAJOR STEPS IN APPLYING PM TO NHTSA PICTURES	**MAJOR STEPS IN APPLYING PM TO ACCIDENT SCENE**
Step One	
❖ Take pictures of exemplar (with calibrated camera)	❖ Take pictures of accident scene (with calibrated camera)
❖ Scan pictures	❖ Scan pictures
❖ Mark points	❖ Mark points
❖ Process	❖ Process
❖ Scale Project	❖ Scale Project
❖ Extract measurements (to verify model-compare driver's side measurements to passenger side)	❖ Extract Measurements
❖ Export model into .dxf format for control point file	
Step Two	
❖ Scan NTSHA pictures	
❖ Import .dxf control file	
❖ Mark control points on undamaged portions	
❖ Process	
❖ Mark crushed points (make sure marked points correspond to points on undamaged vehicle)	
❖ Process	
❖ Establish reference line(s)	
❖ Extract measurements	
Step 3	
❖ Take measurements, crush coefficients, weight, and width of crush and use in equations to get speed before impact	

Crush Measurement Project---Step One

In the Crush Measurement Project, a preliminary publication entitled "PhotoModeler Crush Measurement White Paper" by Steve Flach [10] was consistently used as a source of referral, notably when crushed photos were incorporated into the existing exemplar project.

Groundwork for the Project

The first step in the crush measurement project is to determine the year, make and model of the vehicle you are investigating. Next, an exemplar or undamaged vehicle of the same type must be located, typically at a local dealership. Then several pictures must be taken of the exemplar with the calibrated camera from a variety of angles. The pictures must have good overlap; it is recommended that a single point should reside in three (3) photographs, but no less than two (2). The camera positions usually are at the four (4) sides and the four (4) corners of the vehicle. See Figure 1 for suggested camera angles.

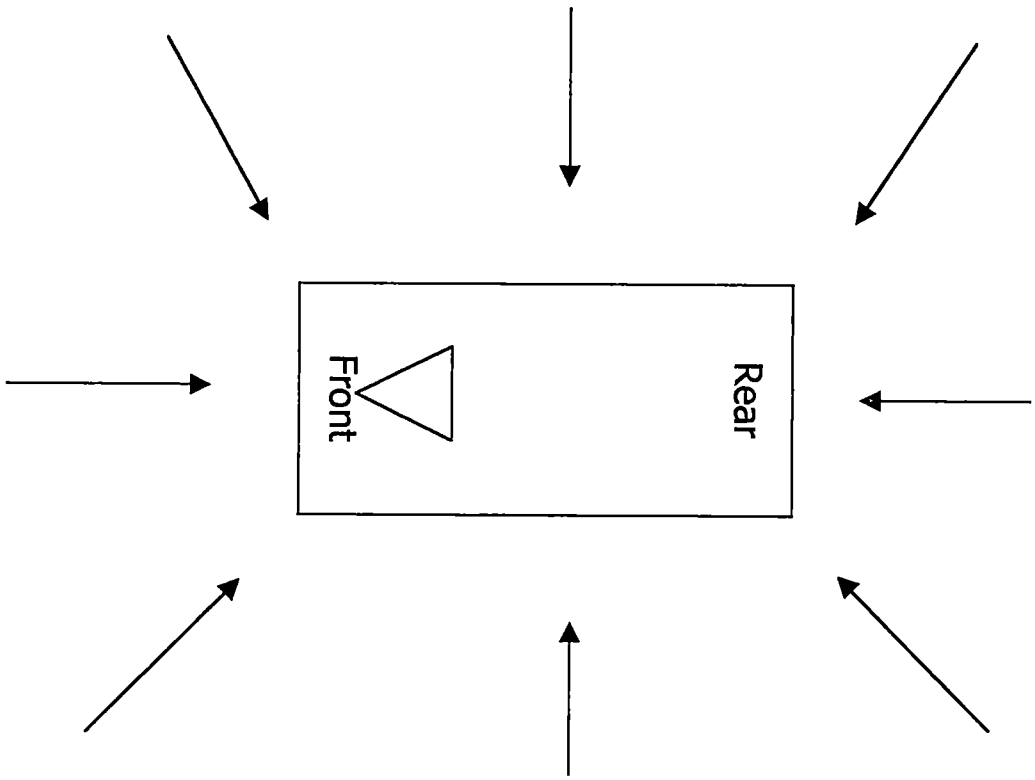


Figure 1. Suggested Camera Angles

If the area of damage to the crushed vehicle is known (e.g. the front), it is a good idea to take some extra pictures of this area (even close-ups) on the exemplar vehicle. This will help later in the analysis. It is also a good idea to take as many pictures of the exemplar as possible, and throw out the ones that are not wanted. A recommended technique is to use one entire roll of film (about 24 exposures) on the exemplar. Bright sun spots and shadows are a common malefactor of photogrammetrists' work, therefore; pictures should be shot in the shade or in overcast conditions to achieve maximum results, if at all possible.

Before this session is completed, a few measurements need to be taken by hand with a tape measure and written down. A small diagram of the object (perhaps a door or a window) and its respective measurements should be drawn on a small tablet. Do not rely on your memory. These measurements allow PhotoModeler users to scale the project, which is a very important step later on in the project. These measurements can consist of any dimension, but it is recommended that the measurements lie between two distinct points on the vehicle which can be seen easily on the photographs. After all the pictures are taken, a one-hour photo shop was located and the film was developed.

Scan Pictures

Before the exemplar pictures are scanned, the best ones must be selected. Select photos which have both fiducials present, are free of harsh shadows, and have a good overlap of common points. A Microtek ScanMaker X6 digitized the pictures in this project. The selected pictures were scanned, given a name, and saved (with a .tif extension) in a directory which could be easily referred to later. Consequently, each image ended up having a file size of approximately 6.5 MB.

Project Setup

Prior to marking points on the photographs, a PhotoModeler project needs to be initiated. From the Start Menu (in a Windows operated PC), select Programs, PhotoModeler, then PhotoModeler 3.1. Then select New Project from the File Menu. A Project Setup Wizard appears and outlines the information required for a PhotoModeler Project. Refer to Figure 2 for this information.

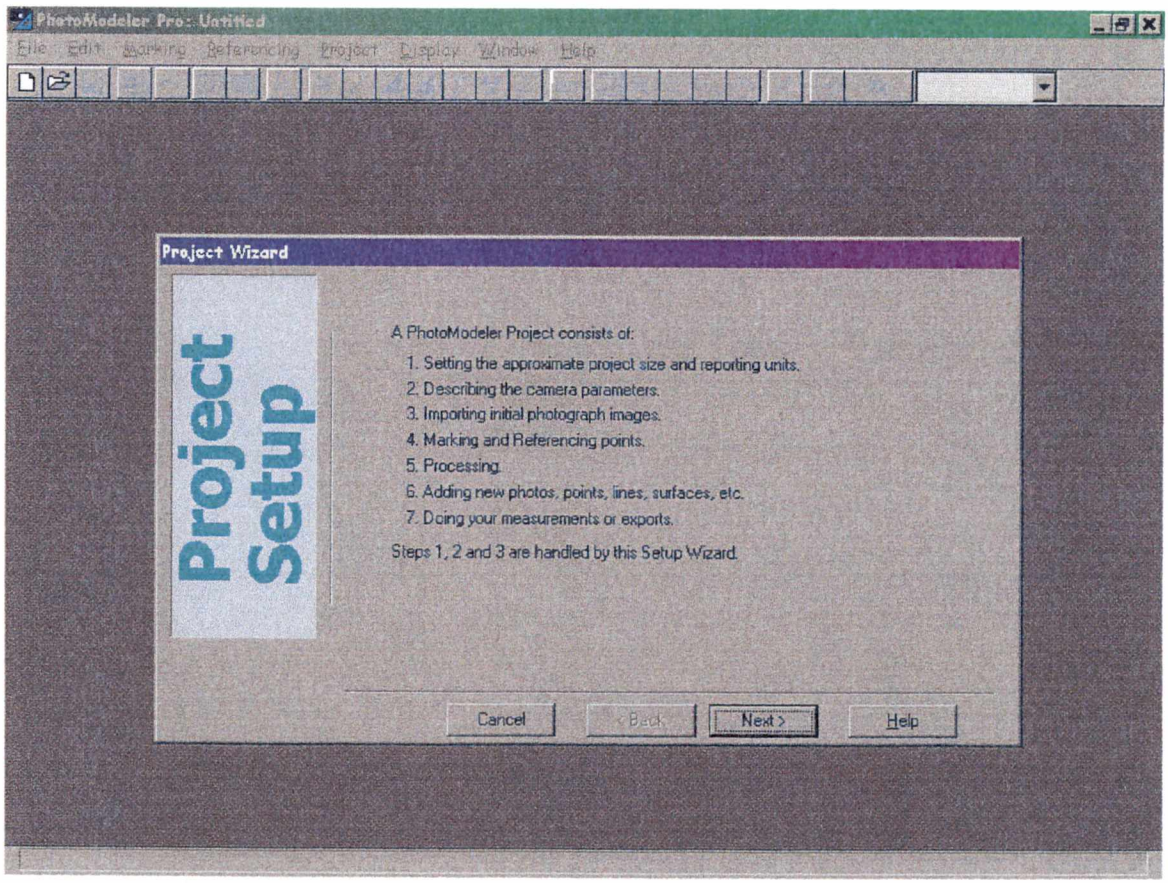


Figure 2. Project Setup Wizard

The next step in the Project Setup Wizard is to input the measurement units that are used in the project. The units used for this project were inches. Then the Wizard prompts for an approximate size of the project being modeled. The value entered here was 168 inches (or 14 feet.) See Figure 3 for this information.

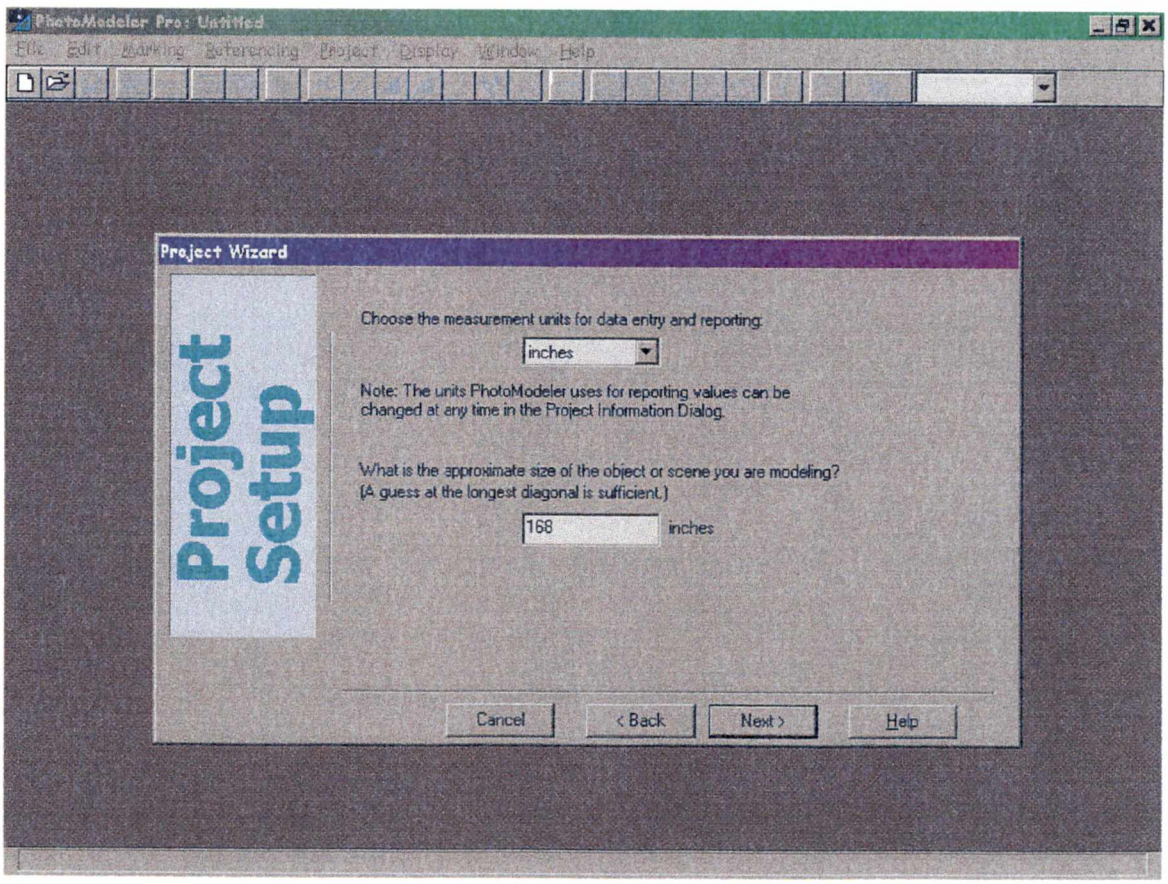


Figure 3. Measurement Inputs

The next step in the Wizard is Camera Setup Information. Here the camera file from the previously calibrated camera is loaded into the software. PhotoModeler was pointed to the directory (via the Browse button) where the calibrated camera files and images were located. Either a .pmr (project) or .cam (camera) file can be selected for camera information. Figure 4 shows the Camera Setup Wizard.

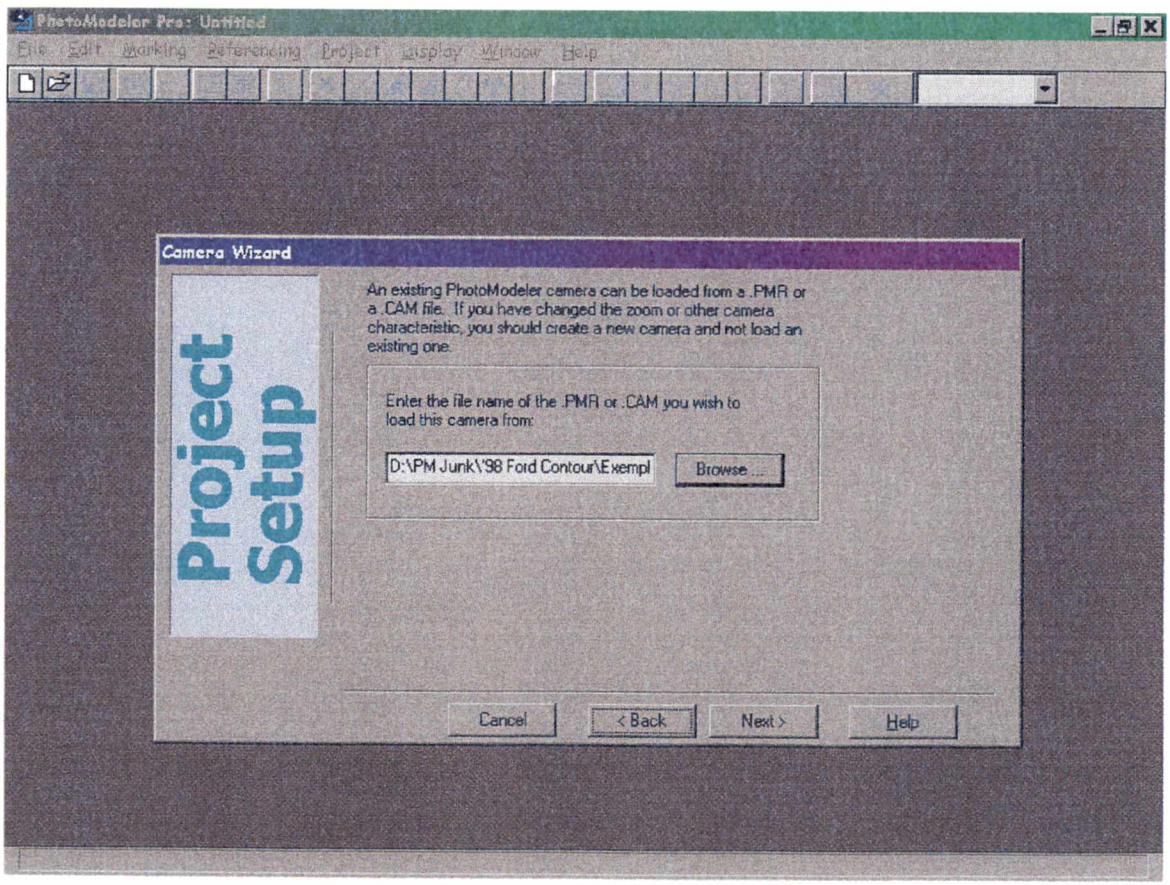


Figure 4. Camera Setup Wizard

After the camera file has been loaded, press the Next button and look at the camera information. This camera information should be the same information found in the camera calibration procedure. Figure 5 shows the camera information dialog.

The next step in Project Setup is adding photographs to the project. PhotoModeler needs to be pointed to the directory where the exemplar photos are stored. This is accomplished initially by pressing the "Add

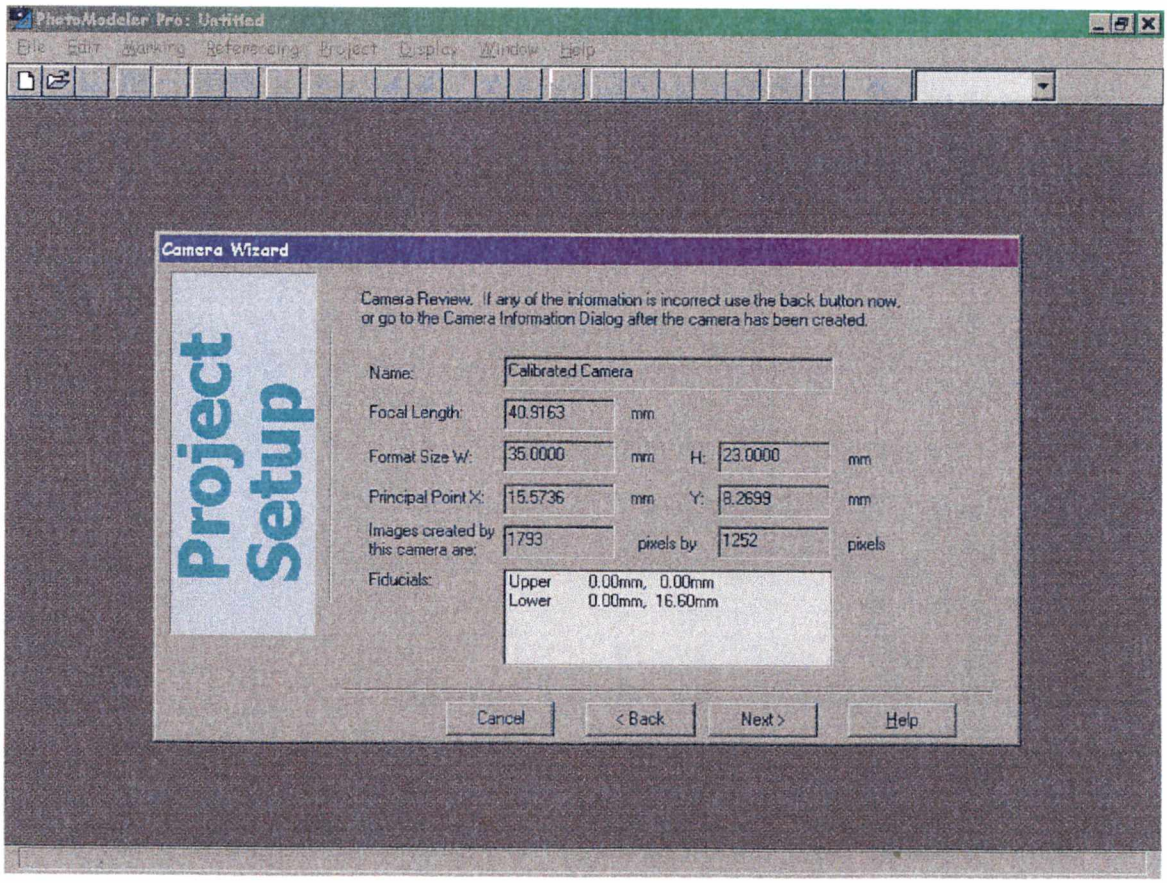


Figure 5. Camera Information

Image Button." When the correct images are found, all photographs in that directory are loaded onto the left-hand portion of the dialog. By holding the "Shift" key down, multiple images can be loaded simultaneously by clicking on the desired images with the left mouse button, and then by pressing the double-arrow key in the center of the window. Adding or removing photographs can be accomplished at anytime in the project, however; it is suggested initially that only a few photos are used at a given time, for this helps users to track down mistakes a lot easier. Figure 6 reveals the "Add/Remove Photographs" dialog.

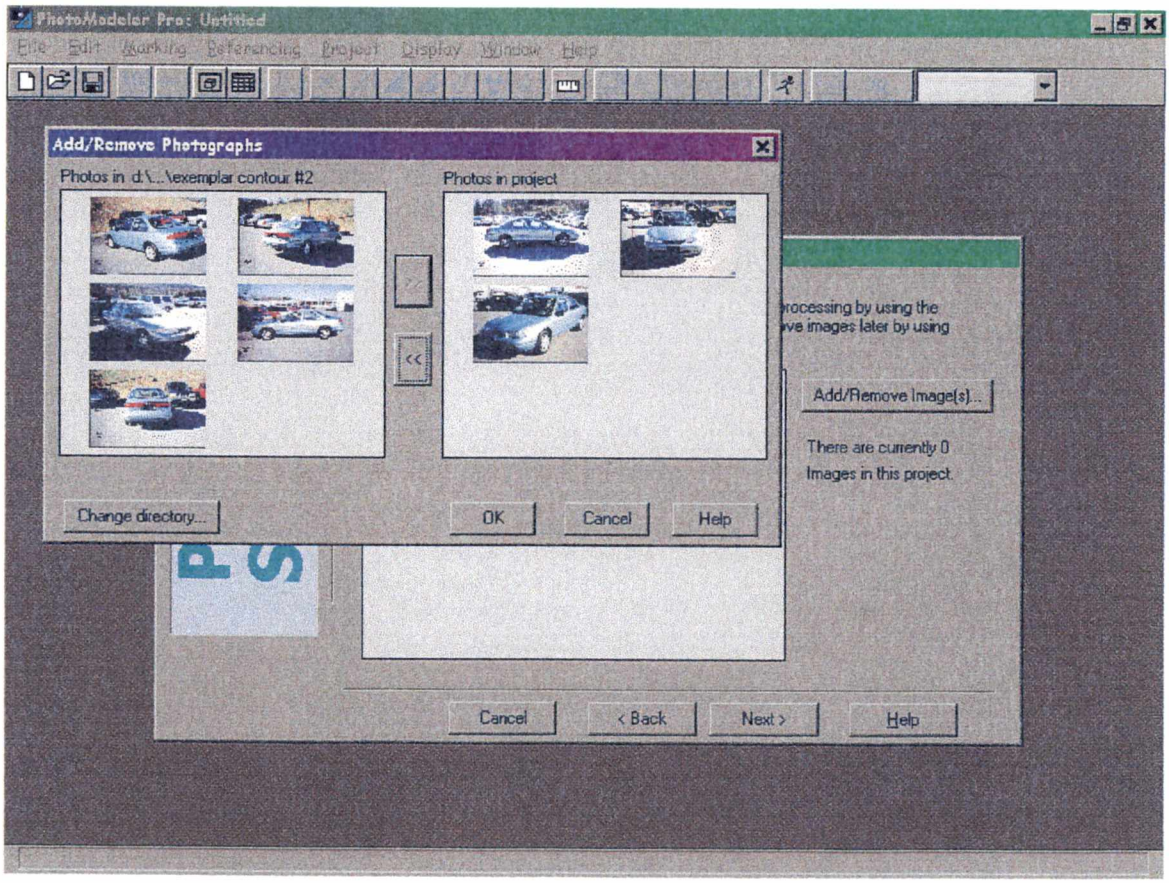


Figure 6. Add/Remove Photographs Dialog

Once the appropriate images are added to the project, the Wizard brings up a final dialog which explains the steps required to complete the project. Figure 7 shows this screen.

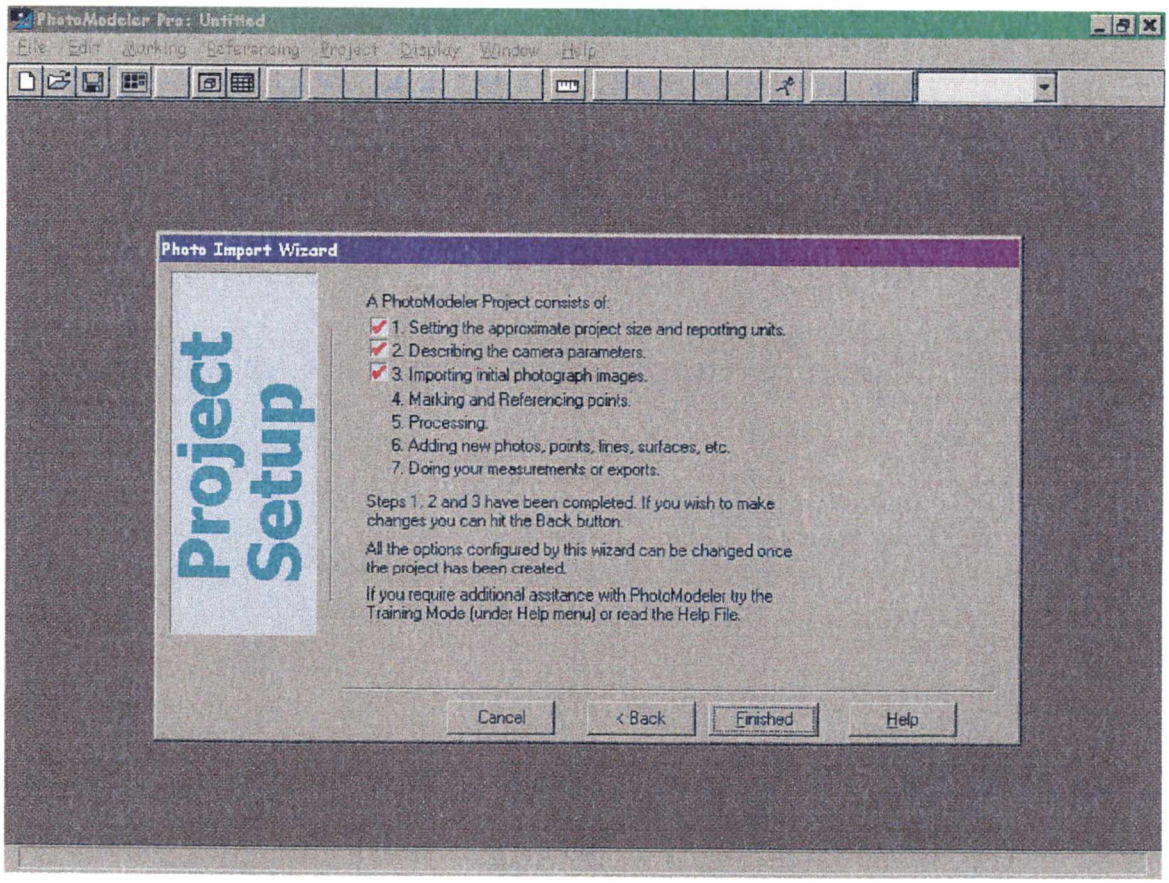


Figure 7. Final Screen on Project Setup Wizard

Mark and Reference Points

After a few pictures of the exemplar are loaded into the project, various points should be marked (with the point marking tool) and referenced (with the referencing tool) to create an accurate 3-D model of the exemplar. When marking points, it is imperative to mark distinct points, and not fuzzy ones. Do not guess! It is better to not mark a point than to have points that are grossly inaccurate. To allow for the most precise placement of points, areas being marked need to be zoomed in as much as possible with the zoom tool.

It is also wise to be consistent in point marking. For example, if points are marked on the inside of a driver's side door (as opposed to marking them on the outside of the door), it is best to mark points using the same convention on the opposite side. This will keep your 3-D model as accurate as possible.

As stated previously, it is a good practice work with only a few pictures in the project at a time. Tracing errors is much easier this way. Typically, the procedure is as follows:

- Mark and reference points on a few photos only.
- Process the project. If processing is successful, save the project.
- Add a few more photos to the project. Mark and reference more points.
- Process the project again. If processing is not successful, then it is known that something went amiss since the last time the project was

saved. Investigate to find the errors. If processing is successful, proceed until the 3-D model of the vehicle is completely finished.

Before marking points on the vehicle, decide on what portion to work on first. If it is desired to work on the front of the vehicle, open the pictures that have the front clearly visible. Zoom in on one photo with distinct points and begin marking (the point marking tool is the "x" shaped button on the toolbar.) Figure 8 shows marked points on Photo 2.

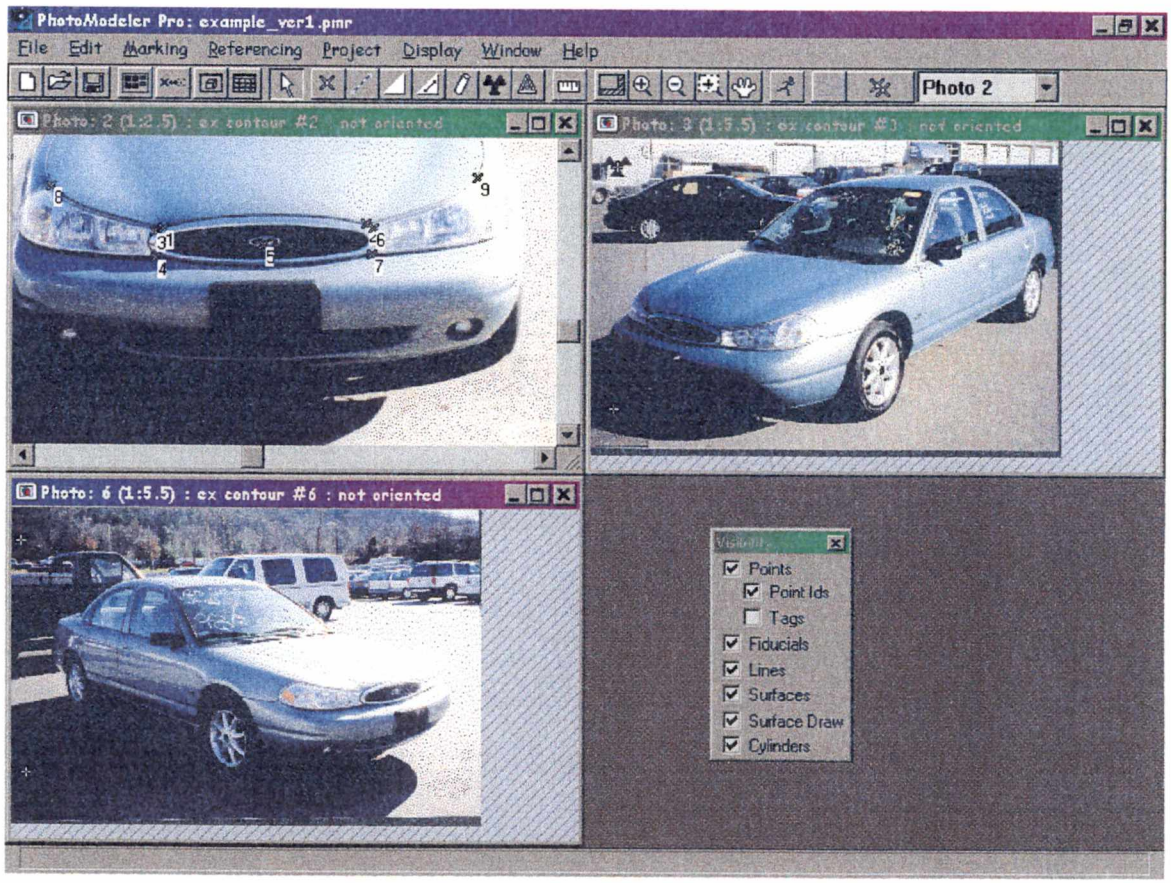


Figure 8. Marked Points on Photo 2

Now it is important to reference the marked points in Photo 2 to Photos 3 and 6. PhotoModeler needs to know that points in different photos are actually the same points in space. The reference tool accomplishes this. Notice that in the upper right hand portion of the screen that there is a dialog that displays "Photo X." This is the reference photo, or the photo which has the points that are to be referenced to other photos. Photo 2 is the reference photo here and referencing can begin.

Point 1 on Photo 2 needs to be referenced to Photo 3, so first the area near the right headlight is zoomed on Photo 3. Then the reference tool button (located next to the reference photo dialog) is clicked and activated. Point 1 on Photo 2 is clicked which indicates that this is the point being referenced (note that the Point ID tag turns red.) The cursor is then moved over to Photo 3, and the referencing tool cursor appears, which looks like a double x. Accurately place the referencing tool on the appropriate point in Photo 3. Now Point 1 is referenced across Photos 2 and 3.

Repeat the same procedure for Photo 6. Have Photo 2 as the reference photo and mark the appropriate point on Photo 6. Repeat until all points are referenced across all photos. If it is desired to reference multiple points at a time, simply hold down the shift key and click on many points in the reference photo. PhotoModeler will allow the user to mark these points one at a time in other photos. See Figure 9 for referencing information.

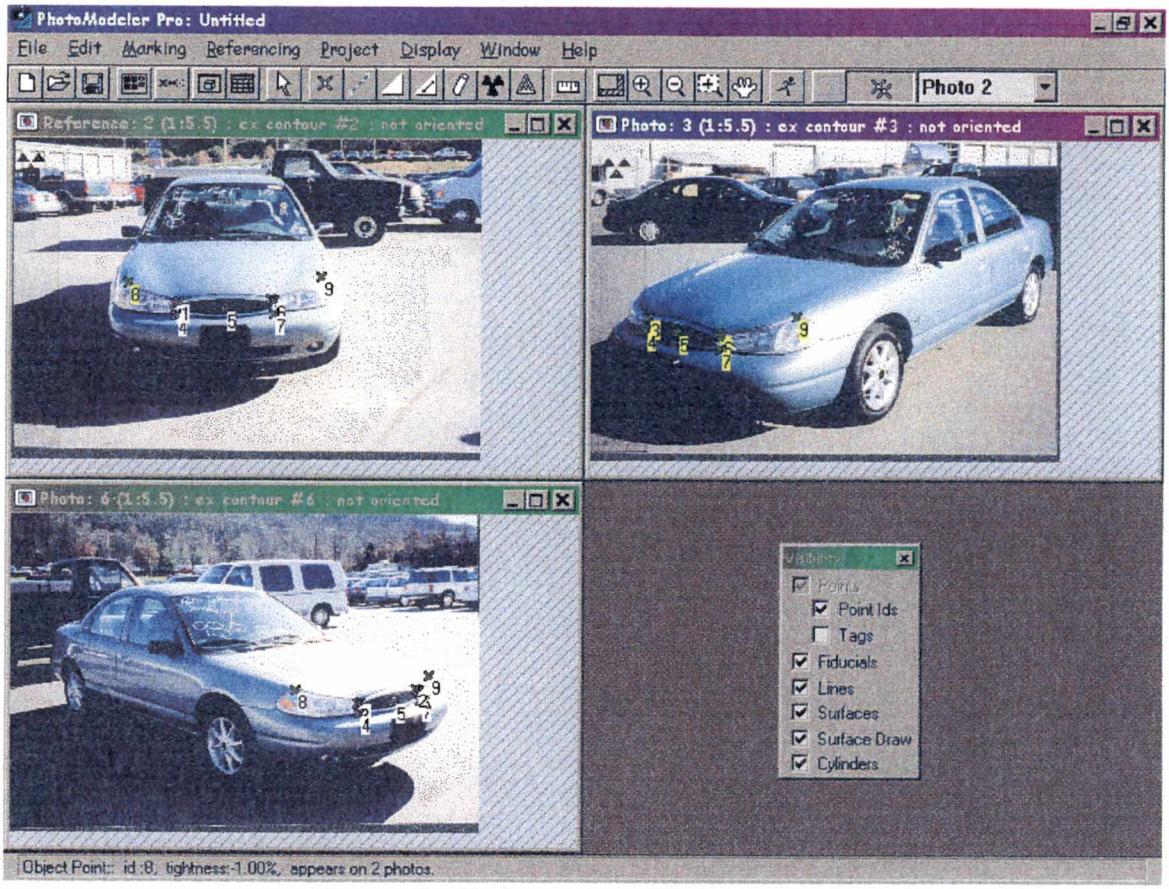


Figure 9. Referencing Points Across Photos

Before processing is performed, the fiducials (upper and lower) need to be marked on all photos. All photos taken with the calibrated camera used in this project have fiducials on the photos, which can be seen in the upper and lower left-hand corners. First zoom on the fiducial symbol on any photo. Then fiducial tool (which looks like a target on the toolbar) is clicked and activated. A dialog appears, which tells the user to mark the upper or lower fiducial. Mark the fiducial in the center of the target as precisely as possible. Repeat this procedure until both fiducials are marked in all photos. See Figure 10 for fiducial marking information.

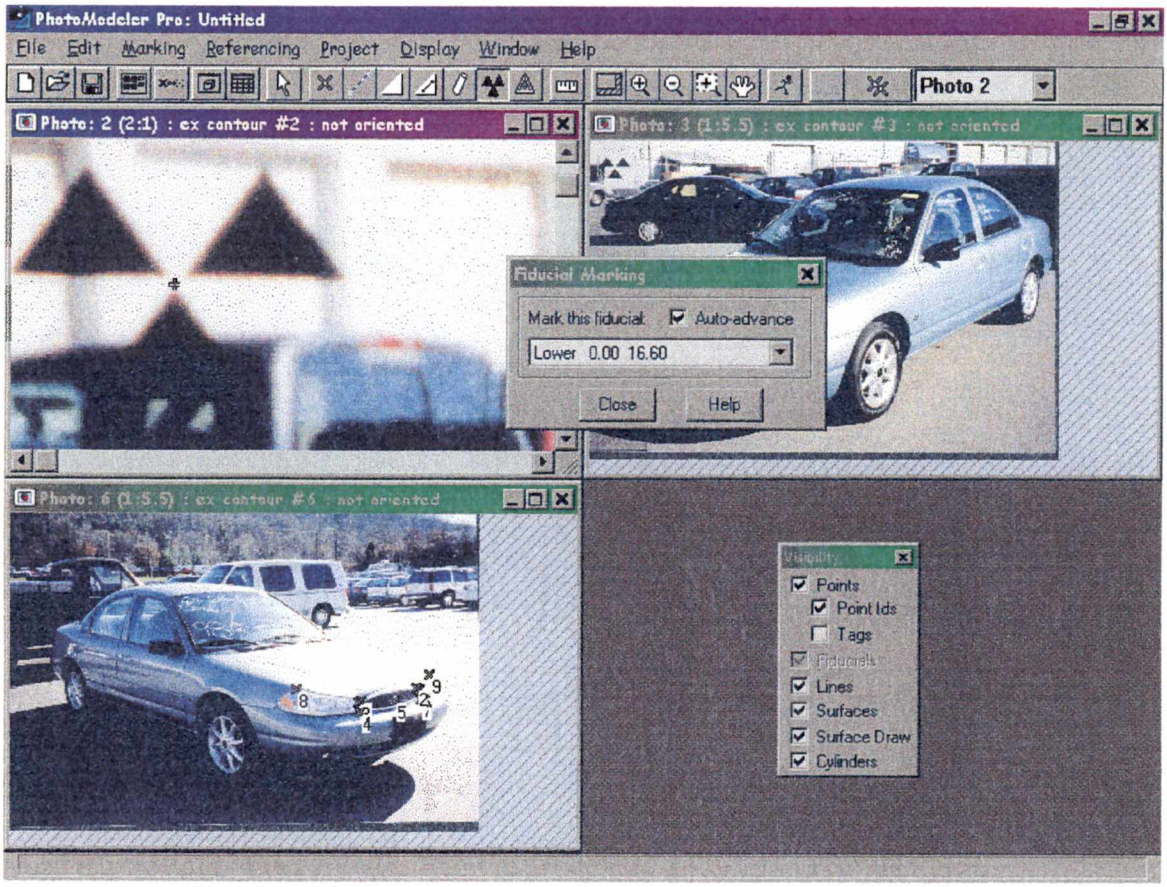


Figure 10. Marking Fiducials

Process

After several more points have been marked and referenced across the photos, processing can proceed. This is accomplished by clicking on the Project menu, and selecting Process. Or an alternate method is to press the Process button (which looks like running stick figure) on the toolbar. Automatically the Audit Summary Dialog appears. This device allows the user to ascertain the state of the project. If the Details button is clicked, then further information is available. Figure 11 shows an example screen of this.

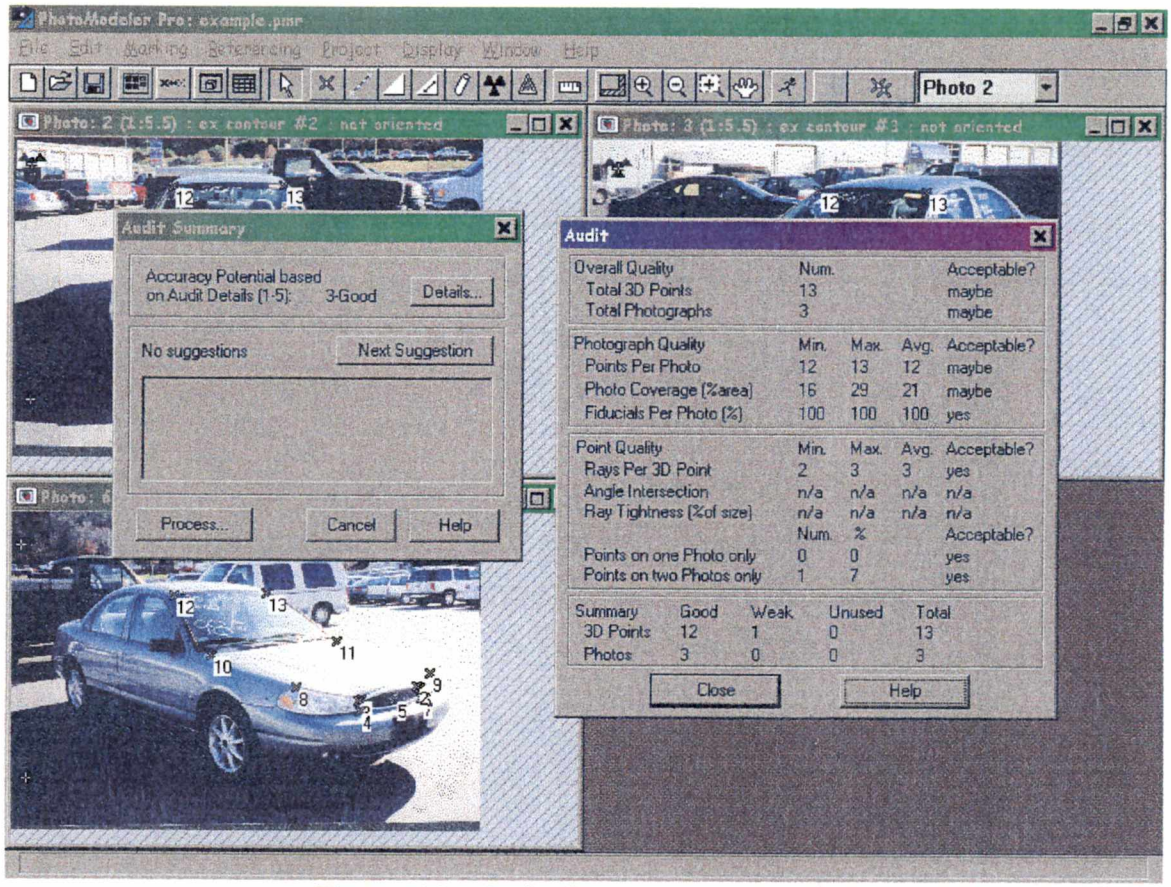


Figure 11. Audit Summary and Audit Details

Now the Process button on the Audit Summary dialog can be activated. The Processing Steps dialog appears, which gives the user various options to the processing actions desired. This dialog is shown in Figure 12.

The Proceed button is clicked and processing begins. At this point in time, PhotoModeler is solving various photogrammetric equations and creating a 3-D model of the exemplar vehicle. An error log and a successful processing window appear. Figure 13 shows that the processing completed successfully.

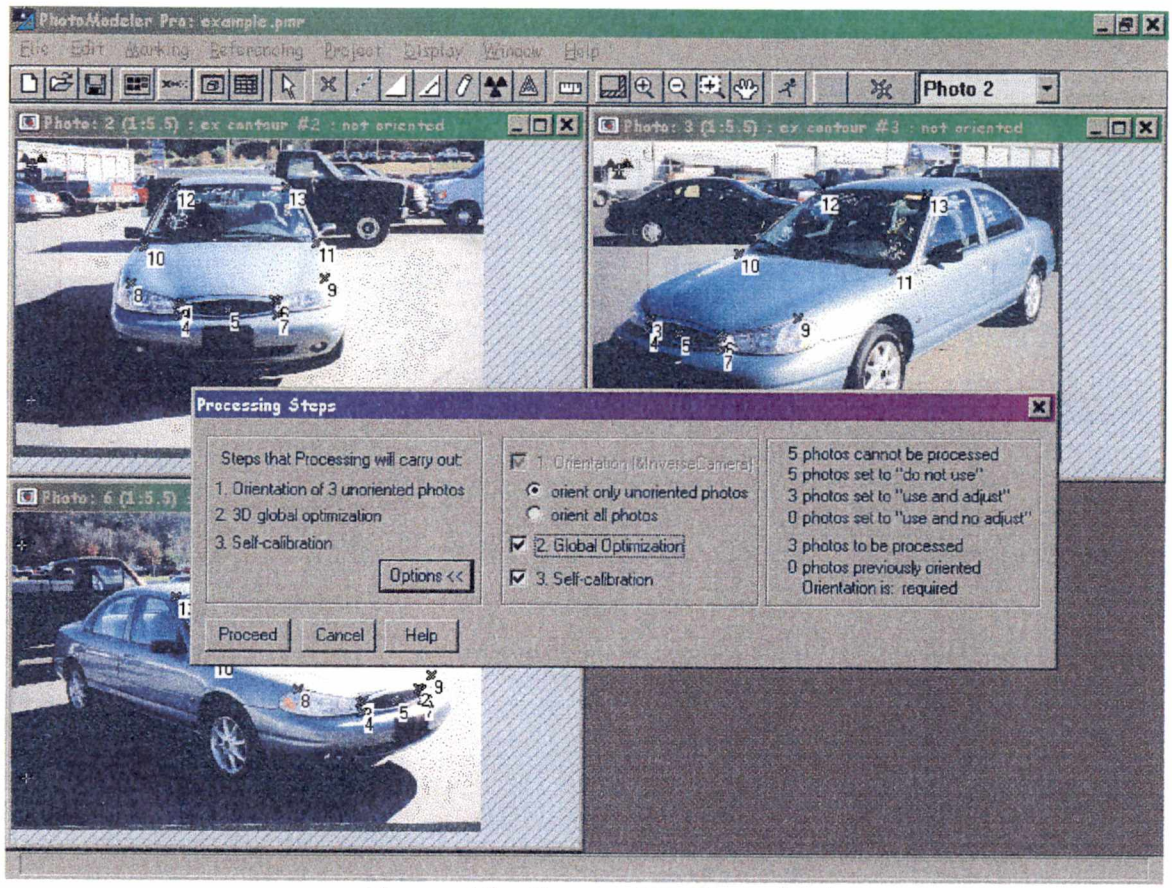


Figure 12. Processing Steps Dialog

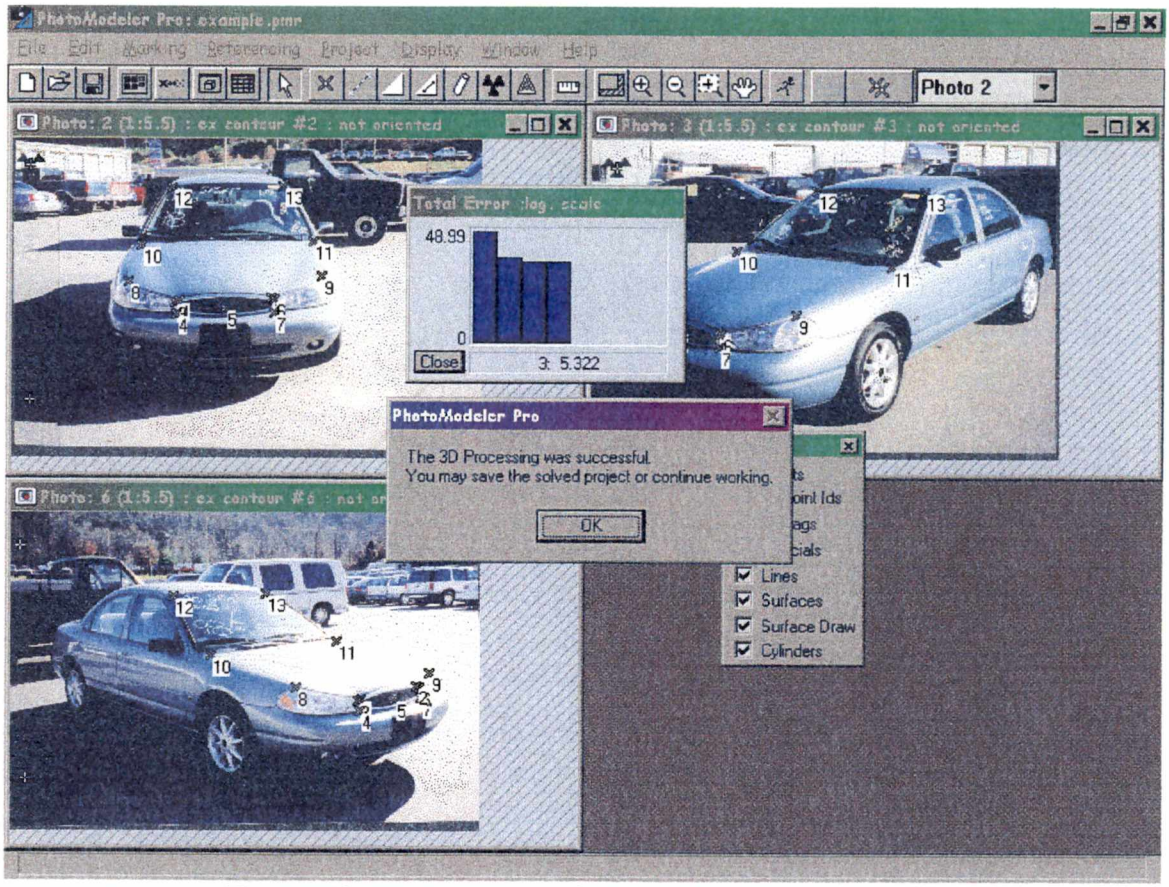


Figure 13. Error Log and Successful Processing Windows

From this point, it is necessary to import more photos, mark, and reference more points, and process between sets of photos. Do this until the entire vehicle has been modeled. Lines (created by using the line tool) between points can be marked as well, which gives the model some shape. Figure 14 shows a finished model, with the 3-D viewer option activated.

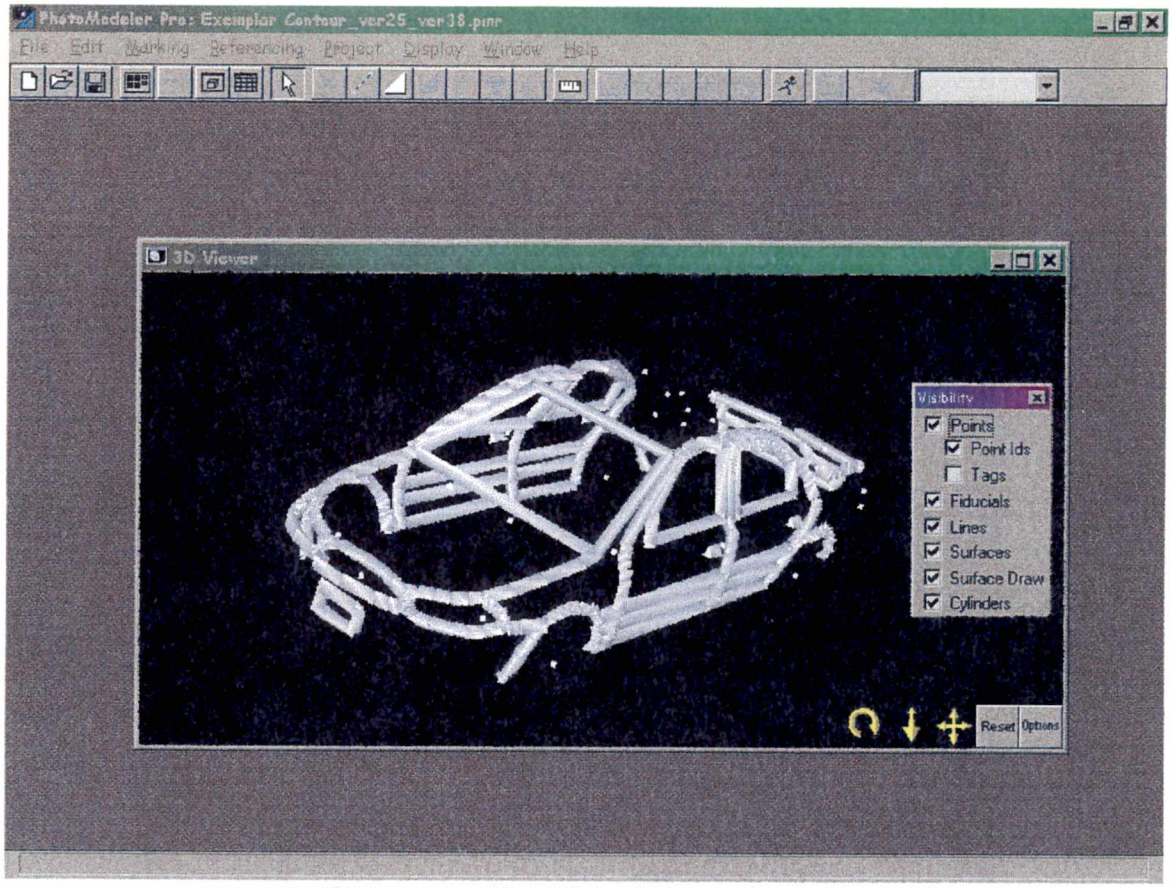


Figure 14. Completed Exemplar 3-D Model

Scale Project

The next step is to scale the project. This is accomplished by giving PhotoModeler one accurate dimension on the vehicle, that was measured beforehand. After the project is scaled, PhotoModeler can give the user any dimension in the project, just as long as that dimension is between two points or a point and a line. Scaling only works on a project that has processed

successfully; extracting measurements from an unprocessed or an unscaled project will not work in PhotoModeler.

First, go to the Project Menu and select Scale/Rotate. When that window appears, select Scale Only on the left-hand portion of the window. On the right-hand portion of the window is where a dimension is defined. The measurement taken in this project was along the bottom edge of the driver's side door, or between points 26 and 27. That measurement was measured as 43.4251 inches. Notice a defined dimension will appear green on the screen. Figure 15 shows this information.

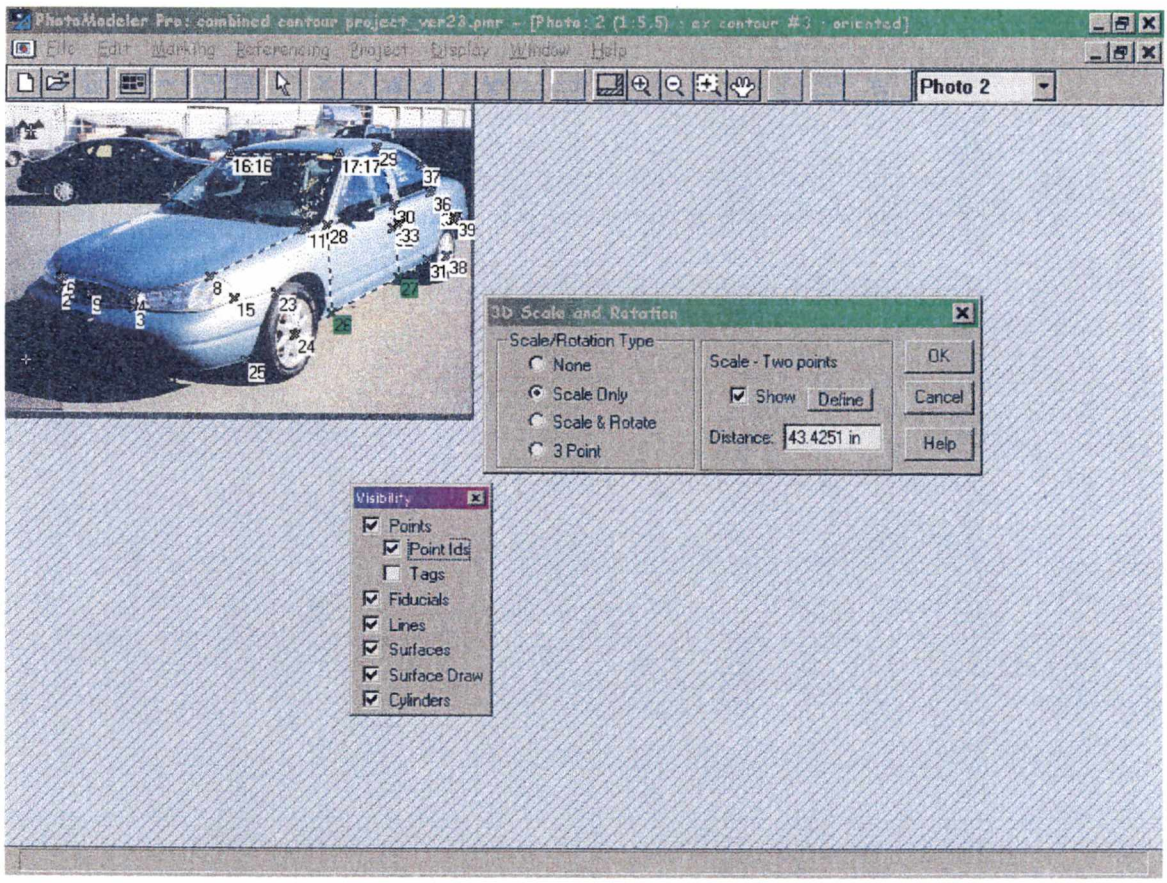


Figure 15. Scaling Information

Extract Measurements

Next, check the accuracy of the 3-D model. This can be accomplished by comparing dimensions on the driver's side to the passenger side. Select the Measuring Tool (which looks like a small ruler) on the tool bar. When this tool is activated, the cursor turns into a small ruler. To measure a dimension, the user selects one point, holds down the shift key, and then selects either another point or a line. The Measurement Dialog tells the user the distance between the two items selected, in the units in which the project was scaled. Figure 16 shows this.

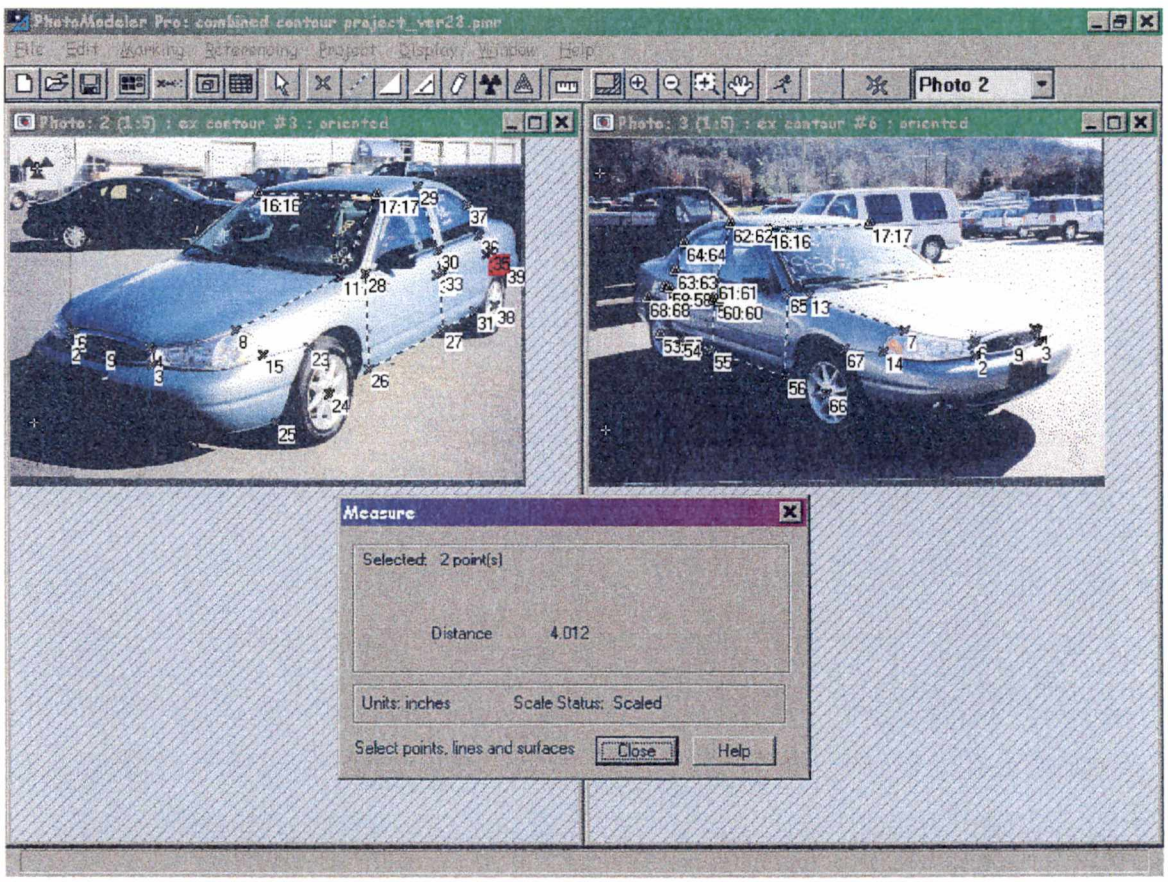


Figure 16. Measurement Tool

One important item to consider when comparing dimensions such as these is the point-marking technique. If, for instance, the driver's side dimensions were marked in a different manner than on the passenger's side, then these dimensions will be quite different. Of course there will be minute variances when good point marking techniques are applied, but the situation will be much worse if the user was not consistent from the onset. Table 4 reveals dimensions between both sides of the vehicle.

Table 4. Comparison of Measurements (in inches)

DIMENSION	**DRIVER'S SIDE**	**PASSENGER SIDE**	**DIFFERENCE**
Along bottom edge of front door	43.425	43.633	.208
Vertical edge of front door window	20.408	20.474	.066
Along bottom edge of rear door	26.445	26.315	.130
Small vertical edge of rear window	10.553	10.408	.145
Rear door handle	4.012	4.066	.054

Export Model

Now that the 3-D model of the exemplar is complete and verified, it is necessary to export this model into a file with a .dxf format. This allows the user to establish a good control point file for use in the crushed vehicle model. Control points are known X, Y, and Z coordinates (determined by PhotoModeler) and will be placed on the undamaged portions of the crushed vehicle. In other words, these positions are "locked in"—dimensionally these areas are the same on both the exemplar and the crushed vehicles. The only difference the two vehicles is the crushed portion in the front.

To export the model, go to the File Menu, and then select Export Model. The Export Model window appears. Make sure that 3-D Points, Lines, and Point ID Tags are checked and the other options unchecked. Also make certain that the file type selected is the .dxf format. Then click OK, give the file a name and save. Refer to Figure 17 for the correct export information.

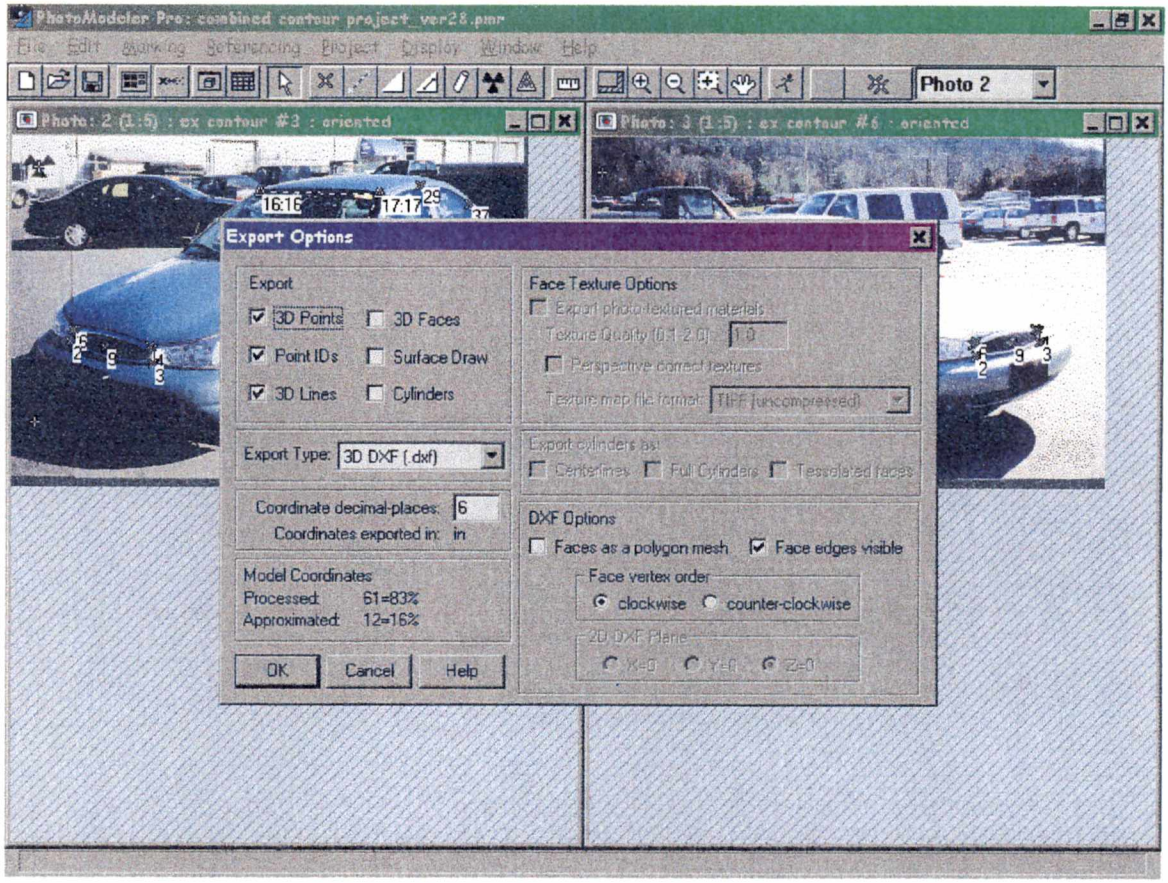


Figure 17. Export Model Into .dxf Format

Crush Measurement Project---Step Two

Scan NHTSA Pictures

In this portion of the project, the pictures of the crushed vehicle (provided by NTSHA) were digitized. The images were scanned with the Microtek scanner and saved into a .tif format. The image file size for each image ended up being about 20 MB (!). Interested readers can view these images in Appendix D.

Import NTSHA Pictures

Now that the crushed photos have been scanned, the project can proceed. First, the project which contains the model of the exemplar vehicle was opened. Then the pictures of the crushed vehicle were opened as well. There are two sets of photos in this one project, taken with different cameras. PhotoModeler has the ability to have multiple cameras in one project.

Since we have no information about the camera that took the NTSHA photos, an Inverse Camera project must be executed. It is very important that the Inverse Camera Feature is activated on the NTSHA photos. This is achieved by depressing the Open Photos button on the toolbar. Click on the double arrows to reveal the Photo Properties button, and click on it. Figure 18 reveals the Photo Properties Dialog.

Photos 9, 10, and 11 are the NTSHA photos, and they have the focal length, principal point and formal aspects boxes checked. Each photo also needs a camera name. This is done by creating a new camera in the Project Camera Dialog, which is accessed by clicking on the Cameras button in the upper right-hand portion of the Photograph Properties Dialog. In the Project Camera Dialog, the user has the ability to enter information about the camera that took the photo. In this project, the photos were given an arbitrary name, the image size was set, no fiducials option was selected, and the inverse camera box was checked. Figures 19 and 20 show the appropriate screens.

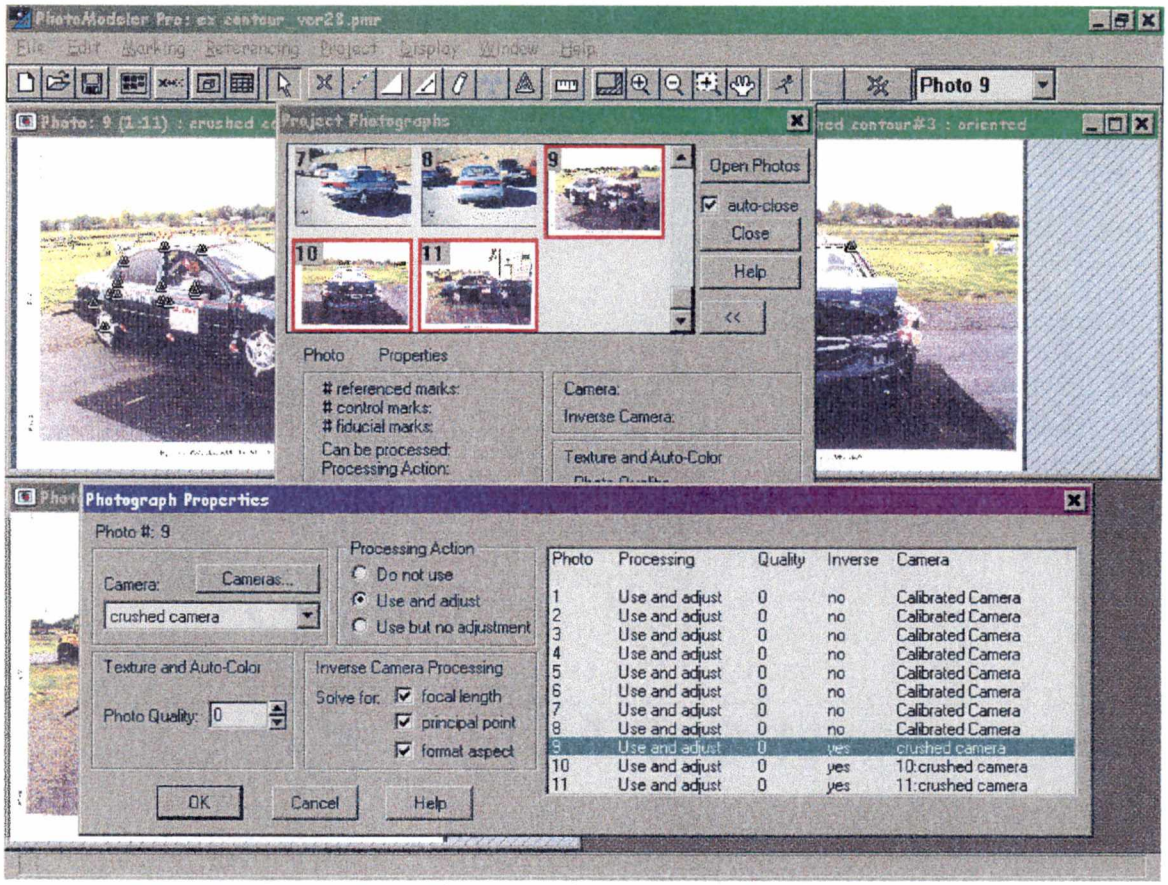


Figure 18. Photograph Properties Dialog

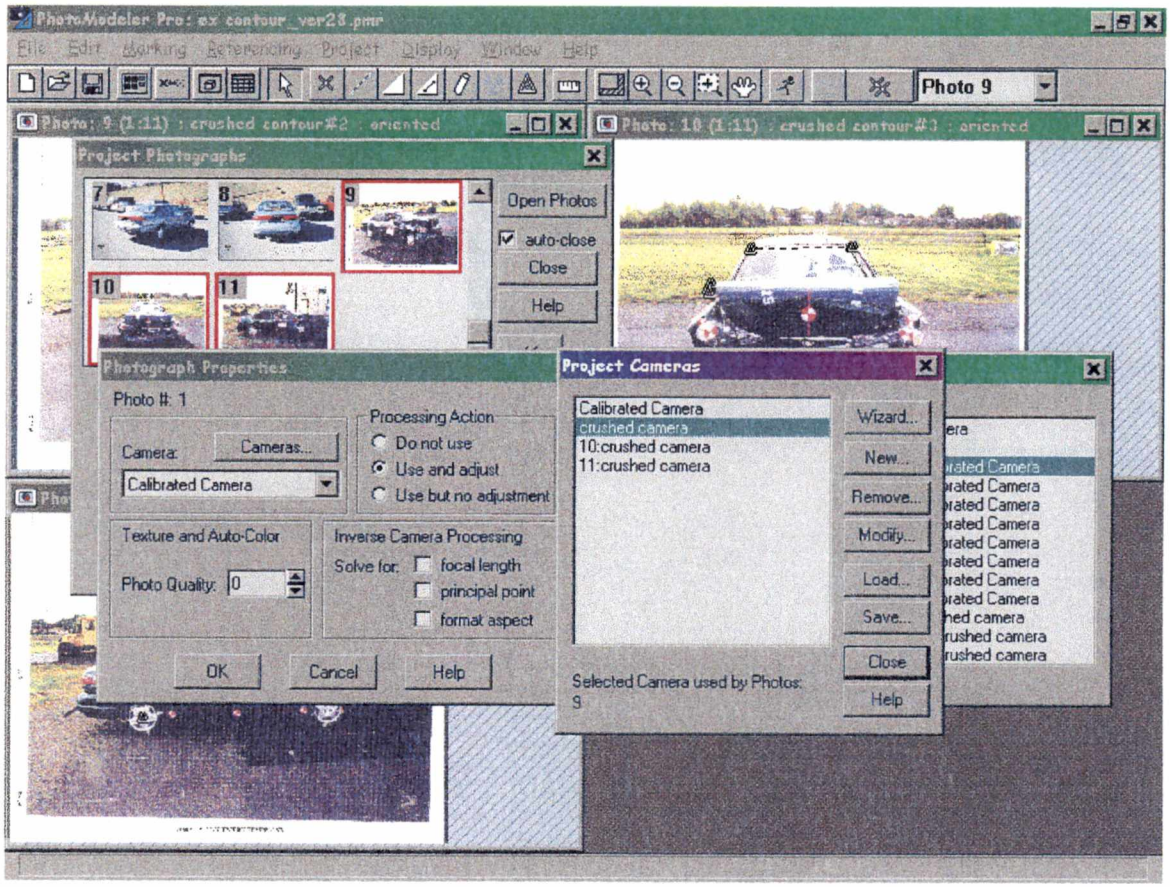


Figure 19. Project Cameras Dialog

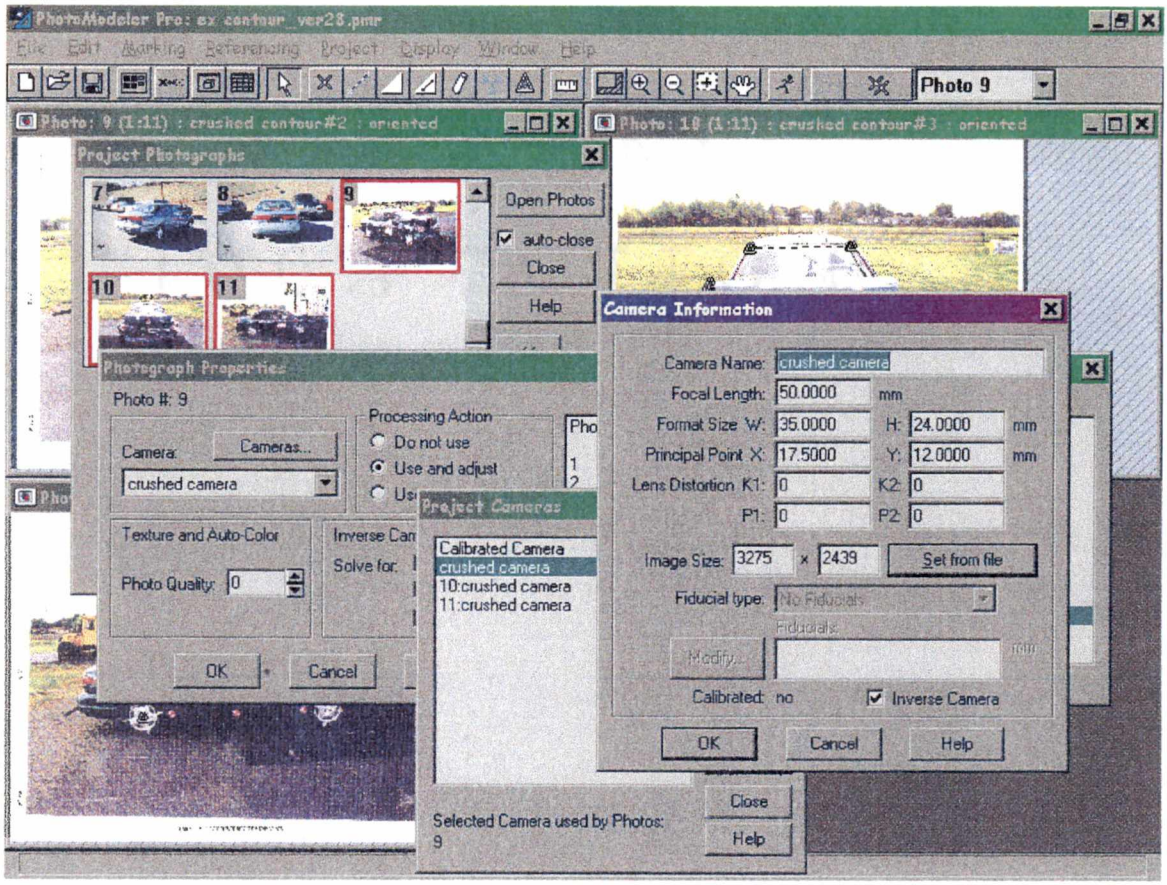


Figure 20. Camera Information Dialog

After the cameras have been named, PhotoModeler will summon a warning, which alerts the user that the same camera name (crushed camera) and its corresponding information can not be applied to the other Inverse Camera photos. PhotoModeler creates a new camera file for each Inverse Camera Photo and gives it a slightly different name. PhotoModeler's Inverse Camera Feature solves important camera information for each photo basically from scratch –none of this information can be forced to be identical if Inverse Camera is really supposed to work; hence, the individual camera files. PhotoModeler has to operate on the premise that the information could be

radically different. Consequently, each photo's camera information usually is only slightly different.

Import .dxf Control File

After the Inverse Camera information has been established, the Control Point file needs to be imported. This is accomplished by depressing the Control Point button (a triangle) on the toolbar. Then the Control Point dialog appears. Now select the Import button to get the Control Import dialog. Here the user defines the importing type (.dxf), units(inches), and file location. Most importantly, the user needs to make certain that the "Do Not Adjust" box is checked, or the project will not work. This allows the Control Points to be "locked in" on the undamaged portions.

Also in this dialog is a caution that photos may need to be reoriented on previously oriented photos. This is the case in this project. Photos 1-8 (exemplar photos) have already been oriented earlier in the project. Now that the new crushed photos have been added to the project, it is necessary to reorient all photos so that the exemplar model and the crushed model can "mesh" together as a single unit. Figure 21 displays this information.

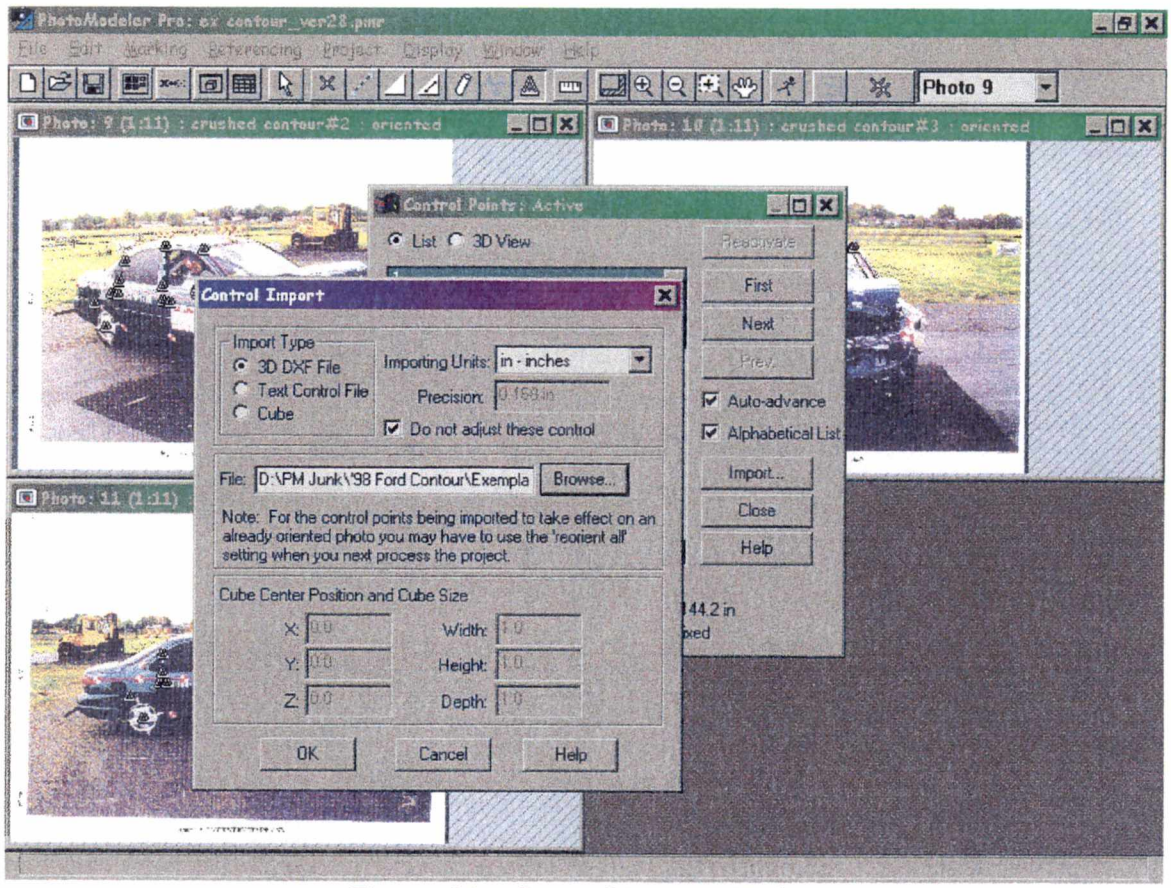


Figure 21. Control Import Dialog

Mark Control Points

After the appropriate information has been entered to retrieve the control file, Control Points must be marked. Remember that Control Points are to be marked on undamaged portions of the crushed vehicle only. Control Points are very precise locations on the vehicle; their placement needs to be handled with great care. Erroneous placement on deformed portions of the vehicle, no matter how slight, will cause great problems for PhotoModeler, and the result may be a

project that will have great trouble processing or will not process at all. It is the user's best interest to place these points very carefully in their correct positions.

Begin marking Control Points by using the respective dialog. In this dialog is a list of the points which correspond various points on the exemplar vehicle. For example, Point 16 is the upper left-hand corner of the windshield. It is imperative to confirm that the Control Point you are placing actually does correspond to the same spot on the exemplar vehicle. Incorrectly placed Control Points will make a project fail more than anything will.

Start with one photo and mark Control Points using the Control Point dialog. Next reference those marks to the corresponding points on the exemplar. Then reference those same marks across the other crushed photos. This assures that PhotoModeler understands that the undamaged portion on the crushed vehicle is the same as the exemplar.

Process

Now that the Control Points are properly marked and referenced across all photos, processing can begin. Select the Process button from the toolbar. The Audit dialog appears just as before and the Process button is selected once more. Select Options from the Processing Steps dialog and be certain to check the box next to option #1, Orient All Photos. Refer to Figure 22.

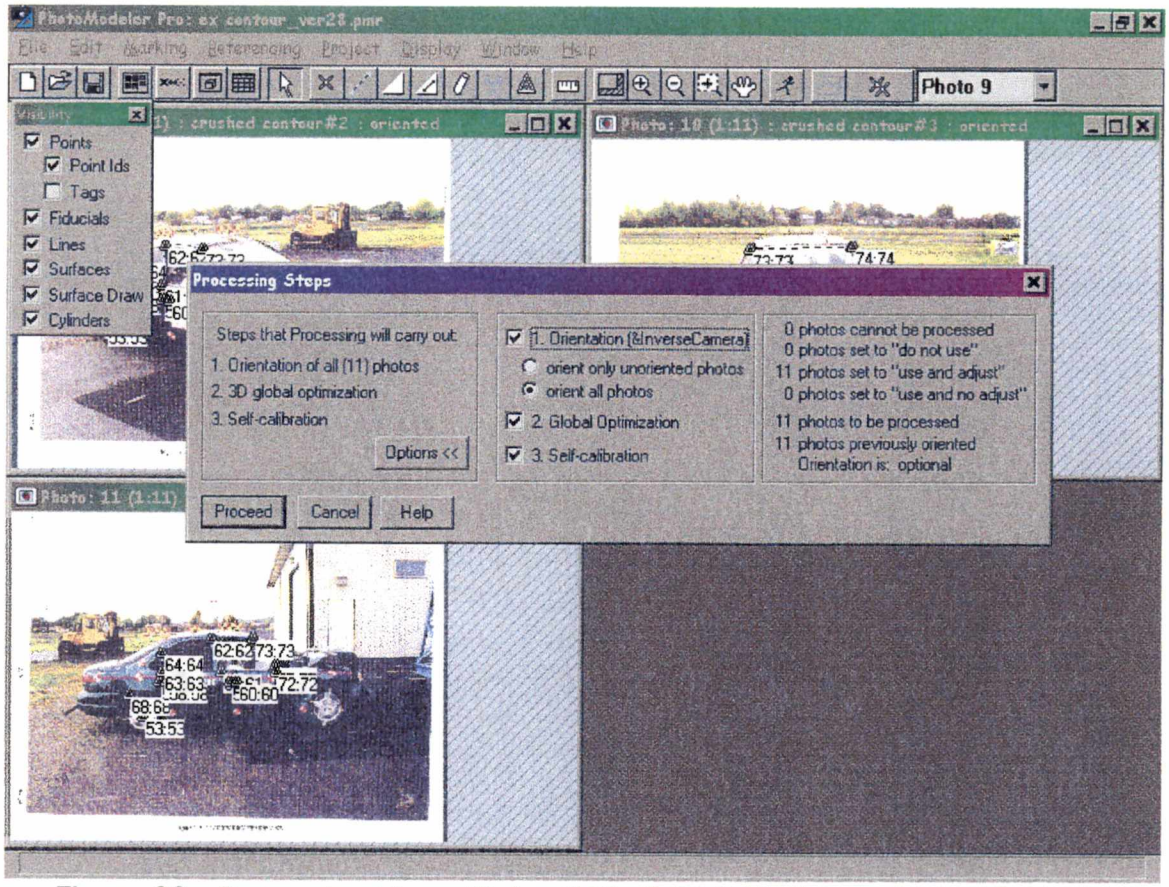


Figure 22. Processing Steps Dialog With Orient All Photos Option Selected

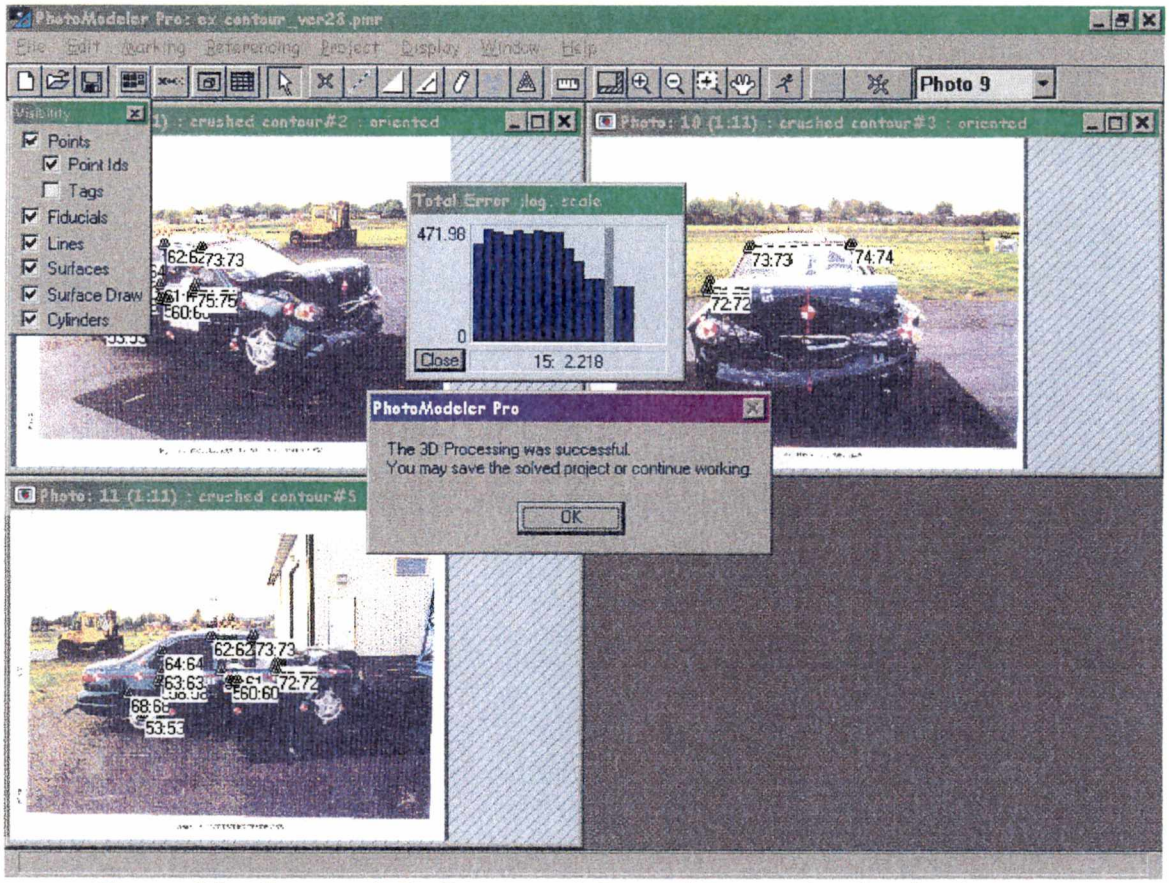


Figure 23. Successfully Processed Control Points On Crushed Photos

After this option is selected, press Proceed. Figure 23 reveals the corresponding error dialog and verification that the project did process successfully.

Mark Crushed Points

Now that the Control Points were properly placed and the project has processed successfully, the next step, which involves marking points on the crushed portions of the vehicle, must be performed.

Before this portion of the project can ensue, a careful study of the crushed section and its corresponding part on the exemplar must occur. This thesis is designed to require six (6) crush measurements across the damaged portion, and they must be evenly spaced out across the width of the crush. Points of maximum crush are of particular interest and they must be identified as well. Each marked crushed point selected for crush measurement analysis must correspond to a marked point on the exemplar. For example, Point 14, which is the corner where the right headlight and hood meets on the exemplar, corresponds to Point 93 on the crushed vehicle. This approach allows for the extraction of the measurements from the 3-D model, which will be discussed in a later segment.

Once identical points on the exemplar and crushed vehicles are detected, marking of the points can begin on the crushed vehicle. These points are marked like any other points on the vehicle with the Point Marking tool, and they must be referenced across the other crushed photos as well. Then the project needs to be processed. Remember to select Reorient All Photos in the Processing Steps Dialog. Figure 24 verifies successful project processing.

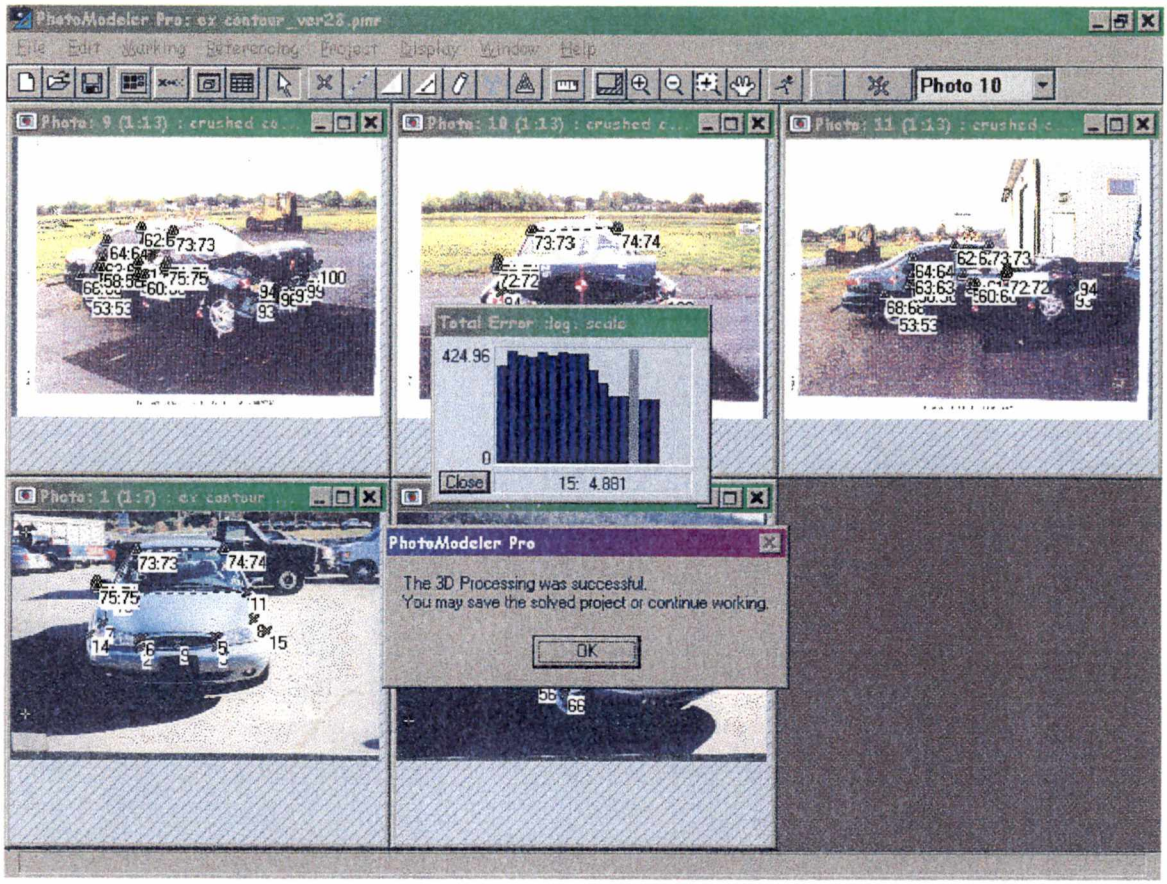


Figure 24. Successfully Processed Project With Crushed Portions Marked

After successful processing of the project, it is a good idea to activate the 3-D viewer to see the crushed points that were marked. To help the user and other viewers to distinguish crushed points from exemplar points, it is beneficial to have the points to be denoted with different colors, instead of both possessing the default color (white.) In this project, the crushed points are distinguished with blue points in the 3-D viewer. This is achieved by launching the Object Properties dialog from the Edit Menu. Then with the all crushed points selected, create a new material called "crushed" and give it the color blue. Figure 25 shows this screen.

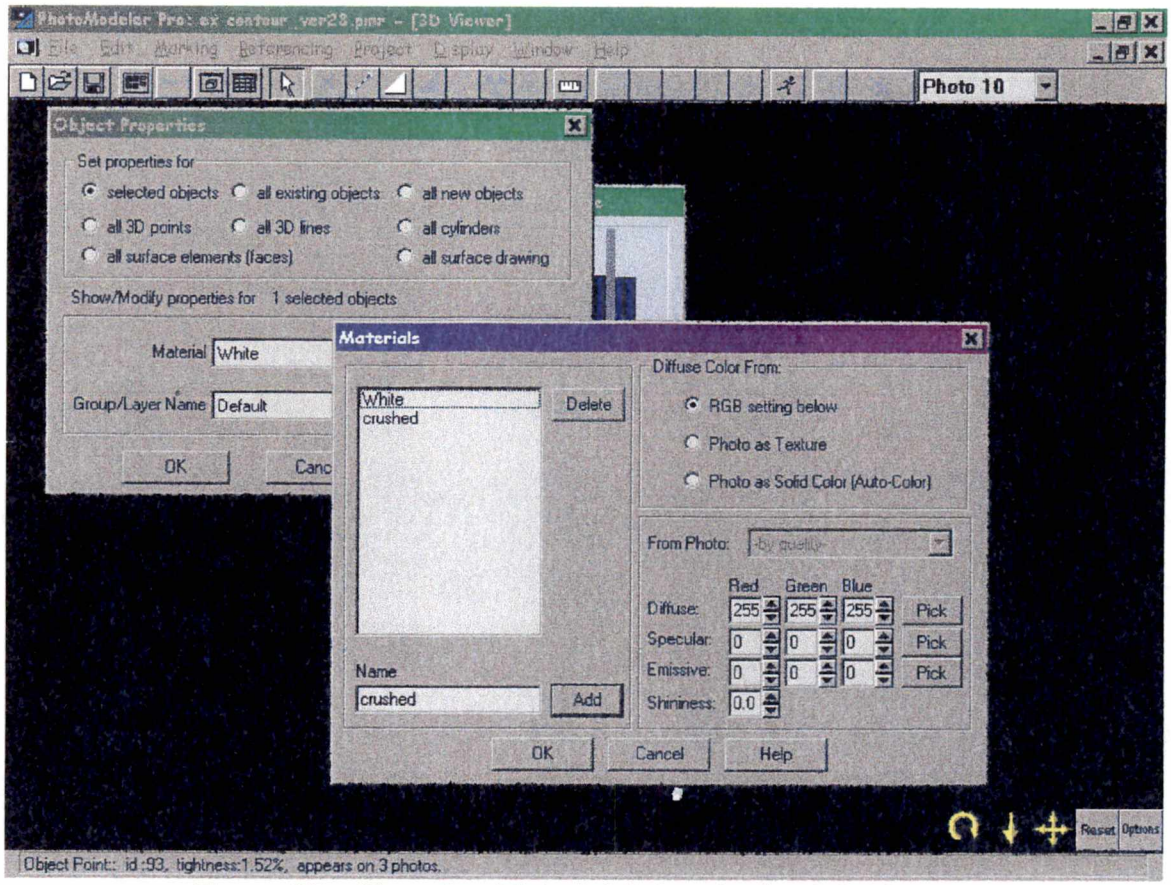


Figure 25. Changing Material Colors in the 3-D Viewer.

Establish Reference Line(s)

Establishing reference lines in the 3-D viewer is a critical step that must be performed before the measurements are extracted. Measurements can be obtained on any photograph once it is processed and scaled, however; accuracy problems can occur when measurements are made without a common datum that is visible on multiple photographs, which consequently in this project, is difficult since two independent sets of photos (exemplar and crushed) are in use. In other words, making measurements in Photo 10 (a crushed photo) and then

making the corresponding measurements in an exemplar photo could lead to errors if the exact same reference line or datum is not used. To counteract this problem, all measurements were made in the 3-D viewer, which has both sets of photos incorporated into one 3-D model. PhotoModeler has a feature, Expand Selection To All Windows, which allows the user to draw a line in the 3-D viewer between two points that are not visible in any of the photographs in the project, but remains visible in the 3-D viewer. The user selects two points in the 3-D viewer from which a good reference line can be erected. A good reference line has approximately the same height as the crushed points. If there is too much vertical separation between the crushed points and a single reference line, then it is wise to establish two (2) reference lines to maximize accuracy. Then corresponding exemplar and crushed points can be measured to this common line of reference and amount of crush can be determined.

To establish a reference line, go to the Edit Menu and select Expand Selection To All Windows. With this feature activated, the user can, with the Line Tool, draw a line (in the 3-D viewer) between two points which can be used for referencing. After the line has been established, it is good to add color to this reference line to ease in measurement extraction. The reference line in this project is yellow, and Figure 26 shows this reference line with the crushed points in the 3-D viewer.

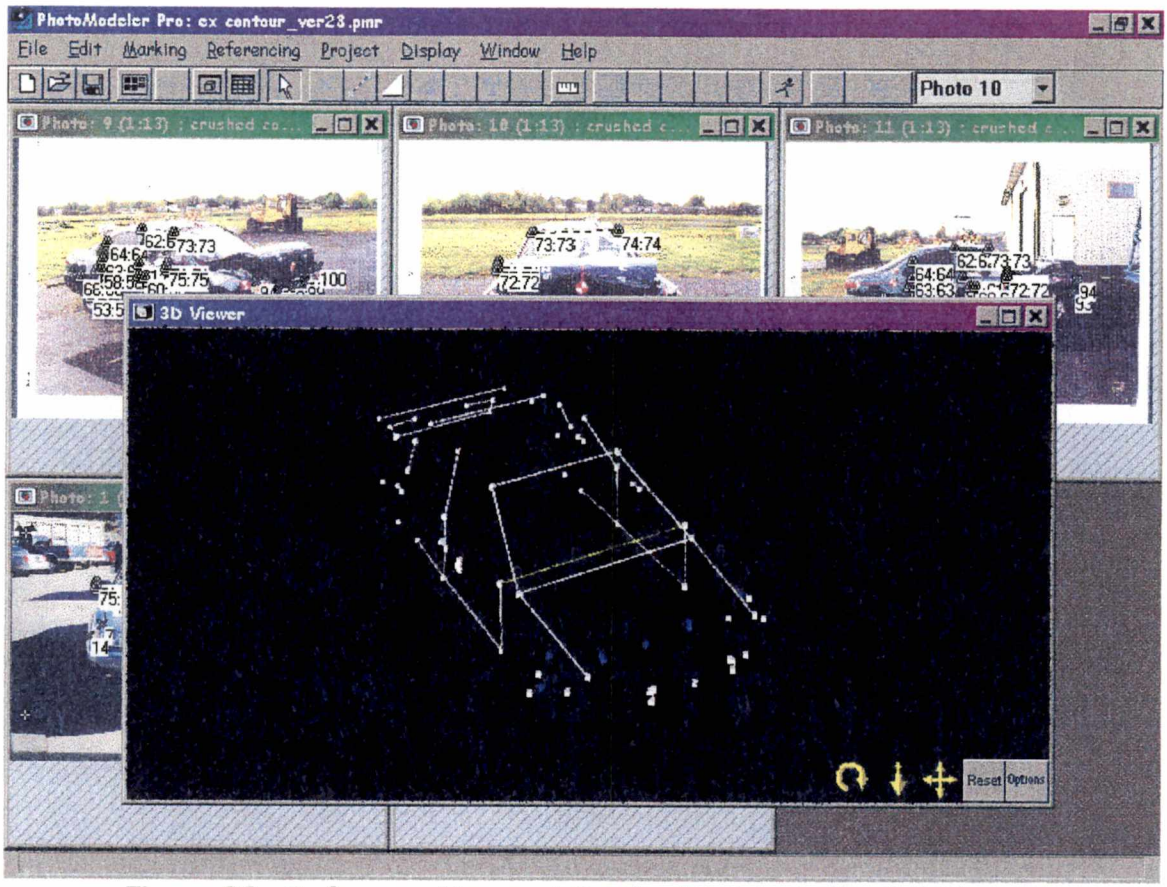


Figure 26. Reference Line and Crushed Points in the 3-D Viewer

Extract Measurements

Now that the reference line and crushed points have been established in the 3-D viewer, extraction of the measurements can ensue. This is accomplished by depressing the Measurement Tool button on the toolbar, which looks like a small ruler. Click on a selected exemplar point (for example, Point 14) in the 3-D viewer (the Point ID bar at the bottom portion of the screen informs the user which point is selected.) The point turns red, and the Measurement Tool Dialog appears. While holding down the Shift key, click on the yellow reference

line. The Measurement Tool Dialog indicates the distance between the selected point and line, which is 41.219 inches. Then find Point 14's corresponding counterpart in blue (Point 93.) The procedure was repeated and a distance of 34.967 inches was found. This means that this portion of the vehicle experienced 6.252 inches of crush. Figure 27 shows the measurement procedure and Table 5 shows the collection of data retrieved from this procedure.

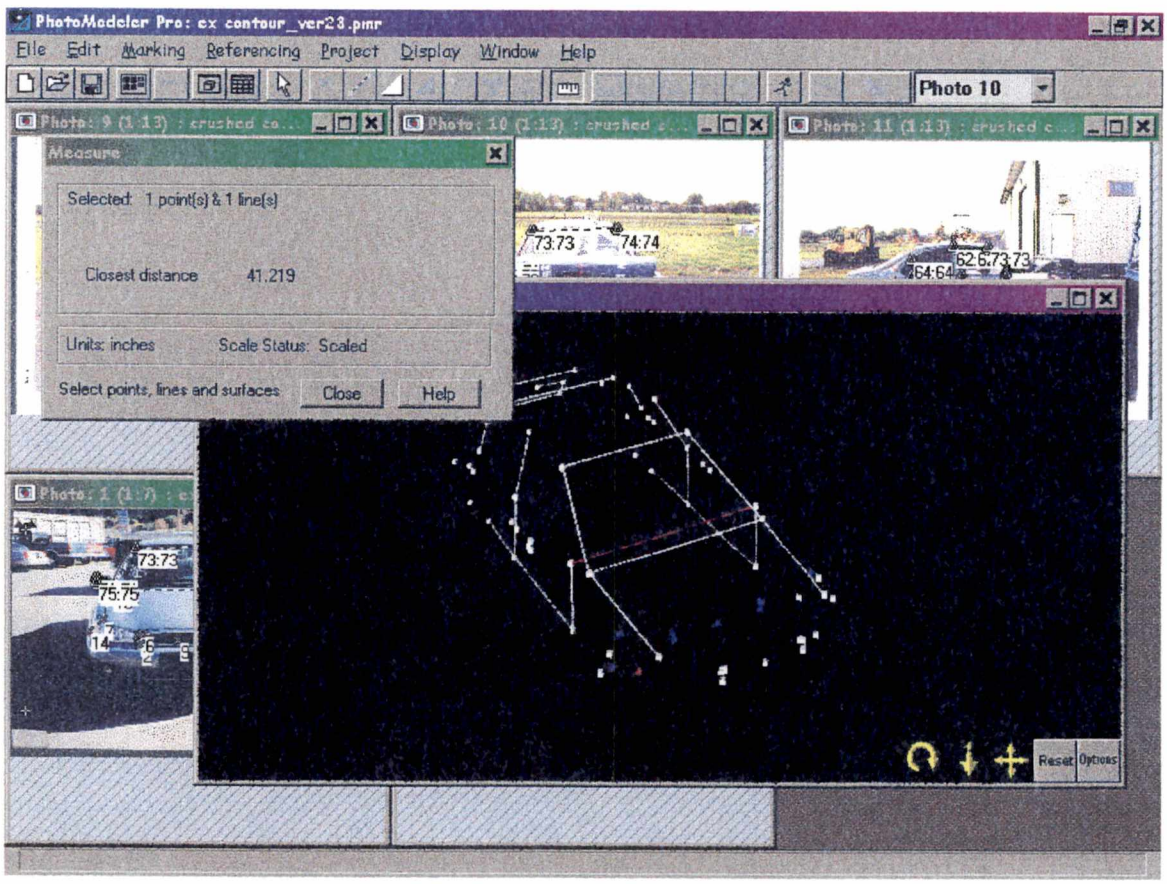


Figure 27. Measurement of Exemplar and Crushed Points Using Reference Line

Table 5. Extracted Measurements From 3-D Viewer

Exemplar Point	Crushed Point	Exemplar To Ref. Line (in inches)	Crushed To Ref. Line (in inches)	Difference (in inches)
14	93	41.219	34.967	6.252
7	94	42.395	32.785	9.610
2	96	53.256	34.549	18.707
9	97	53.691	33.863	19.828
3	99	52.946	32.893	20.053
8	100	42.199	30.879	11.320

Crush Measurement Project –Step Three

The remainder of the Crush Measurement Project will use PhotoModeler's measurements plus other information and tools to determine the speed of the vehicle prior to impact. To complete this project, the following pieces of information are required: crush coefficients, weight of the vehicle, and width of the crush. Tools also required are the Northwestern Equations derived from Traffic Accident Reconstruction which can be found in Appendix C. Front crush coefficients used for this project were purchased from Neptune Engineering Inc. of Clovis, California and can be found in Appendix E. Also, the weight of the vehicle was found on the crush coefficient page provided by Neptune. Lastly,

the width of crush was directly derived from the 3-D model used in PhotoModeler.

Now that all of the missing pieces of the puzzle are found, the determination of the pre-impact speed of the NTSHA vehicle can be proceed.

Given:

W=60.506 in	C_3=18.707 in
G=336.87 lbs	C_4=19.828 in
A=354 lb/in	C_5=20.053 in
B=186 lb/in^2	C_6=11.320 in
C_1=6.252 in	g=32.2 ft/sec^2
C_2=9.610 in	w=3310 lbs

Find: The energy required to crush the vehicle **and** the vehicle's initial speed.

$$E=\frac{W}{5}\left[5G+\frac{A}{2}(C_1+2C_2+2C_3+2C_4+2C_5+C_6)+\frac{B}{6}\left(C_1^2+2C_2^2+2C_3^2+2C_4^2+2C_5^2+C_6^2+C_1C_2+C_2C_3+C_3C_4+C_4C_5+C_5C_6\right)\right]\left(1+Tan^2\vartheta\right)$$

$$E=\frac{60\,506}{5}\left[\begin{array}{l}5(33687)+\frac{354}{2}\left(6\,252+2(9\,610)+2(18\,707)+2(19\,828)+2(20\,053)+11\,320\right)+\\ \frac{186}{6}\left(\begin{array}{l}(6\,252)^2+2(9\,610)^2+2(18\,707)^2+2(190828)^2+2(20\,053)^2+(11\,320)^2+\\ 6\,252\,(9\,610)+9\,610(18\,707)+18\,707(19\,828)+19\,828(20\,053)+20\,053(11\,320)\end{array}\right)\end{array}\right]\left(1+Tan^2\vartheta\right)$$

$$E=12\,1012\left[1684\,35+177(153\,968)+31(2642\,3825+1235\,389)\right]$$

$$E=12\,1012\left[1684\,35+27252\,336+120210\,9165\right]$$

$$E=1{,}804{,}864\,96737 m-lbs$$

$$E=150{,}405\,4139 ft-lbs$$

$$EBS = v = \sqrt{\frac{2gE}{w}} = \sqrt{\frac{2(32\ 2)(150\ ,405\ 4139\ )}{3310}}$$

$$v = 54.095\frac{ft}{\text{sec}} = 36.88mph$$

Accident Scene Diagram

Take Pictures

The first step to properly diagramming the accident scene is to take pictures of the accident scene with the calibrated camera. The same picture taking methodology which was applied in the crush measurement project applies here as well. In other words, there should be a good point overlap, many pictures (throw out the ones you don't need), and most importantly in this case, good vertical separation between the pictures, if at all possible. Luckily, in this project, the accident scene was situated just before an interstate overpass and the pictures did have good vertical separation; the pictures were shot from the overpass and the adjacent hillsides.

Scan Pictures

Just as in the crush measurement project, developed photographs were digitized by means of the Microtek scanner. The photographs were named, saved with a .tif extension, and placed in a directory which could easily be found later.

Project Setup

Project Setup in this situation is exactly the same as in the previous project, with the only exception—the units are reported in feet and the maximum length is one hundred (100) feet. Camera information and Add/Remove Photograph Dialogs are the same too.

Mark Points

After the appropriate photographs have been imported into the project, points can be marked. The point marking/referencing technique is exactly the same as before, with points being marked initially on a few photographs, with more added later. Additionally, the zoom tool was used for precise point placement.

The objects modeled in this project are road markings (marked by a police officer) of a tractor-trailer. These markings pinpointed the tractor-trailer's position at the time of the accident. Also marked was a portion of the aluminum railing for scaling purposes. Figure 28 shows marked points.

Process

Once the points are marked appropriately, processing can follow. This is the same procedure as the crush measurement project. See Figure 29.

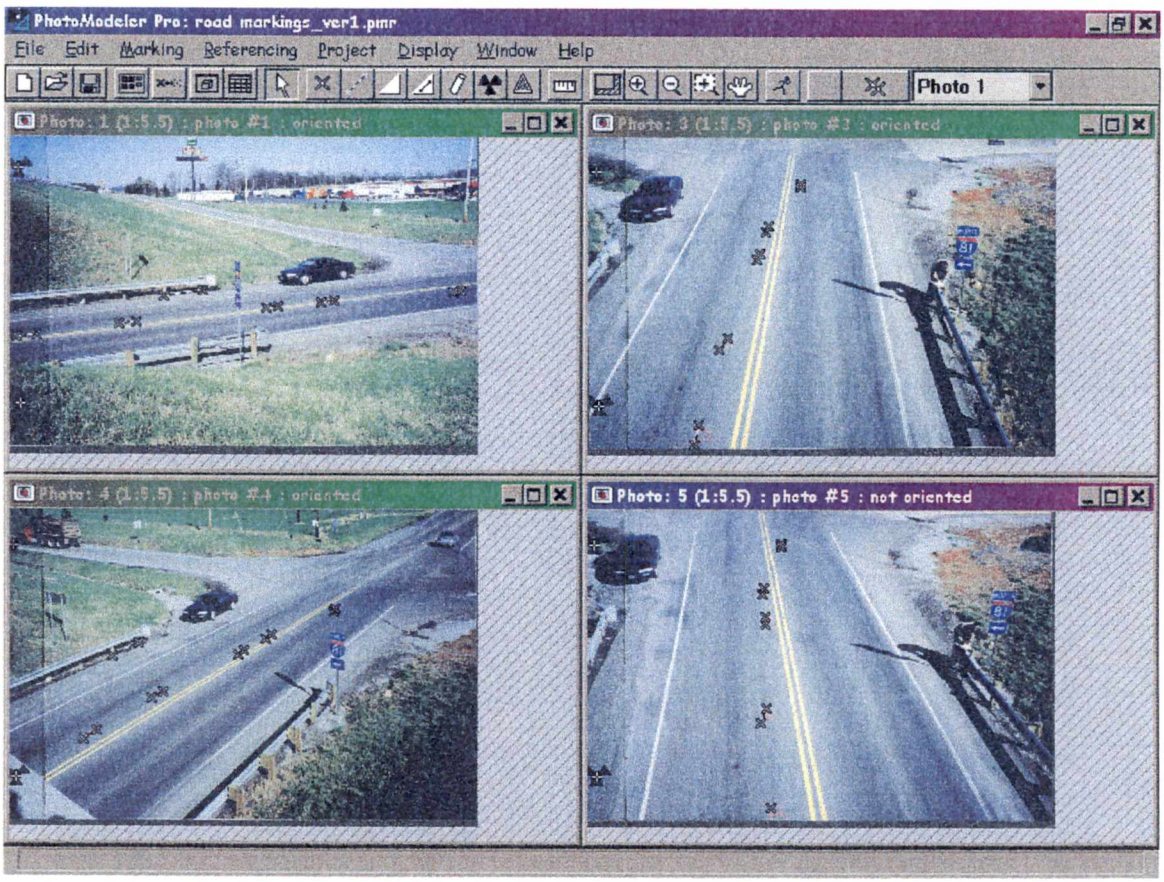


Figure 28. Marked Points on the Accident Scene Photographs

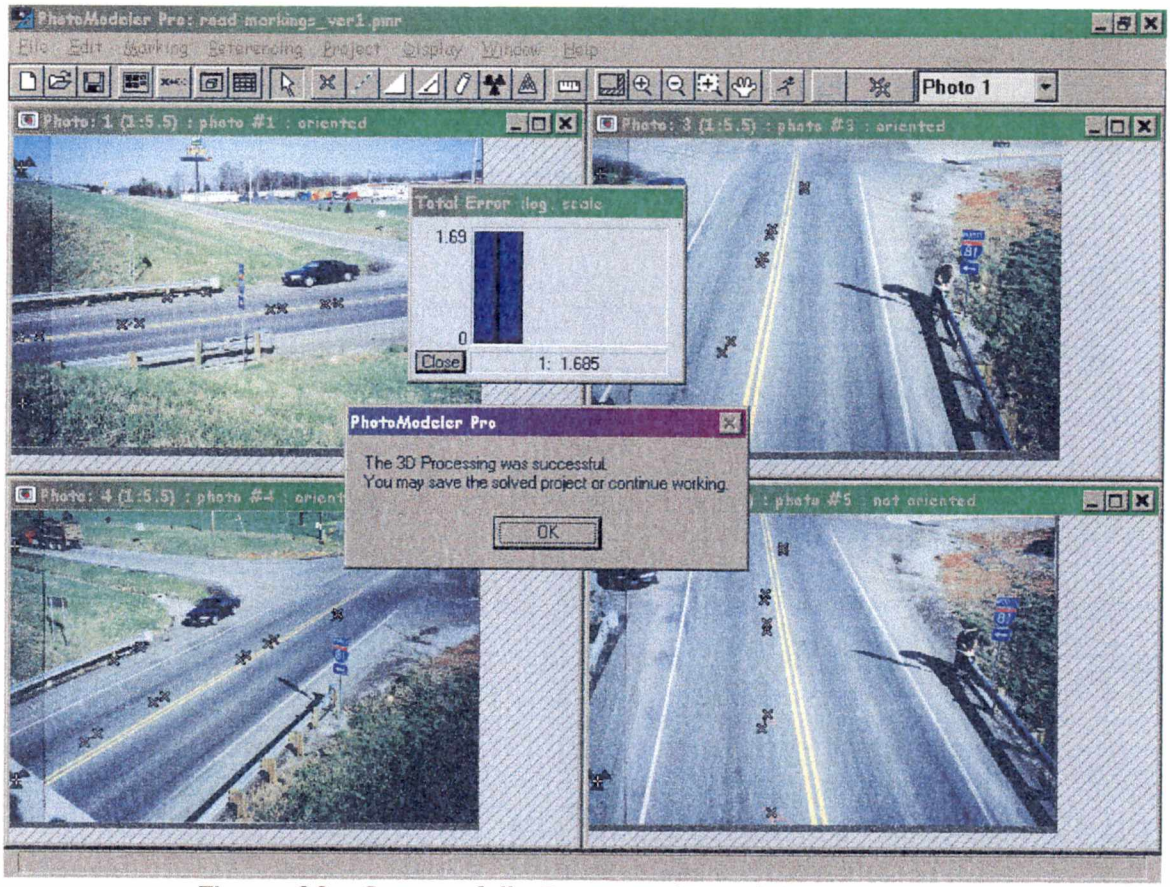


Figure 29. Successfully Processed Road Scene Project

Scale Project

Since the project processed successfully, scaling can now take place. As mentioned before, a portion of the railing was measured, and its value corresponding value was found to be 6.6250 ft. This measurement was entered into the Scale/Rotate dialog and the project was scaled accordingly. See Figure 30 for this information.

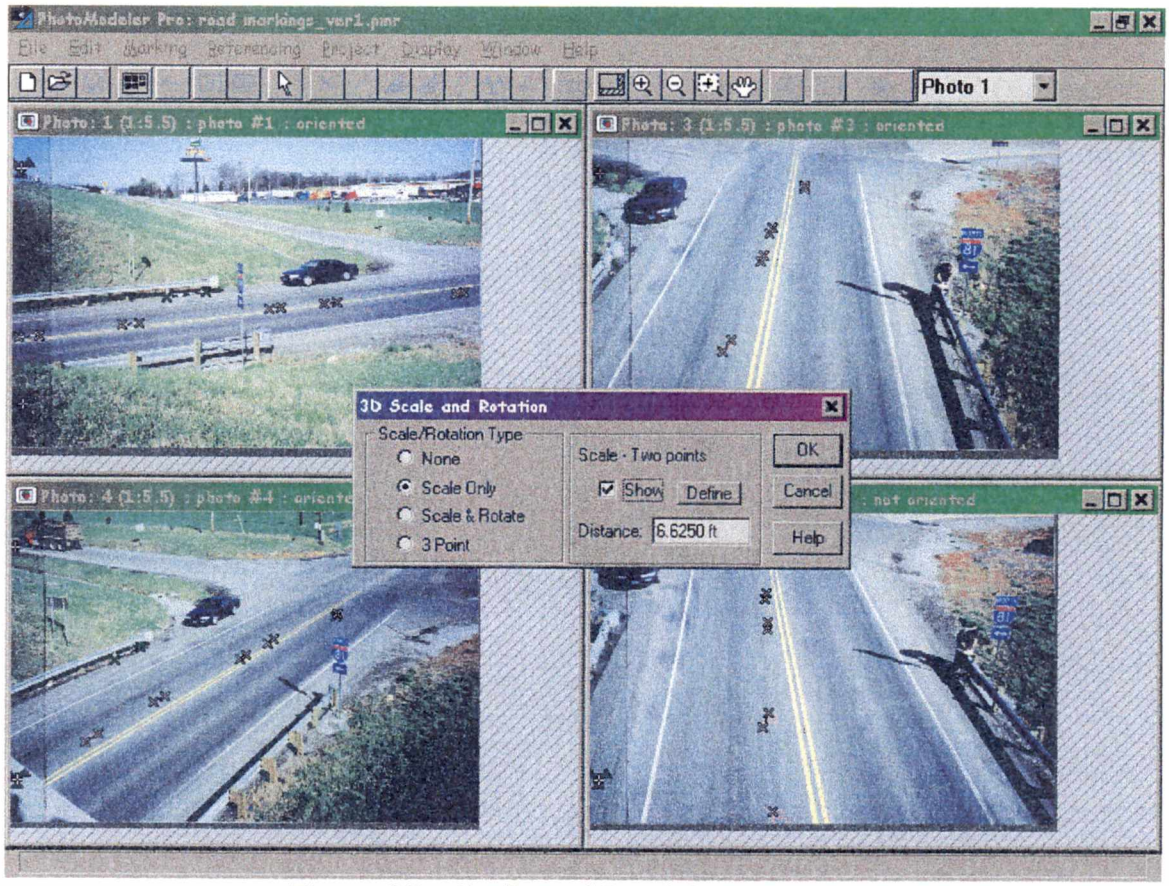


Figure 30. Scaling of Road Scene Project

Extract Measurements

Once the project is properly scaled, extraction of the measurements can take place. As executed previously in the crush measurement project, measurements are obtained via the Measuring Tool by clicking on two points. Figure 31 shows the Measuring Tool Dialog and Table 6 shows a summary of the measurements obtained from this project.

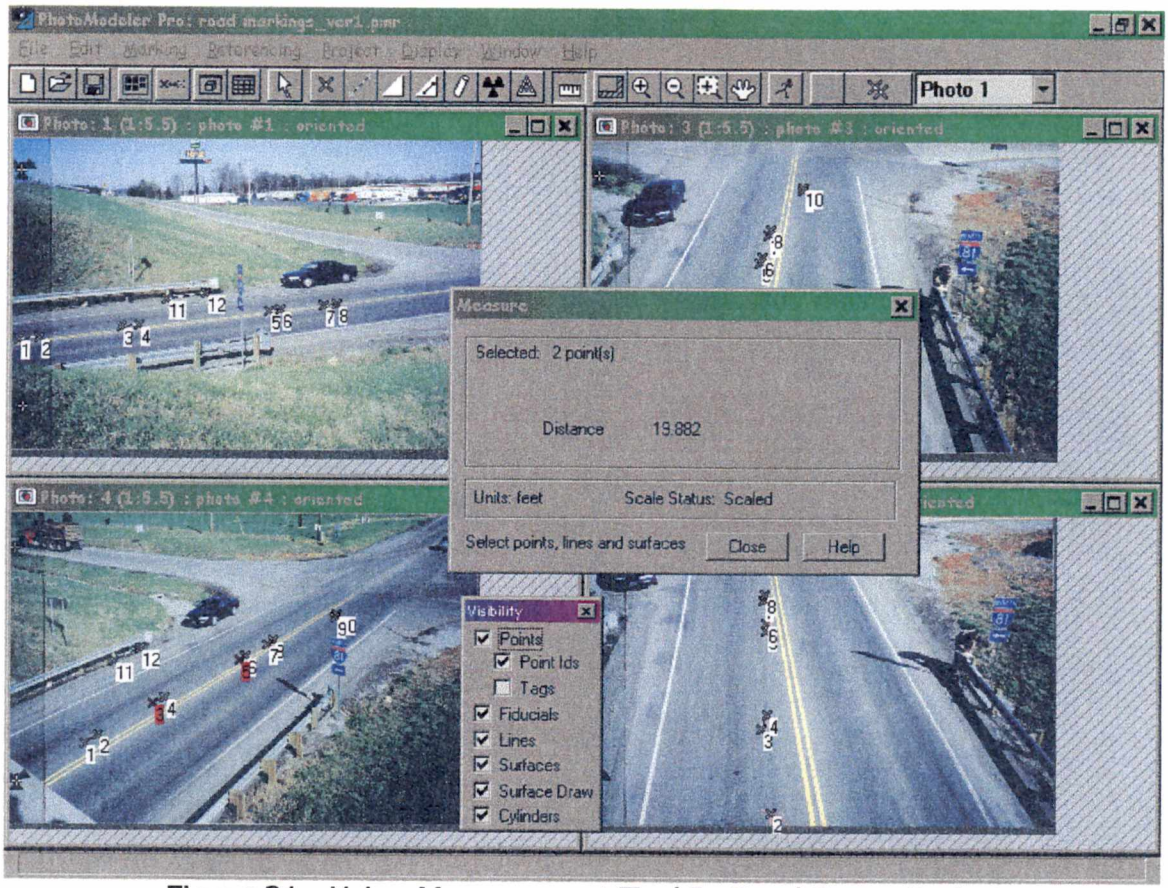


Figure 31. Using Measurement Tool In Road Scene Project

Table 6. Measurements Extracted From Road Scene Project

PhotoModeler Points Examined	PhotoModeler Measurement (in feet)
1 & 3	11.711
3 & 5	19.882
5 & 7	9.085
7 & 9	21.263

CHAPTER IV

RESULTS

Crush Measurement Project

Recall that NTSHA photos were measured in this portion of the analysis, and their crash tests are performed at a predetermined speed. The resulting speed for the crush measurement project (found in Chapter III) is 36.88 mph. NTSHA conducts their barrier tests at 35 mph. This is a 5.1% error.

Accident Scene Diagram Project

Also recollect that in this part of the study, PhotoModeler measurements of an accident scene are compared to hand-retrieved measurements. Table 7 summarizes the results for this segment. The average error or difference is 1.480 inches.

Table 7. Measurement Comparison of PhotoModeler Results vs. Hand Results

PhotoModeler Points Examined	PhotoModeler Measurement (feet)	Hand Measurement (feet)	Difference (inches)
1 & 3	11.711	12.400	8.268*
3 & 5	19.882	20.000	1.416
5 & 7	9.085	9.200	1.380
7 & 9	21.263	21.400	1.644

*The discrepancy in this number verses the other numbers is probably due to poor initial measurement technique. The hand measurement here most likely should have been close to 11.800 feet. When making these measurements, the individuals had to endure very heavy traffic conditions, and at times feared for their safety. Re-measurement of this dimension was considered, but the road markings had faded beyond recognition. This figure was not computed in the previous page's average figure.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

With a 5.1% error in the crush measurement project and an average error of 1.480 inches in the accident scene diagram, PhotoModeler is indeed a suitable measurement tool for the accident reconstructionist, however; there are limitations to this model.

Limitations of Crush Coefficients

According to Cooper [9], the crush coefficients themselves need to be restricted in their use. For example, if the crushed area only involves sheet metal and not the frame of the vehicle, the crush coefficients risk being too high, and an erroneous pre-impact speed may result.

Cooper also maintains that this model may not be applicable in certain override or underride situations. The frame of the vehicle sometimes is not engaged completely in these cases, which can lead to an inaccurate analysis. An example of an underride case involves a 1995 Chevrolet Corsica. The vehicle was modeled with PhotoModeler, and crush measurements were extracted. See Figure 32 and Table 8 for measurement information.

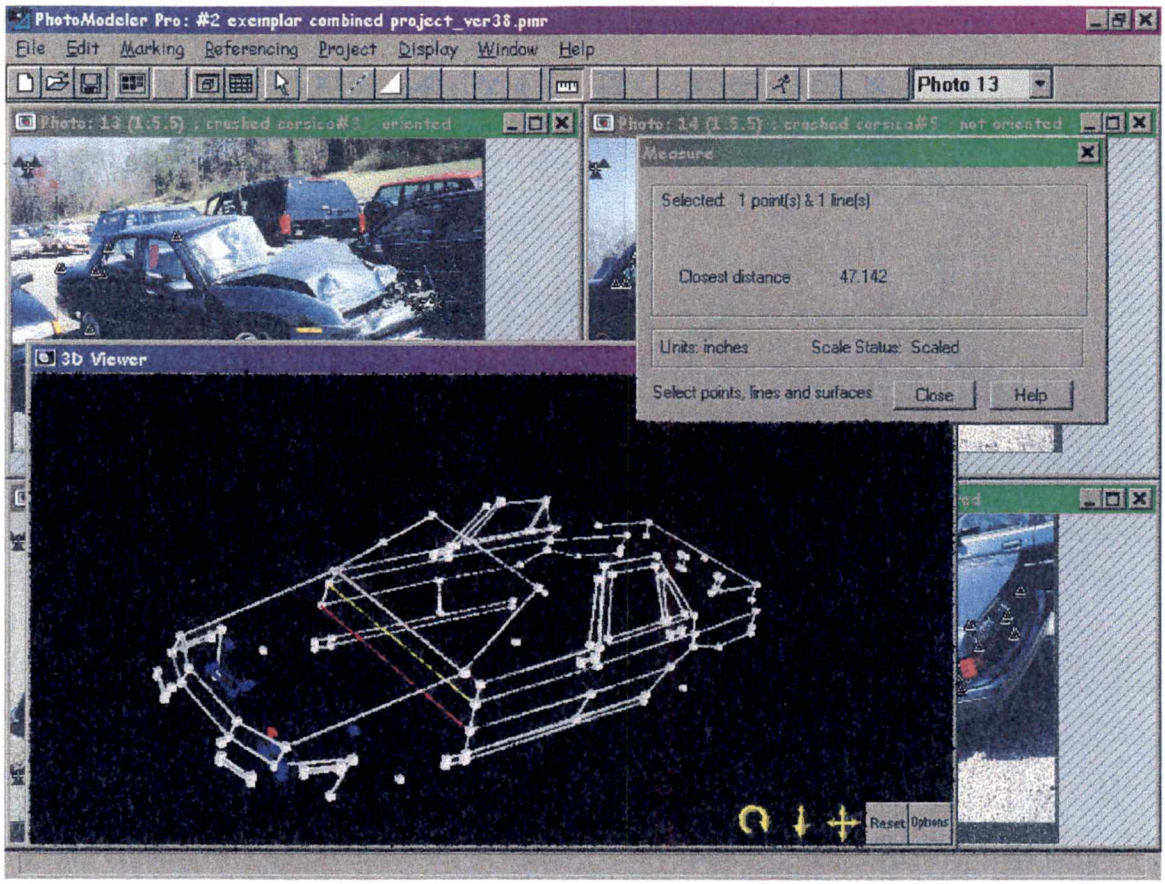


Figure 32. Extracting Measurements from Corsica 3-D Model

Table 8. 1995 Chevy Corsica Crush Measurements

Exemplar Point	Crushed Point	Exemplar To Ref. Line (in inches)	Crushed To Ref. Line (in inches)	Difference (in inches)
93	218	49.724	40.669	9.055
96	220	58.604	40.229	18.375
164	219	57.714	39.334	18.370
165	221	57.641	47.057	10.584
86	222	58.468	48.978	9.490
82	226	49.889	36.032	13.857

Then crush coefficients were obtained from Neptune Engineering, and the values were plugged into the equations. See Appendix F for crush coefficient information.

Given:

W= 54.280 in	C_3=18.370 in
G=399.184 lbs	C_4=10.584 in
A=233 lb/in	C_5= 9.490 in
B= 68 lb/in^2	C_6=13.857 in
C_1= 9.055 in	g=32.2 ft/sec^2
C_2= 18.375 in	w=3234 lbs

Find: The energy required to crush the vehicle **and** the vehicle's initial speed.

$$E=\frac{W}{5}\left[5G+\frac{A}{2}(C_1+2C_2+2C_3+2C_4+2C_5+C_6)+\frac{B}{6}\left(C_1^2+2C_2^2+2C_3^2+2C_4^2+2C_5^2+C_6^2+C_1C_2+C_2C_3+C_3C_4+C_4C_5+C_5C_6\right)\right]\left(1+Tan^2\vartheta\right)$$

$$E=\frac{54\,280}{5}\left[\begin{array}{l}5(399\,184)+\frac{233}{2}(9\,055+2(18\,375)+2(18\,370)+2(10\,584)+2(9\,490)+13\,857)+\\ \frac{68}{6}\left((9\,055)^2+2(18\,375)^2+2(18\,370)^2+2(10\,584)^2+2(9\,490)^2+(13\,857)^2+\right.\\ \left.9\,055(18\,375)+18\,375(18\,370)+18\,370(10\,584)+10\,584(9\,490)+9\,490(13\,857)\right)\end{array}\right]\left(1+Tan^2\vartheta\right)$$

$$E=10\,856[1995\,92+116\,5(136\,55)+11\,33(2958\,67)]$$

$$E=558{,}278in-lbs$$

$$E=46{,}523ft-lbs$$

$$EBS \quad = \quad v \quad = \quad \sqrt{\frac{2\,gE}{w}} \quad = \quad \sqrt{\frac{2\,(32\quad 2\,)(46\quad ,523\quad)}{3234}}$$

$$v = 30.44 \frac{ft}{\text{sec}} = 20.75 mph$$

In this situation, it is not plausible that this vehicle was traveling at a rate of 21 mph—there is simply too much damage to the vehicle overall for this to be true. Furthermore, the driver of the Corsica sustained near-fatal injuries, which certainly is not consistent with a 21-mph crash. Since there was plenty of other damage to the front, top, and side of this vehicle, the estimate of speed using the model used in this thesis is not applicable here. Override situations will yield similar results, and should not be used.

Limitations of PhotoModeler

Recall in Chapter 3 that the exemplar photographs and the crushed photographs are supposed to have identical corresponding points so that crush measurements can be made. If a situation exists where the crushed photos do not have any discernable corresponding points because of extensive damage, then the model used in this project can not be used here. Corresponding points must be found—guessing or approximating the points' location will not yield reliable results.

Potential Impediments in Road Scene Projects

Many times objects such as trees and road signs are used in the analysis of road scene projects, however; trees can be cut down, and road signs are frequently run over and replaced. If at all possible, items that have the potential of being "absent" or "modified" should have its use limited, especially if the scene is visited many years later.

Advances in Software and Technology

Since PhotoModeler was introduced in the early 1990's, many versions have been issued over the years and each version has proved itself more effective than the previous. PhotoModeler 4.0 (version 3.1 was used in this project) is slated to be released later this year, and it reportedly has lots of new features which makes it more powerful than ever before.

Digital camera technology is also advancing all the time. Currently, digital cameras simply do not have comparable resolutions to that of film cameras, and consequently, film cameras are the standard. However, with the advent of more powerful digital cameras, photogrammetrists can become more efficient. Since photographs are digitally recorded on disks or other media and directly input into the computer, film processing and scanning are circumvented entirely, which results in time saved.

REFERENCES

REFERENCES

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10. Flach, S., PhotoModeler Crush Measurement White Paper, Eos Systems Inc., Vancouver, BC, 1998.

APPENDICES

APPENDIX A

APPENDIX A

PHOTOGRAMMETRY EQUATIONS

$$x - x_p = f \bullet \frac{m_{11} \bullet (X - X_c) + m_{12} \bullet (Y - Y_c) + m_{13} \bullet (Z - Z_c)}{m_{31} \bullet (X - X_c) + m_{32} \bullet (Y - Y_c) + m_{33} \bullet (Z - Z_c)}$$

$$y - y_p = f \bullet \frac{m_{21} \bullet (X - X_c) + m_{22} \bullet (Y - Y_c) + m_{23} \bullet (Z - Z_c)}{m_{31} \bullet (X - X_c) + m_{32} \bullet (Y - Y_c) + m_{33} \bullet (Z - Z_c)}$$

where

x and y are image space coordinates

x_p and y_p are the coordinates of the principal point

f is the focal length

m_{mn} are terms from the rotational matrix

$$[M] = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}$$

X, Y, and Z are object space coordinates

X_c, Y_c, and Z_c are object space coordinates for the camera's position

APPENDIX B

APPENDIX B

CAMERA CALIBRATION PROCEDURE

As stated previously in the text, camera calibration ensures that the camera can be used as an accurate measurement device. PhotoModeler's Camera Calibrator computes important parameters such as principal point, focal length, and format size. One important item to remember in camera calibration is that the camera and the scanner are calibrated together. If a different scanner is used, then calibration needs to be executed again.

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 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 digitization of the pictures via scanner. After the pictures are scanned, 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.

Install the Eos Fiducial

Before any pictures of the calibration grid were taken, the Eos Fiducial was installed into the camera being calibrated. The fiducial is a small, clear piece of plastic with two special black marks that is glued into the film plane of the camera. In other words, it will be situated between the lens of the camera and the film negative; this allows any pictures taken with this camera to have the special fiducial marks on it. The fiducial itself is attached to the camera with glue. It is imperative that the fiducial remains stationary, or the calibration will not be successful. After the fiducial insert was installed, a day or so was allowed for the glue to dry before the camera calibration procedure was launched.

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 33 and Table 9 shows the values required and

obtained, respectively, for squareness verification of the calibration image. A check of Table 33 reveals that the squareness requirements were indeed fulfilled.

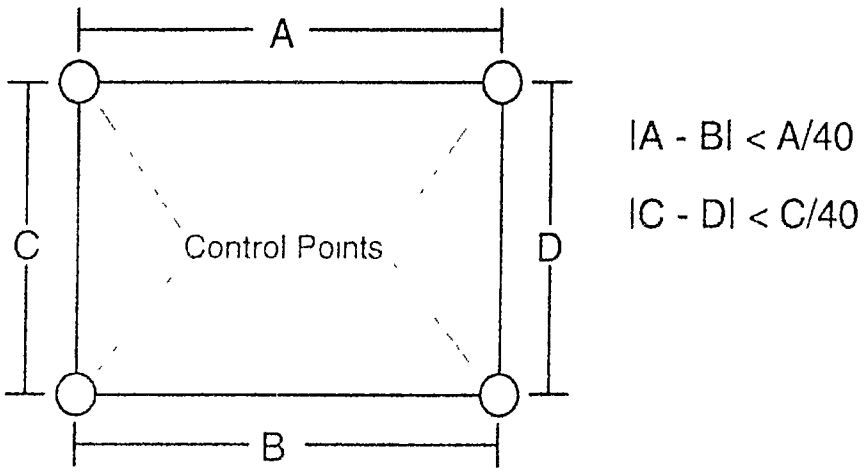


Fig. 33. Squareness Verification Equations
Source: EOS Systems, Inc.

Table 9. 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

Next, a ladder and a utility light were 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 about 4 ft tall. The utility light was used to counteract the darkness on the left-hand side of the room. 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. The light was used so that the fiducials (located on the left-hand side of the image) could be seen in the photograph; without the light, the fiducials would be concealed, and the calibration process could not proceed as planned.

Finally, the user found it useful to counteract the harshness of the camera's flash by applying a piece of tape to approximately one-half of the flash's outer surface. Without the tape, it was found that the images became washed out, which caused the photographs to be of poor quality. After the tape was applied, the pictures were suitable for use with the camera calibration program.

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. The ladder, light, and flash tape

were also used accordingly. To be safe, more than eight (8) pictures were taken, and the best ones were selected at a later time. Lastly, the film was taken to a one-hour photo-processing lab to acquire the needed photographs. Figure 34 shows some of the various photograph positions used in this calibration project.

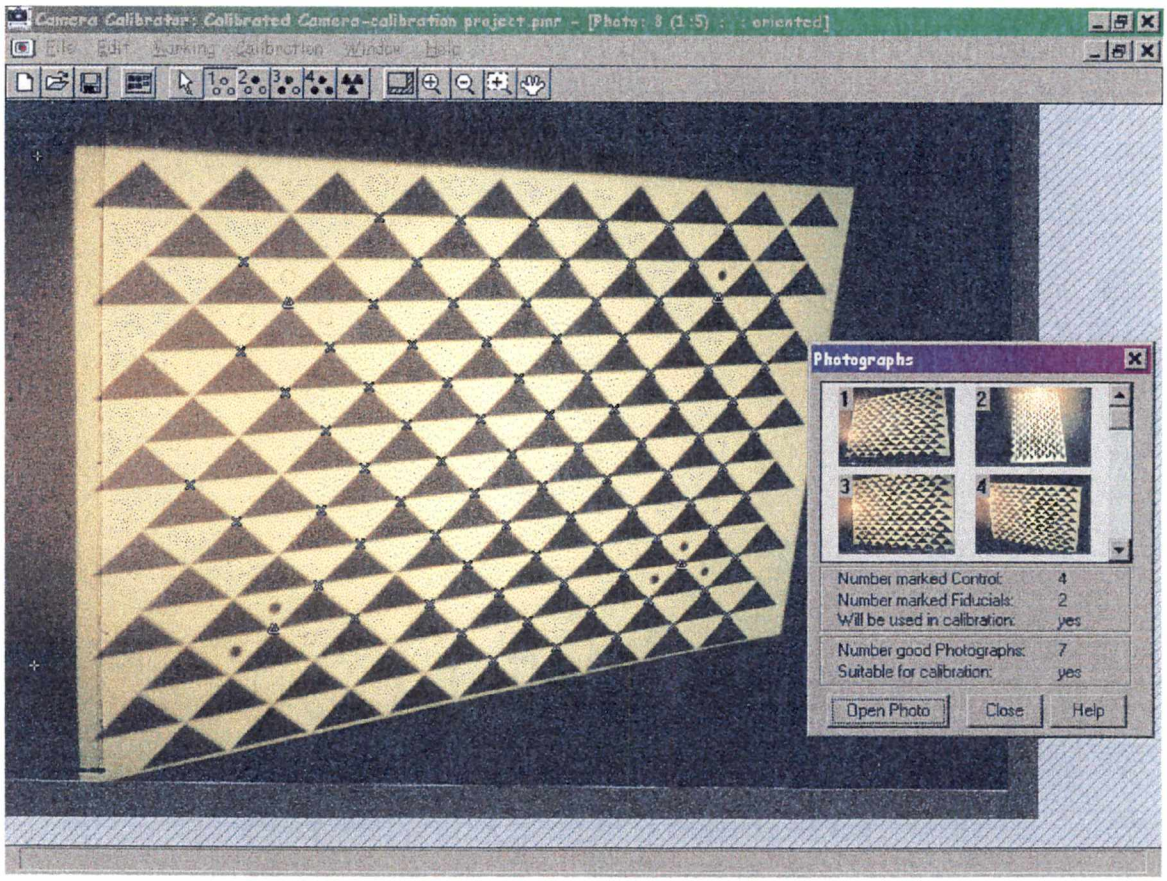


Figure 34. Various Calibration Photos

Select and Scan the Pictures

After the film was developed, the best pictures were selected for the calibration project. Pictures selected had the entire image in the photograph, fiducials present, and were of the needed orientation (upper left, lower right, etc.) The selected pictures were scanned with a Microteck ScanMaker X6, a flatbed office scanner that also has the ability to scan negatives. The photographs were digitized by the scanner into a .tif (tagged image file) format which is the most suitable format for photogrammetry purposes. The images were given a name, saved, and put into a directory which could be found later by PhotoModeler's Camera Calibrator.

Start the Calibration Project

For a Windows operated PC, go to Start, Programs, PhotoModeler, and Camera Calibrator 3.1. 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 35 for this information.

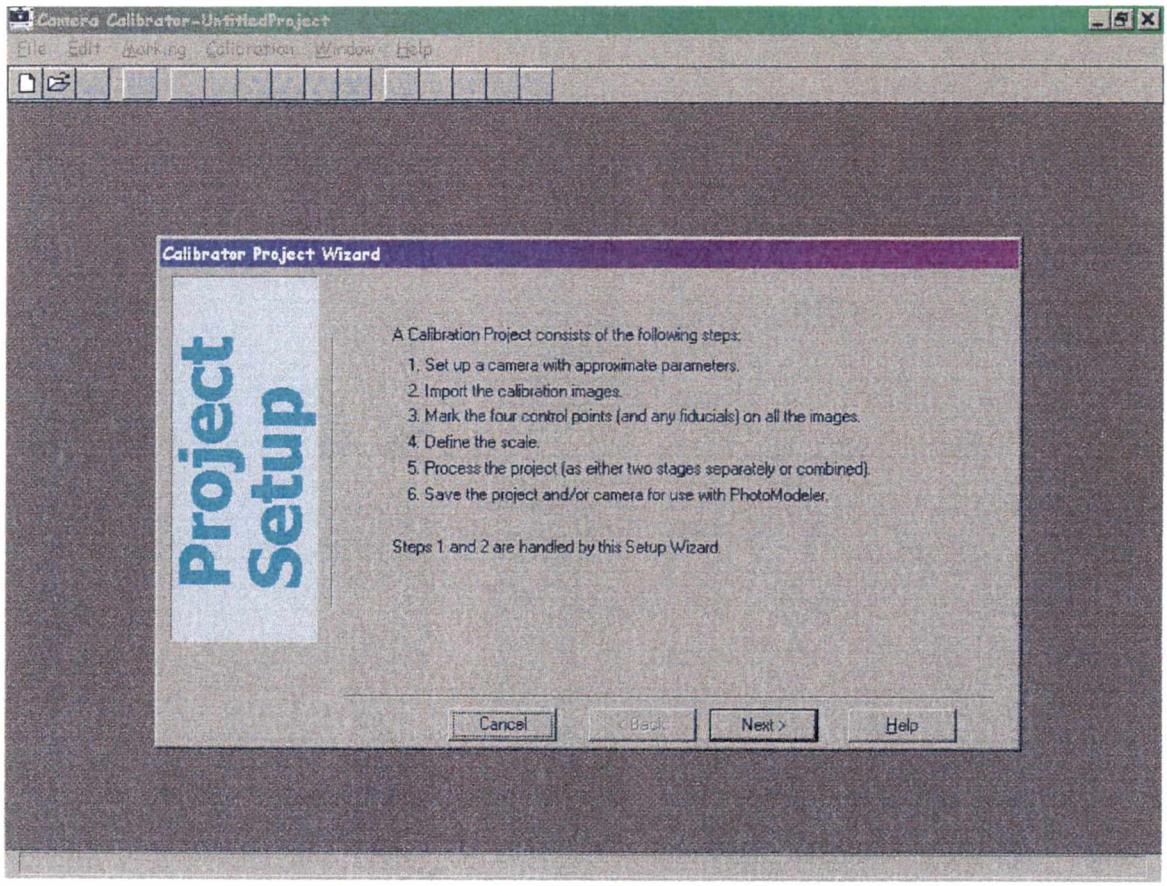


Figure 35. Camera Calibrator Wizard

Next the camera information, such as camera name (Calibrated Pentax), type of camera (35 mm), focal length (38 mm), and image resolution size (1787 x 1238 pixels) that was used was entered into the Wizard. Then the images were loaded in to the program by finding the correct directory.

Mark Points

First, the Fiducials were marked on all eight (8) photographs. Figure 36 indicates marked fiducials.

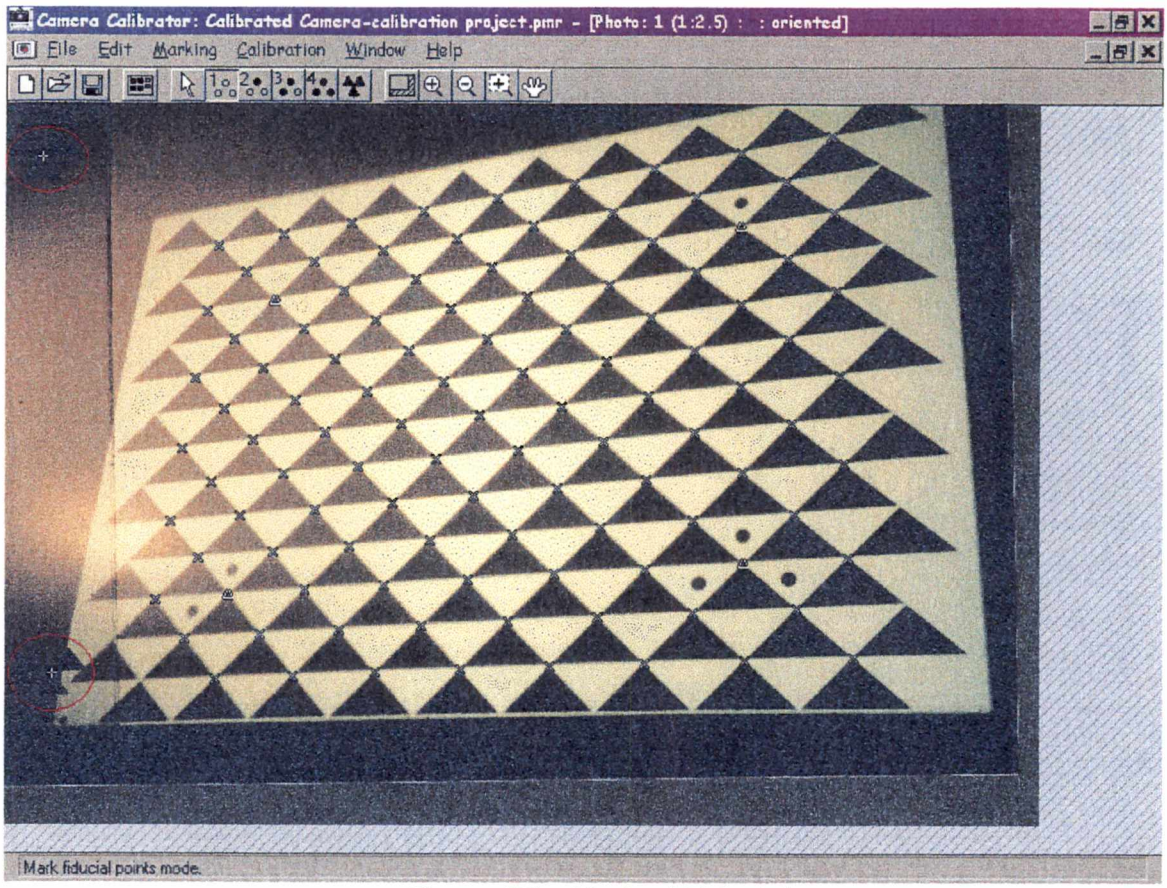


Figure 36. Marked Fiducials

The fiducials were marked with the fiducial marking tool which is located at the top of the screen on the toolbar. Next, the four(4) control points are 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 37 shows marked control points.

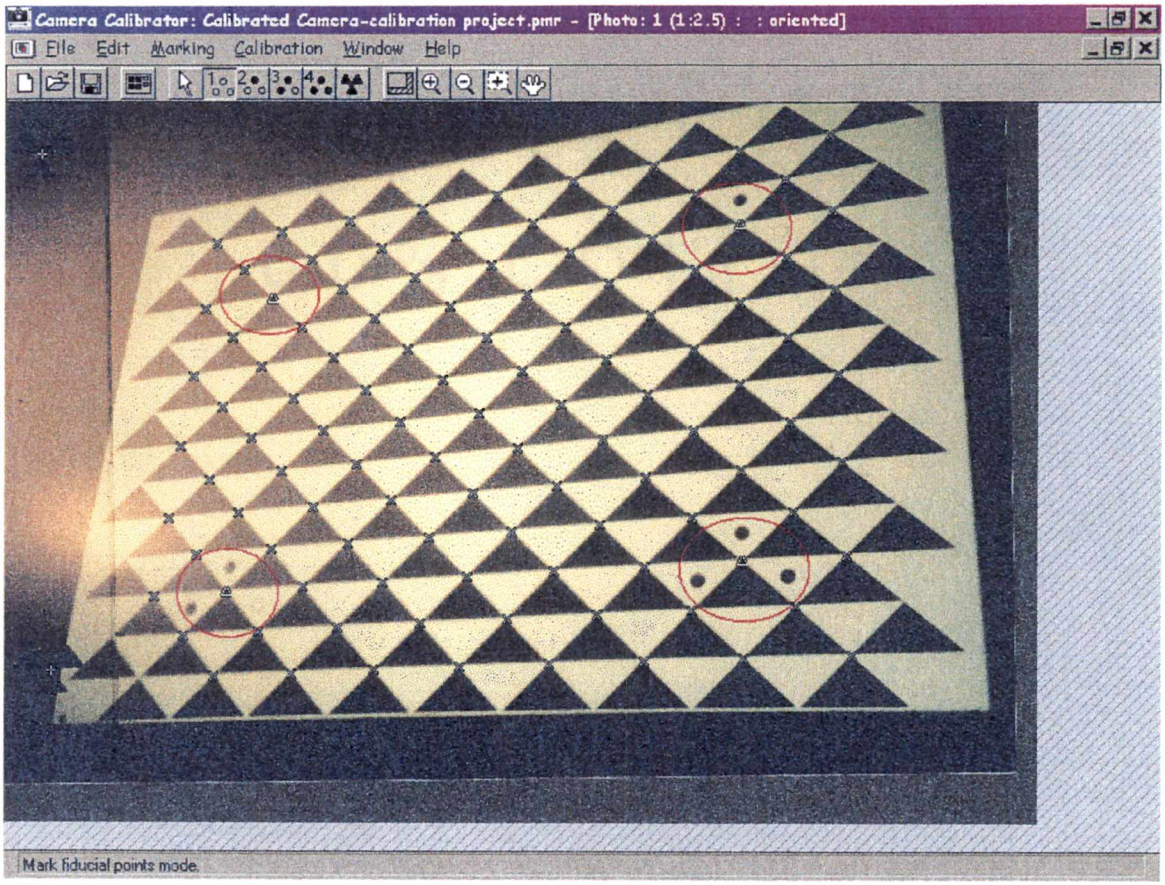


Figure 37. Marked Control Points

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 number one and four. A flexible tape measure (similar to the kind used in sewing) was physically taped on the wall between control points one and four 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 one and four are highlighted in green. See Figure 38 for this information.

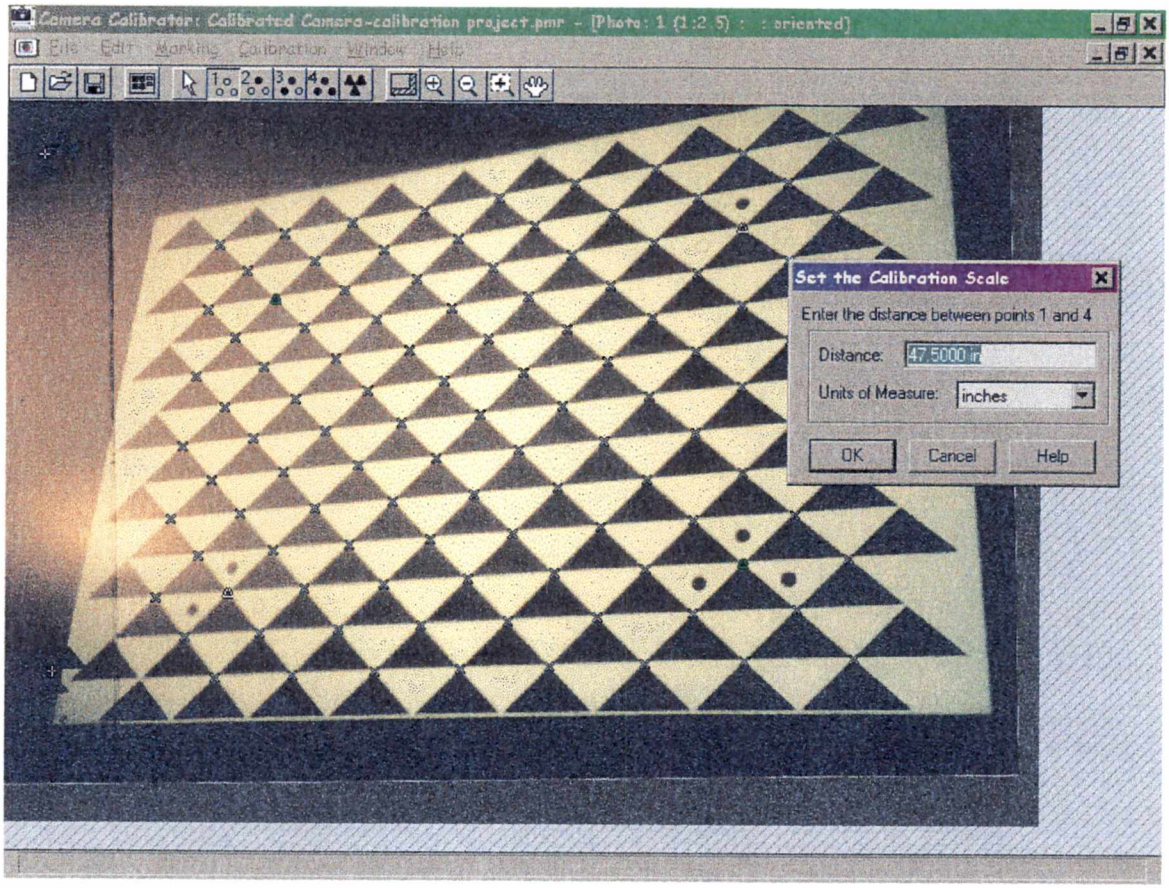


Figure 38. Scaling the Calibration Project

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 39 for this project's error dialog.

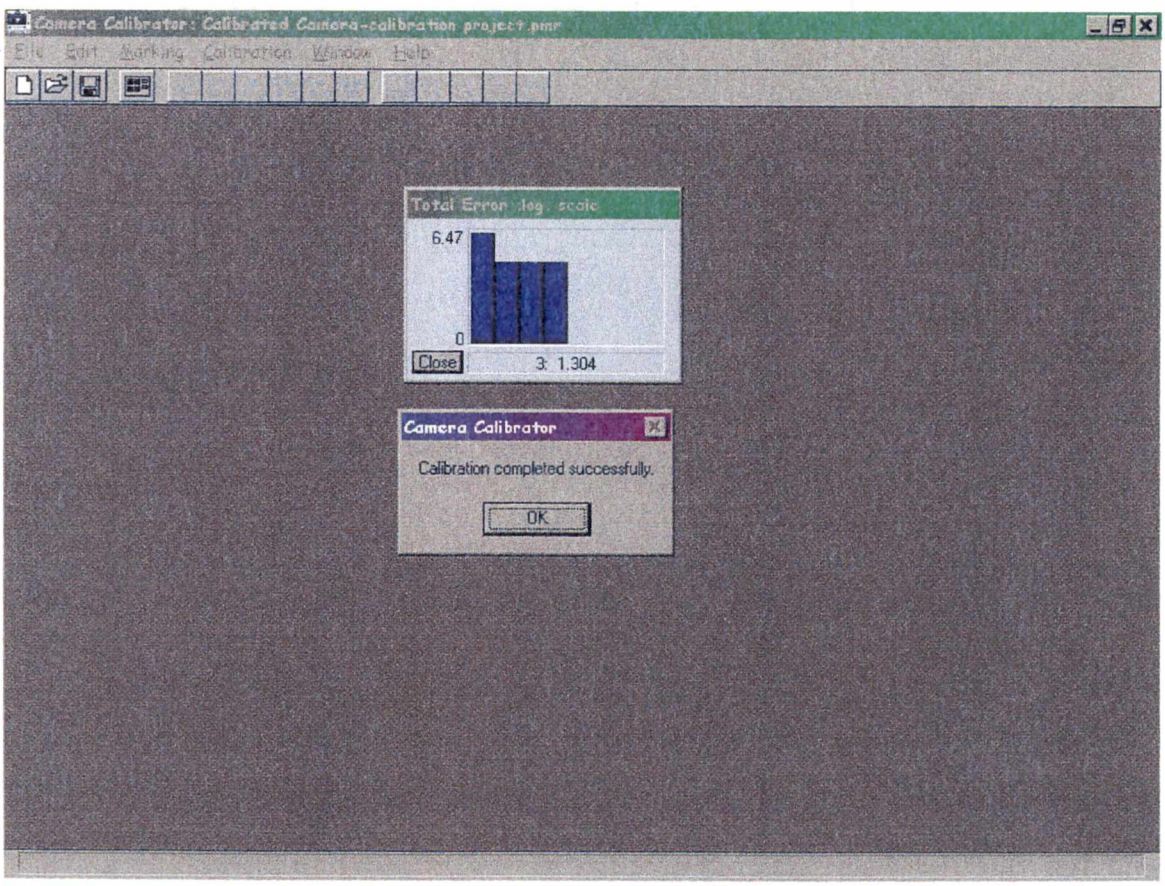


Figure 39. Error Dialog for Calibration Project

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 40 that other camera parameters have been solved as well. Now the camera is a suitable measurement device with PhotoModeler software.

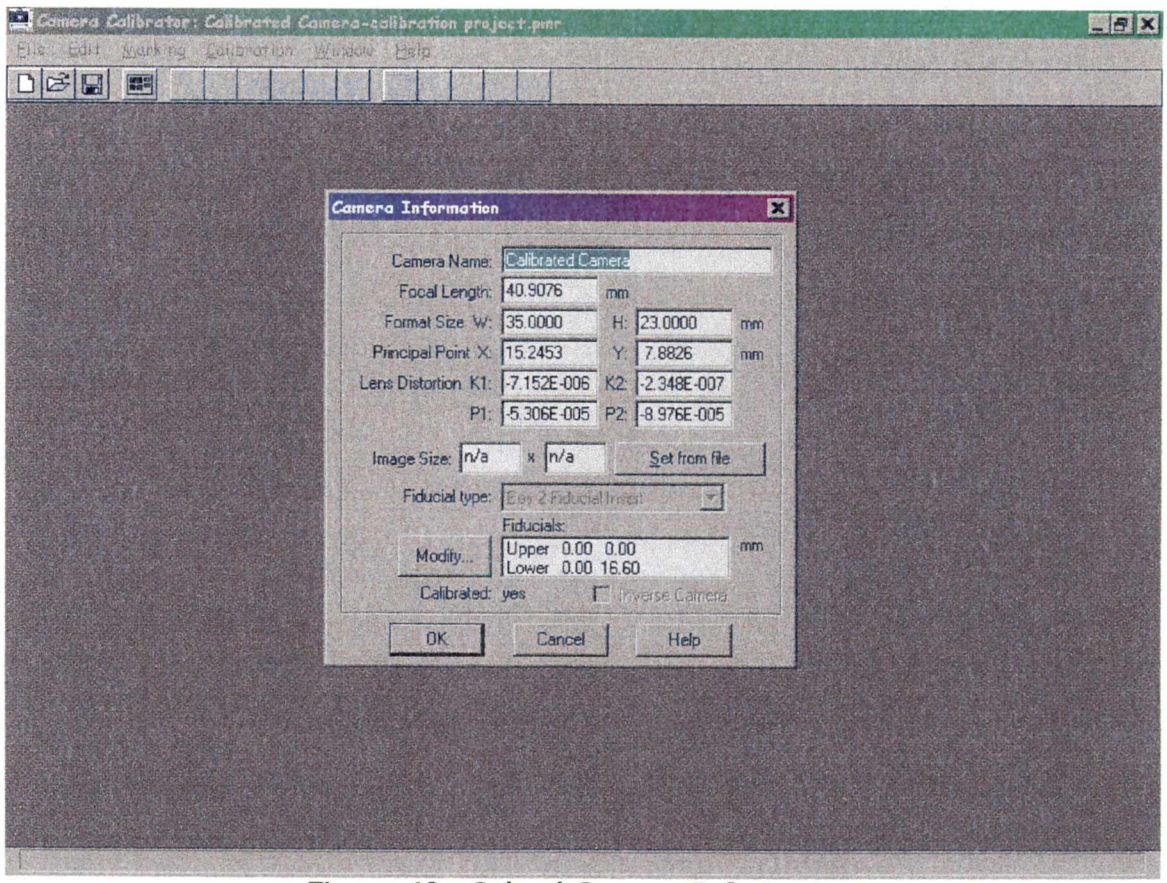


Figure 40. Solved Camera Information

APPENDIX C

APPENDIX C

EQUATIONS FROM TRAFFIC ACCIDENT RECONSTRUCTION VOL.II [9]

$$E=\frac{W}{5}\left[5G+\frac{A}{2}(C_1+2C_2+2C_3+2C_4+2C_5+C_6)+\frac{B}{6}\left(C_1^2+2C_2^2+2C_3^2+2C_4^2+2C_5^2+C_6^2+C_1C_2+C_2C_3+C_3C_4+C_4C_5+C_5C_6\right)\right]\left(1+Tan^2\vartheta\right)$$

computes the amount of energy dissipated by the crush damage,

where

E is the amount of energy dissipated (in-lbs.)

W is the width of the crushed region (in)

G is the energy dissipated before permanent deformation occurs(lbs.)

A is the maximum force per inch of damage width which will not cause permanent damage (lb./in)

B is the spring stiffness per inch of damage width (lb/in^2)

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

Θ is the angle of the force to the vehicle's surface

$$EBS = v = \sqrt{2g\frac{E}{w}}$$

computes the velocity of the vehicle,

where

v is the velocity of the vehicle (ft/sec)

g is the gravitation constant (ft/sec^2)

E is the amount of energy dissipated by the crush (ft-lbs.)

w is the weight of the vehicle (lbs.)

APPENDIX D

APPENDIX D

NTSHA PHOTOS

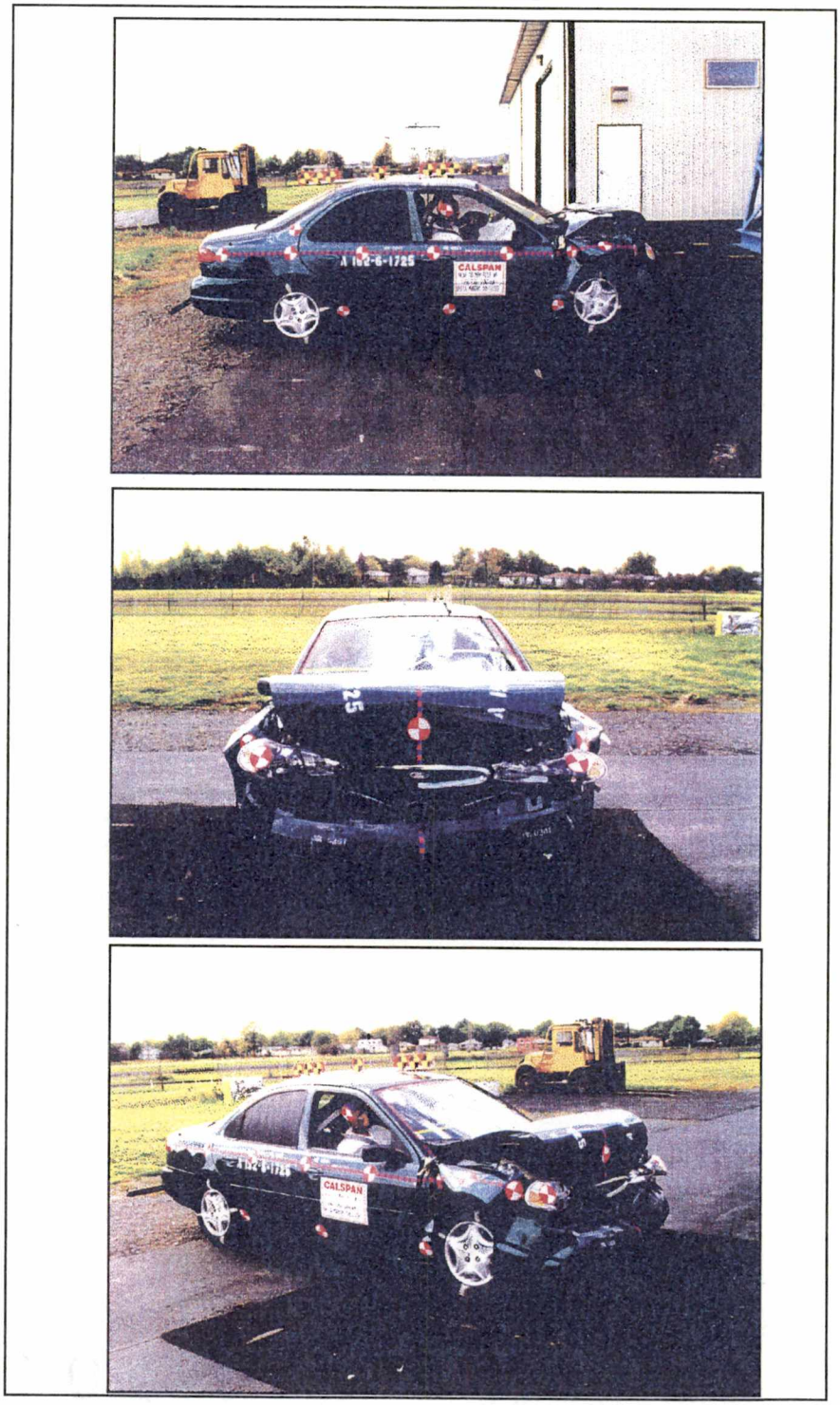


Figure 41. NTSHA Photos Used In This Project

APPENDIX E

APPENDIX E

CONTOUR CRUSH COEFFICIENTS

Vehicle Crush Stiffness Coefficients

Neptune Engineering Inc

REF NO	YR	MAKE	MODEL	BODY	TRAN	VIN	WB	WT	V EFF	PDOF	%OL	RG s	X_C	b0	b1	Kv	A	B	TEST#
Contou08	98	FORD	CONTOUR	4S	AF	1FAFP5339WH118227	105 0	3310	35 0	0	100%	6	14 0	4 2	2 20	240	354	186	A7708
						Strd Weight		2859						4 50	Default Value For b0*				

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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

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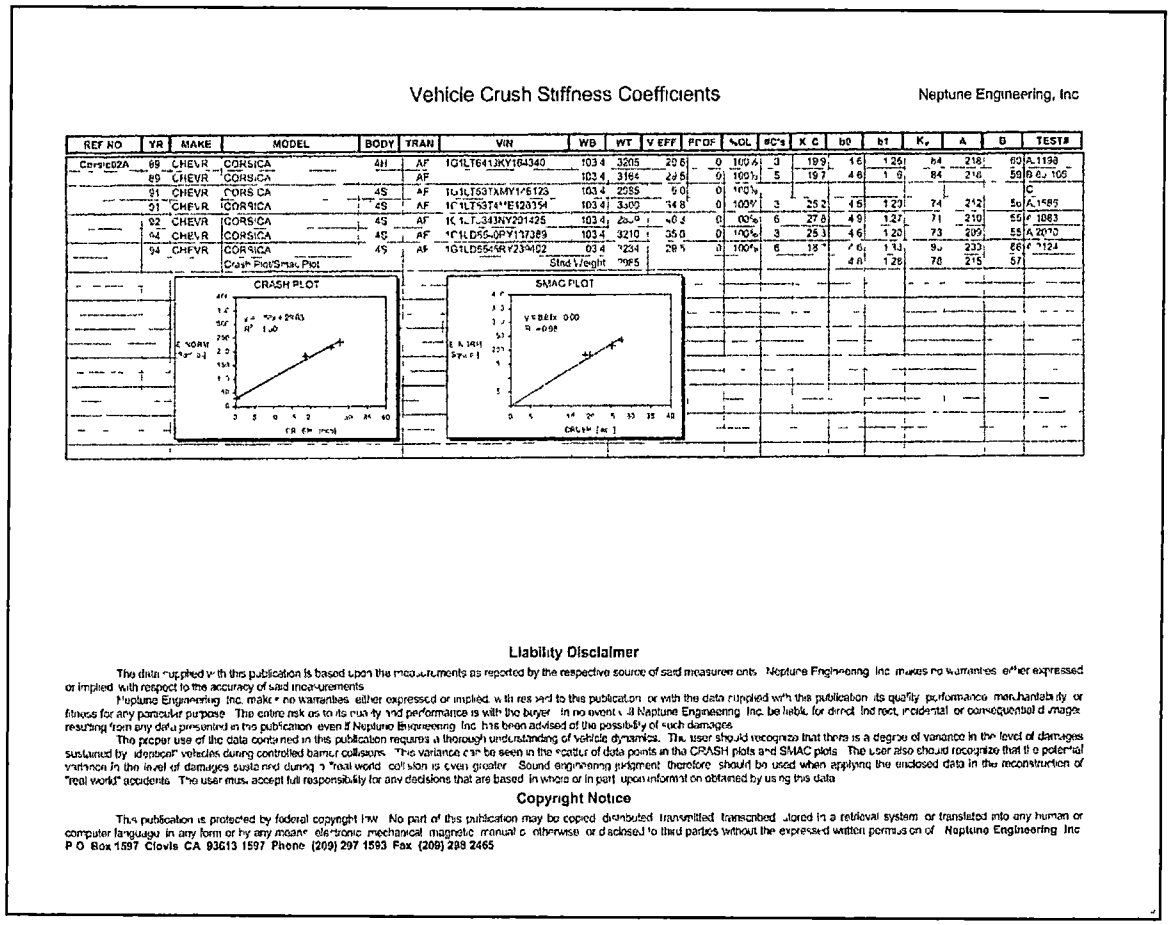
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P O Box 1597 Clovis CA 93613 1697 Phone (559) 297 1593 Fax (559) 298-2485

Figure 42. 1998 Ford Contour Crush Coefficients

APPENDIX F

APPENDIX F

CORSICA CRUSH COEFFICIENTS



Vehicle Crush Stiffness Coefficients

Neptune Engineering, Inc

REF NO	YR	MAKE	MODEL	BODY	TRAN	VIN	WB	WT	V EFF	PDOF	%OL	#C's	K C	b0	b1	K_y	A	B	TEST#
Corsica02A	89	CHEVR	CORSICA	4H	AF	1G1LT641JKY164340	103.4	3205	20.8	0	100%	3	19.9	4.6	1.26	84	21.8	6.0	A-1198
	89	CHEVR	CORSICA		AF		103.4	3164	29.8	9	100%	5	19.7	4.6	1.0	84	21.6	5.9	B-0105
	91	CHEVR	CORS CA	4S	AF	1G1LT53TXMY165173	103.4	2955	6.0	0	100%								C
	91	CHEVR	CORSICA	4S	AF	1G1LT53T4ME120354	103.4	3302	14.8	0	100%	3	25.2	4.6	1.20	74	21.2	5.6	A-1585
	92	CHEVR	CORSICA	4S	AF	1G1LT53TXNY201425	103.4	2609	30.3	0	00%	6	27.8	4.9	1.27	71	21.0	5.5	A-1083
	94	CHEVR	CORSICA	4S	AF	1G1LD55J0PY117389	103.4	3210	35.6	0	100%	3	25.3	4.6	1.20	73	20.9	5.5	A-2010
	94	CHEVR	CORSICA	4S	AF	1G1LD5545RY234102	103.4	3234	28.5	0	100%	6	18.1	4.6	1.13	9.0	23.0	6.6	A-1124
			Crash Plot/Smac Plot					Std Weight	2985					4.6	1.26	78	21.5	5.7	

CRASH PLOT

SMAC PLOT

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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.

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Figure 43. 1995 (and 1994) Chevrolet Corsica Crush Coefficients

VITA

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Lara Lynn O'Shields was born on February 14, 1972 in Sevierville, Tennessee. 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 one brother, Seth O'Shields, who was born on September 21, 1987. In 1990, she graduated from Gatlinburg-Pittman High School in Gatlinburg, Tennessee and entered The University of Tennessee, Knoxville that fall into the Pre-Pharmacy Program. After 1.5 years, she switched to the College of Engineering and received a Bachelor of Science degree in Industrial Engineering in December 1995. She has varied experience, which includes the electronics, automotive, hospital, and restaurant industries. A Master of Science degree in Industrial Engineering was (finally) awarded in August 2000.

Lara's pastimes include spending time with family, friends, and especially her animals. Music is one of her passions. She enjoys playing several instruments and singing in church. Riding motorcycles and flying in single-engine planes are also fun activities for Lara.

Currently residing in Sevierville, Lara plans to enter into the Ph.D. program in Engineering Science (with a concentration in Industrial Engineering) in the fall semester of 2000. She ultimately wants to teach and consult.