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A SIMPLE SYSTEM FOR DATA ACQUISITION AND PHOTOGRAMMETRIC ANALYS--ETC(U)
FEB 80 A D HOWARTH

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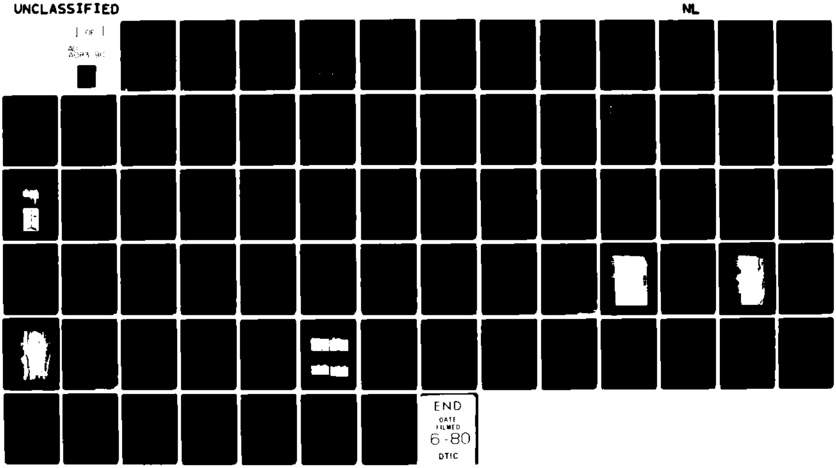

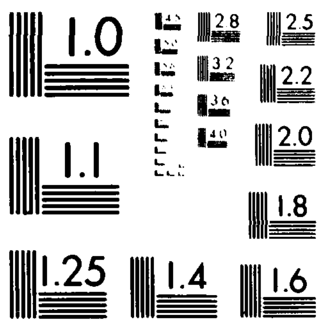
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LEVEL III

A simple system for data acquisition and photogrammetric analysis in traffic accident investigations.

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Final Report; 29 Feburary 1980

A thesis submitted to Iowa State University of Science and Technology, Ames, Iowa 50010, in partial fulfillment of the requirements for the degree of Master of Science.

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A simple method for the recording, documentation, and analysis of metric (measurable) traffic accident information using photogrammetric related techniques is presented. Using nonmetric cameras and perspective grid theory, this economical system will meet or exceed the quality of traffic accident diagrams prepared using conventional investigation survey techniques. Integrated procedures for stereoscopic coverage and extension from planimetric to three dimensional mensuration are developed.

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A literature review is included which describes the European use of stereometric systems applications to traffic accidents and their success with these systems. Reference is also made to courtroom admissibility of the accident diagrams and photography. Also, a pilot project conception is offered. This conception minimizes training burdens, can be initiated in phases and can be evaluated without disrupting current procedures.

A simple system for data acquisition and photogrammetric analysis in traffic accident investigations

by

Allan D. Howarth

A Thesis Submitted to the

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I. INTRODUCTION AND OBJECTIVES

A. Introduction

This thesis resulted from a suggestion by my major professor, Dr. R. L. Hardy. My original concept of a thesis topic was not very specific; I simply wanted to study some aspect of close range photogrammetry. Karara (1972) has defined close range applications of photogrammetry as those involving a distance of less than 1000 feet from the camera to the object or objects of study. These are nontopographic applications involving medicine, dentistry, archaeology, architecture, and many others. In most of the published literature concerning these applications, a great deal of attention is paid to preplanned acquisition of suitable photographic data. Dr. Hardy focused my attention on the rather contrasting situation in close range photography for traffic accident investigation, and closely related cases involving litigation or out of court settlement based on close range photographic evidence. Pre-planned photographic data acquisition seems to be an exceptional case in this type of application. Dr. Hardy has been personally involved as a photogrammetric expert witness in two court cases, and one out of court settlement involving close range photogrammetry. His analysis and testimony had to be based on use of close range photography which was not pre-planned for photogrammetric use. More explicitly, it was news or commercial photography which just happened to be available. He noted that the availability of pre-planned photogrammetric data associated with traffic accident investigations would have greatly reduced his fees, and presumably the fees of many other consultants in photogrammetry.

Other economic considerations certainly are involved, but they have not been adequately identified. Very few, if any, details have been published by consultants in this area. Some publications, such as the Police Evidence Library (1965), have referred to the existence of such consulting, but only as an incidental topic. Dr. Hardy expressed the opinion that this is due to the unique nature of each case of data acquisition. It is doubtful that such cases could be used by consultants as a model for adequate data acquisition on a routine basis. The resulting photogrammetric analysis, while it may satisfy the needs of the client, is somewhat of an expedient in a technical sense. It may be original and innovative in getting the most out of an inadequate data source, but that in itself is not likely to be considered as an advancement of the science of photogrammetry. Therefore, publication of such material would likely focus on the already known problems of data acquisition in this application, rather than on a proposed solution in the form of a recommended data acquisition-data reduction system for future use on a routine basis. To be effective, a proposed solution must be acceptable to both traffic enforcement agencies and to photogrammetrists.

It was suggested that I write a preliminary proposal for a study of the technical and economic feasibility of implementing a simple system involving data acquisition and data reduction for application to traffic accident investigation in the State of Iowa. It was envisioned that my thesis could be considered as the first phase of a potentially more comprehensive project. Later phases could conceivably be expanded into a pilot project involving federal support, with joint participation by Iowa State University and a law enforcement agency in Iowa.

My preliminary proposal resulted in the approval of a project entitled "Use of Photogrammetry in Traffic Accident Investigations", supported as Departmental Research Activity in the Department of Civil Engineering through the College of Engineering Research Institute. Necessary travel, photo services, and other minor expenses were supported by this approved project. The investigations associated with this project have provided the basis for this thesis.

B. Objectives

After a few false starts, the objectives of the investigations associated with this thesis have evolved to the following:

--Based on a literature review, to analyze and compare systems of close range data acquisition and data reduction, as applied to traffic accident investigations, in the United States and internationally.

--Also based on literature review, to compare and analyze conflicting views by the photogrammetric and traffic investigation communities as to the degree of sophistication needed for traffic accident reporting.

--Based on the preceding analysis, to investigate the technical and economic feasibility of at least one simple but integrated photogrammetric system of data collection and data reduction for traffic accident applications.

--Based on the preceding analysis and feasibility investigations, to recommend a system, or systems, for utilization in a federally supported pilot project to improve traffic accident investigation in Iowa.

An important secondary objective was to develop the necessary contacts and a rapport with at least one law enforcement agency in Iowa. It is envisioned that a successful pilot project must involve cooperation between at least two interested parties, i.e., the traffic investigation community in Iowa and photogrammetric experts at Iowa State University.

I. LITERATURE REVIEW

A. Introduction

1. The traffic accident diagram situation

The diagram of the accident scene is that portion of the traffic accident report which contains the data concerning the measurements and relative locations of the physical evidence recorded at the accident site. There are two basic procedures for acquiring this metric information. These will be referred to as conventional and photographic methods. Both of these methods are currently being used in varying degrees of sophistication throughout the countries of the world.

Conventional methods are those procedures of recording measurements which are associated with elementary surveying. The most common practice within this method is the use of a measuring tape (Berling, 1970); however, conventional methods also include the use of pacing, measuring wheels, and rudimentary triangulation (Baker, 1975). Accident investigation procedures within the United States are almost exclusively confined to the use of conventional methods for the acquisition of metric information.

The second method is termed photographic because it involves the use of photographs to supply the metric information necessary to prepare the traffic accident diagrams. These photographs are unique in that they have been taken with prior consideration given to the subsequent photogrammetric analysis and, therefore, contain some type of reference scale. There are two variations of the photographic method currently being applied to traffic accident investigations. One is called stereometric photography and the other referred to as perspective grid photography.

Stereometric systems have been employed for the recording and analysis of traffic accidents by various European police agencies for some 40 years (Lillesand and Clapp, 1971). Sally (1964) reports that traffic authorities in Switzerland could not imagine analyzing accidents without such systems. The Federal Republic of Germany and Japan use stereometric systems extensively and have even outfitted special investigation vans with these cameras mounted through the roof. This investigative procedure is so popular in Japan that they now have a textbook for training recruits in its uses and applications (Danko, 1979). This system, according to Sally (1964), is also used in France, Italy, and Great Britain. Within the United States, however, this author has no knowledge of any accident investigation agency using stereometric systems.

Perspective grid photography is the other variation of the photographic method of recording accident related information. This variation has found application within the United States, but is has been only recently applied on a routine basis, and only on a limited scale. The Minnesota State Patrol began using this system in 1975 as a pilot project for recording accident information in the Minneapolis-St. Paul metropolitan area (Crawford, 1978). According to Sgt. Myron Lofgren (telephone interview, Nov., 1979) of the Minnesota State Patrol's training center, this pilot project was a success and it is currently being expanded into statewide utilization. The Minnesota State Patrol is the only police agency known to this author that utilizes this photographic method on an operational level. Crawford (1978) points out that, although perspective grid photographic concepts are taught to those investigators attending the Northwestern University Traffic Institute, this instruction is limited to familiarization rather than operational efficiency.

In assessing the current situation of recording traffic accident metric information, there is a definite difference between methods employed in Europe and those used in the United States. European countries and Japan use photographic methods of the stereometric variety, while the investigative agencies within the United States, with the exception of the Minnesota State Patrol, use conventional methods.

2. Comments on technology

According to Berling (1970), there are stereometric systems which can give accurate measurements to within 5 cm (2 inches) at a distance of 30 m (98 feet). This slight error drops off significantly as the distance is decreased. These stereometric systems represent the most sophisticated photographic process as applied to accident investigation in use today.

The advancement of this technology comes from the European continent, and was initiated (Berling, 1970) by traffic authorities desiring a more efficient and reliable means of recording traffic accident information. Chronologically, this advancement proceeded from the use of conventional methods, through a series of photographic methods utilizing the concepts of grid photography, to the eventual use of stereometric systems (Berling, 1970).

Photographic evidence recording with the stereometric systems began in 1933 (Danko, 1979). Hence, over 45 years of documented records concerning the technological aspects of this application are available. This technology is readily available. However, those traffic authorities contacted by this author were unaware of this system or its application to traffic accident investigation.

3. Status of photogrammetric consulting

As previously defined, photographic methods require that some consideration to a reference scale be given prior to the actual photography, and that the method is used on an operational level. Photogrammetric consulting cannot be defined as a photographic method under these considerations because it often involves the use of photography not taken for documentation of metric information and normally occurs only upon the request of a concerned party. This photogrammetric consulting has, however, been used in connection with traffic accident investigations in the United States and is, therefore, relevant to considerations of photographic methods.

Dr. R. L. Hardy has given expert witness testimony on several occasions concerning measurements from photographs (personal interview, 1979-1980). The Police Evidence Library (1965) documents three case studies of photogrammetric consultation in which a photogrammetrist is called upon to give expert witness testimony concerning measurements and locations of objects within a photograph. This, at least, indicates that there is some degree of demand for photographic analysis of traffic accidents.

This photogrammetric consulting is severely restricted in application because the photographs are generally not taken with forethought given to subsequent analysis. In the cases cited by the Police Evidence Library and those which Dr. Hardy analyzed, the photographs contained no reference scale nor was there any information concerning the lens characteristics of the camera, camera position, or camera height. Because of this, the analysis of the photograph must be elementary and less authoritative in comparison to analysis of a photograph which was taken for photogrammetric purposes.

There is a lack of published material in regard to photogrammetric consulting, even though there are a significant number of cases for which photogrammetrists give expert witness testimony relating to chance photography of an incident. This lack of published material hurts in two ways. First, it does not let the traffic investigation community realize the potential for photographic documentation, and, second, it hinders the determination of the potential demand for photographic recording methods.

In terms of photogrammetric consulting, this represents a deficiency in data acquisition. The photographs are deficient in that they are not taken for the professional purpose of data reduction (Police Evidence Library). This deficiency manifests itself in the quality and quantity of photogrammetric analysis.

4. Misconceptions and misunderstandings

Photogrammetry and traffic accident investigation are separate, distinct professions which have very little in common with one another. Because of this, there is little interaction between the two fields and, therefore, problems develop in the transfer of knowledge. This eventually causes misconceptions or misunderstandings.

Baker (1975) offers the following about the application of photogrammetry to the general procedure of accident investigation: "It is true that by photogrammetry, maps can often be made from photos, but this is a tedious and therefore expensive process. A specially trained engineer may require days to make a scale diagram or map from photographs". This is a good example of a misconception offered by an authority on traffic accident investigation. This statement may, in fact, be true if the application is meant to mean the large scale production of topographic maps covering many square miles. However, it is certainly not true when considering a dozen or less photographs taken of an accident site. Berling (1970) offers evidence in which a scaled diagram of an intersection, showing crosswalks, meridian dividers, turn arrows, roadside structures, skidmarks, and automobile locations, required approximately four hours to prepare from photography that required less than 20 minutes to obtain. Hardegen (1974) reports that approximately 1-3 hours would be needed, depending upon the extent of coverage, for the preparation of a scaled diagram of any accident site. Misunderstandings of this magnitude greatly impair the promotion of photographic methods.

Baker (1975) also offers the following advise concerning the use of photographs for accident information:

> An investigator should think of photos only as a means of recording what he has seen that he thinks is important; he should avoid taking pictures as a substitute for observations. He should not expect to find in a picture what he failed to note before he made the picture.

The subtle point seems to be that photographs only duplicate what the investigator observes and, therefore, is a redundant procedure. It certainly has the effect of discouraging photographic documentation of the accident site. Sgt. Myron Lofgren, of the Minnesota State Patrol, contends that investigators often overlook the important observations using conventional methods, but that they are documented when using photographic methods. Offered in the same context, Hardegen (1974) states that one of the advantages of a photogrammetric method is that it is not subject to the unavoidable misreadings, misunderstandings, and writing errors afflicting tape measurements, angular errors, or errors and omissions of important details. In other words, photographs often record observation failures.

Photogrammetric literature has made frequent reference to the use and application of its science to that of traffic accident investigation. Whenever this application is directed to potential use within the United States, the tendency is to recommend the use of the most technical and sophisticated systems available. Over 15 years ago, Sally (1964) presented a technically convincing argument for the use of stereometric systems, and concluded that these systems could be utilized to their fullest extent for accident investigation. Since these systems are still not being used in the United States, there must be some misunderstanding by photogrammetrists. Ghosh (1979) points out that "...the working photogrammetrist must keep in mind that decisions concerning the end product of photogrammetry are often economic rather than technical".

Photogrammetrists are also quick to compare the successful use of photographic methods used in Europe to the potential use of such methods in the United States. These comparisons are not, however, extended to include the organizational structure of the police forces. Within the United States, Baker (1975) explains that programs for accident investigation should be tailored for each department because the needs, resources, and capabilities of police agencies differ significantly. This is especially true between urban and rural departments. The extent of these differences is obviously greater between departments in Europe and the United States, if for no other reason than the size of the countries involved. To date, photogrammetrists have recommended photographic methods which imitate those used in Europe on purely technological considerations.

These misconceptions and misunderstandings seem to exist among both photogrammetrists and accident investigators. Accident investigators perceive photogrammetry as being too technical and photogrammetrists, on the other hand, recommend systems using the most technologically advanced equipment and theory without economic considerations.

B. Traffic Accident Investigation

"Traffic accident investigation...is mainly a matter of obtaining, recording, refining, and interpreting information", according to Baker (1975). An immediate distinction must be made between traffic accident investigation as a process and as a procedure. As a process, the term is meant to include all types of investigation and can be broken down into five levels of activity for which investigative procedures are applied. According to Baker (1975), these levels of activity are 1) reporting, 2) at-scene investigation, 3) technical preparation, 4) professional reconstruction, and 5) cause analysis. The two investigative procedures of concern to this thesis are those of levels two and three. Reporting, professional reconstruction, and cause analysis involve procedures for identifying the accident, determining how the accident happened, and determining why the accident happened, respectively (Baker, 1975). The at-scene investigation involves investigative procedures for data acquisition and the technical preparation level includes analysis and organization of that data to include preparation of diagrams. Because technical preparation is heavily dependent upon the observations made during the at-scene investigation, it is this investigative procedure of traffic accident investigation to which attention is directed.

According to Baker (1975), the at-scene investigation involves "examining and obtaining additional information at the scene which may not be available later...", and that this information supplements the accident report. An accident report is prepared for every accident investigated; however, as the degree of severity increases, the preparation of this report becomes more involved. The additional or supplemental information will be in the form of photography and field notes of measurements (Baker, 1975). The preparation of this accident report is an important part of the at-scene investigation.

The accident report is normally a standardized report requiring the investigator to give a response to a wide variety of topics. Although this report may vary in format and/or degree of preparation, it is usually a highly organized form for recording the identifying and descriptive data relating to the accident. Lillesand and Clapp (1971) identified the following basic categories of data that would be recorded at a reportable accident:

--location of the accident;
--identification of drivers and vehicles;
--details of damage, injuries, and fatalities;
--road characteristics, surface, and defects;
--traffic control at location of accident;
--light and weather conditions;
--driver violations;
--driver and pedestrian action;
--physical condition of drivers and pedestrians;
--vehicle condition; and
--diagram of accident circumstances.

It is this information which is then used for purposes of accident reconstruction, cause analysis, and legal investigations. It is intuitive that an increase in accuracy, detail, and reliability of this report would also improve the capabilities of the follow on process.

It is a matter of conjecture whether the standardized accident report improves or limits the data collection process. It has the advantage of making sure information is recorded but tends to limit the recording of anything not listed on the form (Baker, 1975). Measurements are an example of this. As Baker (1975) explains, measurements are often neglected or improperly recorded causing uncertain recollection and crude guesswork at some later time. This information is directly related to the diagram of accident circumstances.

Data concerning measurements and relative locations of the physical evidence are normally recorded on the accident diagram. The metric information contained in this diagram may include measured evidence such as skidmarks, holes, scattered debris, puddles of water, oil, or blood, final location of vehicles, and location of injured personnel (Police Evidence Library, 1965). This information must be measured and recorded during the conduct of the at-scene investigation. If a measurement is overlooked or improperly recorded, the accuracy and reliability of the diagram are decreased.

This study directs its attention toward the development of the accident diagram and those processes which rely on metric accident information. This diagram is no more than a plan of the accident scene, however, the degree of sophistication and the means of obtaining the dimensional data for the construction of this diagram are not always the same. This means the diagram may vary from a simple sketch showing relative positions to an accurately prepared map utilizing survey techniques.

It is extremely desirable that these diagrams be as complete, accurate, and true to scale as possible. Berling (1970) states that the more accurate and complete the surveying of the accident site, the final position of the vehicles involved in the accident, and the entire topography of the scene, the more reliable the assessment and the statistical evaluation for collision investigation. However, as the seriousness of the accident increases, so does the probability of an error in the survey of the accident site or in the omission of a measurement. Priority must be given to the immediate care and transport of any injured personnel involved, the testimony taken of any witnesses at the scene, and the return to free-flowing traffic established. Danko (1979) contends that the officer "is expected to be a doctor, photographer, psychiatrist, surveyor, minister, mechanic, assessor, coroner, judge, and a stenographer..." in addition to his duties as an investigator. Baker (1975) also notes that the investigator must be able to discharge other responsibilities, such as protection of life and property, which are not investigative by nature. Berling (1970) states that the demand for a fast, safe, and complete survey of an accident site without disturbance of the traffic flow is actually a contradiction in itself.

At most accidents, the police investigator is required to make a value judgment as to what is important enough to include in the diagram. He must first decide whether (Baker, 1975) the diagram is needed for working purposes only, or whether it may be needed for display purposes, such as in a courtroom. If it is needed for display purposes, the amount of detail is increased (Baker, 1975).

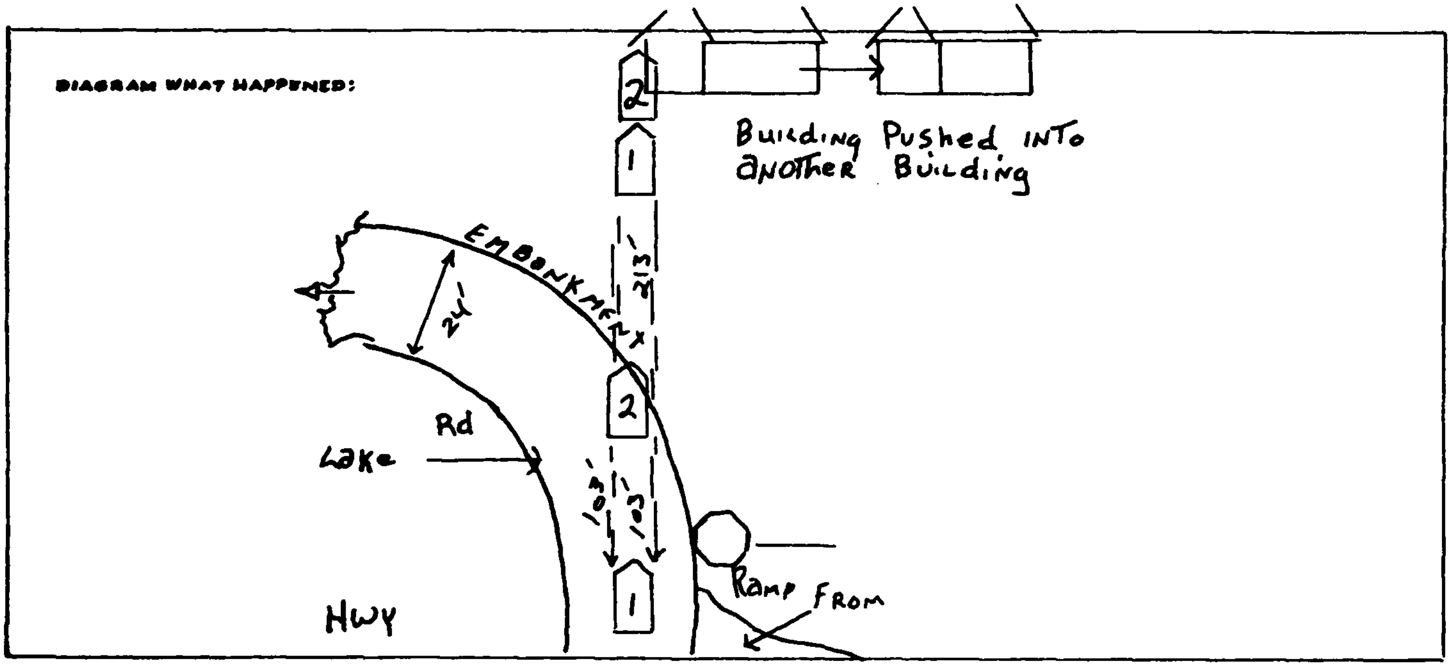
It is evident that the accident diagram is a very important part of the at-scene investigation procedure. Its development suffers and is hindered by time constraints resulting from other responsibilities and the need to decide which measurements are important. Accuracy, reliability, and completeness of the diagram are, consequently, variable with respect to individual accidents and investigators.

Fig. 1 is an edited example of an actual diagram extracted from a traffic accident report. This figure represents the typical diagram prepared for each accident and included in the accident report. Fig. 2 is an example of a supplemental diagram. These diagrams are generally prepared when the severity of the accident warrants better quality and greater quantity of measurements. This figure is also an actual diagram extracted from a traffic accident report.

C. Photographic Applications

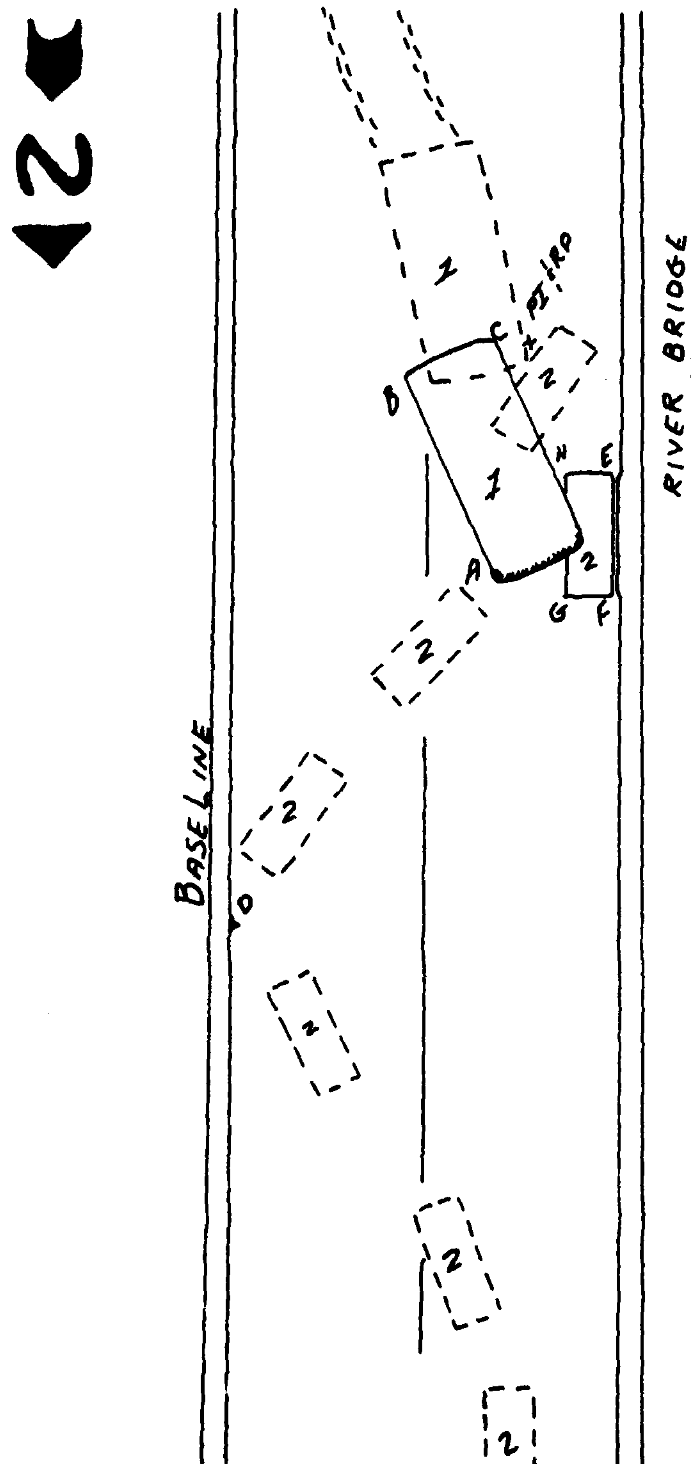
1. Photogrammetric interest

"Photogrammetry", as offered by Ghosh (1979), "has been defined by the American Society of Photogrammetry as, '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 definition includes such processes as the recognition and interpretation of objects as well as processes involving precise dimensional measurements to obtain direct information relating to the size and shape of objects (Ghosh, 1979).



[Narrative transcribed from actual report: "Vehicles #1 & #2 were westbound on Lake Road at the intersection of #5. #2 was the lead car traveling at a high rate of speed, missed the curve and traveled 179' down an embankment and hit a garage at the bottom of the enbankment. #1, who was following #2, saw #2 miss the curve and tried to stop but went down the same embankment and struck #2 in the rear causing a personal injury accident".]

Fig. 1. Example of a traffic accident diagram; transcribed from an actual traffic accident report



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B	10 4/W	122 10/N
C	18 4/W	122 6/N
D	0	55 11/N
E	23 0/W	133 5/N
F	23 0/W	142 9/N
G	18 2/W	142 1/N
H	17 10/W	134 8/N

PAVEMENT WIDTH 23'

Fig. 2. Example of supplemental diagram; transcribed from an actual traffic accident supplemental report

Although the principal and best known application of the science of photogrammetry is undoubtedly the use of aerial photographs in the field of topographic map making (American Society of Photogrammetry, 1979), the science is generally concerned with any endeavor for which measurements are required and which can be photographed. As explained by Karara (1972), photogrammetrists have attempted to apply their techniques outside the field of topographic mapping since the early days of photogrammetry. This lead to the concept of nontopographic photogrammetry.

Recently, nontopographic photogrammetry has become an umbrella term for many diverse applications to different fields. Close-range photogrammetry is the subdivision that links photogrammetry to traffic accident investigation.

Close-range photogrammetry, as defined by Karara (1972), normally implies that the distance from the camera to the object being photographed is less than 1000 feet (about 300 meters). It was the close-range application of photogrammetric theory that led to the development of the stereometric systems.

Nontopographic photogrammetry and its subdivision of close-range are just beginning to come of age within the United States. This is evidenced by the fact that the first text on the subject (Handbook of Non-Topographic Photogrammetry) was published in 1979. It is also an indication of the desire of photogrammetrists to show that photogrammetric applications can provide measurements to almost everything that can be photographed.

2. Stereometric systems

As previously noted, stereometric systems are used in several countries in direct application to traffic accident investigations. For this reason, a brief description of this system is offered for familiarization purposes. As with other photographic processes, this system consists of the data acquisition stage and the data reduction stage.

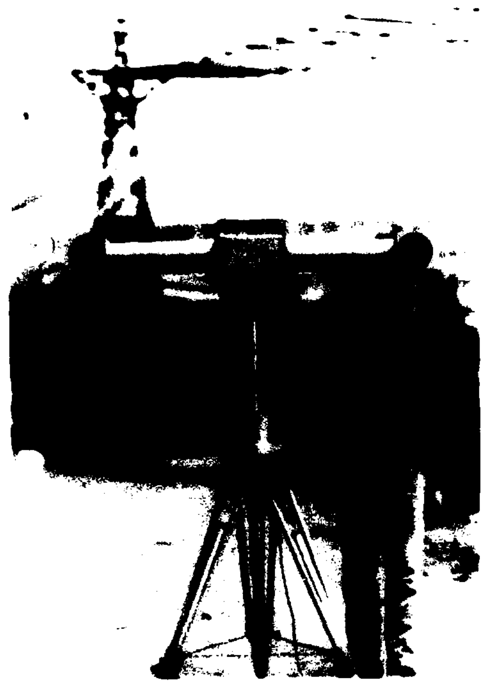
Of primary concern in the data acquisition stage is the camera used to take the photography. This system employs a stereometric camera. As the name implies, this camera images a stereo pair of photographs and is metric by definition. According to Karara (1972), metric is used to identify cameras that have been designed and built for survey purposes, as opposed to nonmetric cameras which have not. More details on this subject are presented in III.A.

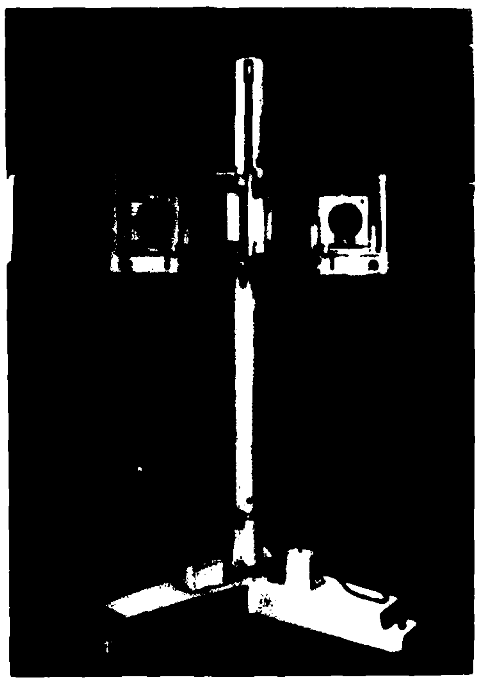
A stereometric camera is essentially two metric cameras (or chambers) mounted on a bar of definite length. The camera axes are parallel to each other and are perpendicular to the base or bar upon which they are mounted. This arrangement is called the normal case of photogrammetry (American Society of Photogrammetry, 1979), and, with few exceptions, all stereometric cameras are limited to this orientation. Figs. 3a and 3b show examples of stereometric cameras.

These cameras were developed for work in close-range photogrammetry, and, although they do not have an adjustable focus, most of them do have provisions for changing the principal distance which allows for focus ranging. These cameras are designed to use glass plates for producing

Fig. 3a. An example of a stereometric camera. This is a Jenoptik SMK 5.5/0808 with a fixed camera base length of 120 cm. Several manufacturers offer systems like this one. It is the most common stereometric model used for traffic accident investigation photography

Fig. 3b. Another type of a stereometric camera. This is also a Jenoptik. This camera offers a variable base length of 35 to 160 cm and an adjustable height post of between 0.6 and 2.1 meters





the negatives, however, there are at least two manufacturers producing models which will accommodate roll film.

There are numerous manufacturers of stereometric cameras producing a wide variety of models. In most cases, the model of the camera must be matched with the project, and it is this lack of versatility that is a disadvantage of stereometric cameras. Prices for these cameras are generally in the $4000-$6000 range.

Stereometric cameras are used to produce a stereopair of photographs. These photographs can then be placed under a stereoscope or in a stereoplotter and viewed as a relief model in three dimensions.

The data reduction phase, according to the American Society of Photogrammetry (1979), refers to those processes which convert information obtained from photographs into maps or into a form of digital representation. This is analogous to the photogrammetric analysis stage as discussed earlier.

There are three alternative approaches toward data reduction which depend to a large degree on the system used to acquire the photography and the desired form of the final product. These are referred to as analogue, analytical, and semi-analytical methods. According to the American Society of Photogrammetry (1979), the analogue approach is recommended when the final output is in the form of a contour map.

The analogue approach refers to the use of a stereoplotting machine to graphically reconstruct a contoured plan view from a stereo-pair of photographs. The diapositives (or negatives) are oriented in the stereoplotter in such a way that they correspond exactly to the orientation they had when the film was exposed in the camera. They project a three dimensional image onto a tracing table from which an operator simply needs to locate and record the lines of equal depth. This process is not extremely complicated, nor is it overly time-consuming. A plotter operator can be sufficiently trained to become familiar with the procedure and instrument within two weeks (Berling, 1970).

There are many stereoplotting machines on the market today. However, stereometric photography as a close-range application is not compatible with those stereoplotters designed for the normal photogrammetric application of topographic map making. As pointed out by the American Society of Photogrammetry (1979), most stereoplotters are designed for specific stereometric systems and may not accommodate photography from cameras of different manufacturers. For these reasons, care must be taken to assure a system compatibility between the camera and stereoplotter.

A stereoplotter is a very expensive item. Prices will average about $45,000.

Stereometric systems are important to the concept of applying photographic procedures to traffic accident investigations because they have been fairly well-documented. Most of this documentation, however, comes from Europe. Although stereometric coverage and its use (Danko, 1979) has been employed in Europe for over forty years in the reconstruction of accident sites, this author is aware of only three articles published in the United States concerning its potential use. Sally, in 1964, reviewed the European technique and recommended its use, especially in larger cities. Lillesand and Clapp, in 1971, actually used a stereometric camera and stereoplotter and conducted field work in connection with traffic accidents. They showed that the use of stereometric cameras improved the quality of accident diagrams. Danko, in 1979, also reviewed the practice of other countries and recommended its use in the United States.

Based on work in Europe and Japan, that of Lillesand and Clapp, and analysis by U.S. authors, it can be stated that stereometric systems offer important advantages over conventional techniques of traffic accident investigation.

The reliability and accuracy of stereometric procedures are superior to the conventional methods of taping (Berling, 1970). Blunders, such as misreading or misrecording, involving taped measurements are eliminated (Hardegen, 1974). Also, any omission of a taped distance can be quickly and accurately determined (Berling, 1970).

The photographs are totally unbiased and are complete in recording the scene of the accident (Danko, 1979). Often, eye-witness testimony of the accident consists of vague impressions or inaccurate recollections, or is biased to the point of falsehood (Police Evidence Library, 1965). Stereopairs can be viewed under a stereoscope and serve as a three-dimensional aid in a courtroom (Berling, 1970). Even if the accident site undergoes changes, the photographs can accurately show the condition at the time of the accident (Hardegen, 1974).

Stereometric recording offers the distinct advantage of being able to construct cross sections and profiles of the surrounding area. Slopes, banks, and gradients can have vital importance in accident reconstruction (Berling, 1970).

The stereometric operation represents a time savings in the restoration of traffic flow. It requires less time to set up the camera, establish some control points, and photograph the accident site than it does to obtain the required measurements by tape (Hardegen, 1974).

Lillesand and Clapp (1971) concluded that "the implementation of stereometric camera systems can significantly improve the collection, the accuracy, the preservation, and the presentation of metric accident data".

3. Perspective grid photography

Perspective grid, according to Wolf (1974), is the name applied to the representation on a photograph of the perspective view of a square grid pattern on the ground. This concept is best illustrated by an example. Suppose a picture is taken at some angle other than vertical from an airplane over a section of flat terrain. Also suppose that there are roads equally spaced and forming squares upon the terrain. If, for example, the road directions were north-south and east-west and the picture was taken with the camera pointing north, then all north-south roads would appear to converge (vanish) at a common point (Wolf, 1974). The squares formed by the roads would appear on the photograph as a pattern of quadrilateral grids.

There is more than one way to employ the concepts of perspective grid in its utilization toward map or diagram compilation. One way is to attach a glass plate with a grid system to the camera. As Berling

(1970) points out, this method is rather limited in its application since it requires the camera to have a fixed focus and the grid must be pre-calibrated to a certain height above ground and correspond to a certain camera axis orientation.

A second application is found in work done by photogrammetrists in the planimetric mapping from oblique aerial photographs. It is often called the Canadian Grid method in this application as it was used (Wolf, 1974) extensively for planimetric mapping of Canada's flat wilderness area. In this application, the photogrammetrist makes use of high quality cameras designed for survey work. Then, as Wolf (1974) indicates, if the flying height of the plane, the focal length of the camera, and the depression angle from vertical of the camera are known, a perspective grid can be prepared. This grid pattern is developed from geometric and trigonometric relationships.

The third application involves the use of a template which is placed in the image area prior to photography. This application is taught at the Northwestern University Traffic Institute and is the photographic system which was recently put into practice by the Minnesota State Patrol. It is this application which is examined herein and further reference to perspective grid will be made with this application in mind.

As defined by Baker (1975), a perspective grid template is a square or rectangle of known size placed on a flat surface so as to appear in a photograph as a basis for locating marks or points which also show in the photograph of the surface. With this perspective grid template in the photograph, the entire photograph can then be divided into segments of known dimension. Referring to the previous example, this is essentially the same as having only one square of the road network, photographing the area, and then extending the network on the photograph with sets of parallel lines in perspective projection.

Once the series of photographs are divided into segments, a diagram of any scale can be constructed by simply measuring the lengths and widths of the data contained in the photographs and transposing them to the diagrams.

There is one major distinction between this application and the first two. The camera used in this application is generally a nonmetric camera while the other applications use cameras designed for survey purposes (metric cameras).

This application has been used in connection with traffic accident investigations, but only on a very limited scale. This author is aware of only one published article concerning its use on an operational level. According to Crawford (1978), the strongest argument for the use of perspective grid photography in accident investigations is its simplicity. Also, many of the same benefits as applied to the stereometric techniques have been achieved by the Minnesota State Patrol with their use of perspective grid photography. According to Crawford (1978), these include a decrease in investigation-related trooper injuries, a drop in the average on-scene time per accident, an increase in the ability to investigate all accidents in detail, and a permanency of record. It is the contention of Crawford (1978) that the use of this method has significantly increased the quality of accident investigations.

The only serious disadvantage of this method is that only two dimensional measurements can be taken and the terrain needs to be relatively flat. This system, by itself, is not useful for determining heights of objects, slopes of embankments, or depths of ditches. According to Sgt. Myron Lofgren of the Minnesota State Patrol (telephone interview, 1979), these problems had not yet surfaced in their day-to-day operation.

D. Photographic Systems and the Judicial Process

As suggested by the Police Evidence Library (1965), photogrammetrists have often been called upon to give expert witness testimony in a court of law. In order to apply his expertise, however, it must be established that the photographs are true and reliable representations of the scene. Since the photogrammetrist, in all probability, did not take the picture, he cannot be expected to do this. According to Quinn (1979), courts have stated that it is not sufficient for a photographer to merely say he has taken the photographs; he must identify the subject and testify that it represents the area. If there are elements of authentication missing between the time the picture is taken and when it is admitted into court, the credibility, and hence the admissibility, of the photograph are subject to doubt. The photogrammetrist, according to the Police Evidence Library (1965), will generally only give testimony as to the photogrammetric analysis and leave the credibility and admissibility of the photograph to some other authority.

Baker (1975) states that there is less suspicion of photographs than there used to be, especially those dealing with traffic accidents. On the other hand, suspicion still exists and, according to Quinn (1979), we must appreciate that many trial judges and lawyers are aware of the possibility of "trick" photographs being presented to them. Traffic accident investigators are aware of this, and are taught to establish a continuity of custody whenever they make a photograph.

The stereometric systems employed in Europe (Hardegen, 1974) and the perspective grid method used by the Minnesota State Patrol (Crawford, 1978) are common in that the chain of custody of the photographs falls within the jurisdiction of the traffic authorities. In terms of admissibility of the photographic evidence, neither Europe nor Minnesota has encountered any difficulties. In fact, according to Lillesand and Clapp (1971), "it can be said that the 40 years of favorable judicial experience with the stereometric process has resulted in unquestioned court admissibility of stereometric evidence in European courts" (emphasis added). Sgt. Lofgren (telephone interview, 15 Nov. 1979) confirmed that the Minnesota courts have maintained the admissibility of their perspective grid product.

In connection with the judicial process, an advantage of accident information obtained from a photographic process is that it is objective by nature (Berling, 1970). This is contrasted to eye-witness testimony which is subjective evidence. The problem with eye-witness testimony, according to the Police Evidence Library (1965), is that it often consists of vague or inaccurate recollections, "or is biased to the point of falsehood". The importance of this objective evidence in one European country is underscored by Sally (1964) in quoting a letter from the Police Department of the City of Basel in Switzerland which states that the "...courts base their decision fully on the photogrammetric evaluation of the pictures taken".

III. DEVELOPMENT OF THE SIMPLE PHOTOGRAPHIC SYSTEM

A. Data Acquisition Stage

1. Camera selection

As previously noted, the concepts of perspective grid photography have been used with metric and nonmetric cameras. The decision was made to use a nonmetric camera despite the statement offered by van Wijk and Ziemann (1976) that "It would...not be practical to use non-metric cameras in routine, close-range applications such as...the recording of traffic accidents in which many different sites and camera stations are involved". Again, it appeared that this statement was offered in the context of analytical photogrammetry with emphasis on high precision technology rather than simple methods offering moderate accuracy and precision with economic advantages.

The use of nonmetric cameras, as opposed to metric cameras, for photogrammetric purposes has the following advantages and disadvantages, according to the American Society of Photogrammetry (1979) Advantages are 1) general availability; 2) flexibility in focusing range; 3) some are motor driven, allowing for quick succession of photographs; 4) can be hand held and thereby oriented in any direction; and 5) the price is considerably less than for metric cameras. Disadvantages are 1) the lenses are designed for high resolution at the expense of high distortion, 2) instability of interior orientation, 3) lack of fiducial marks, and 4) absence of level bubbles and orientation provisions precludes the determination of exterior orientation before exposure.

In evaluating the advantages, general availability means that nonmetric cameras can be easily obtained through a camera distributor.

Flexibility in focusing range refers to the ability to focus the camera at different object-to-camera distances. This is especially useful if a camera might be required for general work.

The ability to apply a motor drive to the film is an advantage of limited concern in this application. It is doubtful that an accident investigator would find this advantage as little more than a convenience.

The ability to hand hold a nonmetric camera and orient it in any direction offers a distinct advantage. The ease of operation as compared to metric cameras is especially important if the camera is to be used by personnel not especially trained in photography.

The cost advantage of nonmetric cameras is considerable. While a good nonmetric camera system will generally cost less than $500, a metric camera will start in the neighborhood of $3000 and can approach $10,000.

The first disadvantage refers to the high distortion of nonmetric cameras as compared to metric cameras. This is a comparative value and is important especially in analytical work requiring high precision.

The instability of interior orientation refers to problems dealing with the location of the principal point as the focus of the camera is changed. The classic methods of photogrammetry rely on the consistency of location of this point.

The lack of fiducal marks only magnifies the second disadvantage. They are used to locate the principle point, but since the principle point location is not consistent in nonmetric cameras, adding fiducal marks would serve no meaningful purpose.

The inability to determine exterior orientation before exposure means that known directions of camera axis orientation in the horizontal and vertical planes are not obtainable. To overcome this disadvantage would negate the advantage and simplicity of using a hand held camera.

The decision to use a nonmetric camera for data acquisition was made after consideration of all of the above, but with emphasis on the following two reasons:

1) Nonmetric cameras are much easier to operate and understand, which is in keeping with the objective of developing a simple system.
2) Nonmetric cameras offer a distinct cost advantage, which takes on added significance if more than one camera is required to provide coverage for a given area.

Two different cameras were used in acquiring the photography for this report, however, both were 35 mm cameras. It was felt by this author that a 35 mm camera was the best selection as a general purpose camera. The first was a 35 mm Canon TX classified as a single lens reflex (SLR) model equipped with a 50 mm f/1.4 lens. The second was a Pentax Spotmatic II. This is also a 35 mm single lens reflex camera and it was also equipped with a 50 mm f/1.4 lens.

The 50 mm lens allows for an angle of view of 43° and is normally the standard size lens supplied by the camera manufacturers. They are a basic all around lens, which offer an advantage over wider angle lenses in that they have a faster speed and can therefore accommodate a greater variety of light conditions.

Neither camera proved difficult to operate. They both had a built-in exposure meter which made the task of selecting shutter speeds and aperture openings a simple operation. Approximately 30 minutes was all that was required to review each operating manual in order to obtain operational efficiency.

2. Object space control

The application of a photographic procedure requires some type of object space control system to be established. In other words, in order to determine the length, width, or height of some object as seen in the photograph, there has to be some way to determine the scale relationship within the photograph. This is done by identifying reference points within the photograph for which the spatial relationship between them is known. This known spatial relationship supplies the object space control and needs to be established for each of the three dimensions. It would be a fallacy to assume that scale in one dimension is equivalent to the scale of another.

To be practical toward use at a traffic accident scene, this control object or system must 1) be easily transportable, 2) take a short time to set up, and 3) be capable of being handled by one person.

The perspective grid template meets these criterion, however, it affords only planimetric object space control. It does not give any scale reference toward height.

The template (or perspective grid) used in this method is 2 feet square. The grid lines are all 3/4 inches in width except for the two end lines perpendicular to the axis of the camera. These were made to be 1½ inches in width in order to provide greater clarity within the photograph itself. The template itself varies from 2 feet square by no more than 1/8 of an inch. At 24 feet from the template, this deviation from 2 feet square means that reduced measurements can be no better than ± 1.5 inches. This template can be seen in Fig. 5b.

The use of traffic cones was added for giving an object space control system in the third dimension of height. Traffic cones were used because they are generally available to a traffic accident investigator. On a terrestrial photograph, relative height of an object is a function of the depth that the object appears in the photograph. This means the cones have to be set up so that a continuous scale can be established. These traffic cones were slightly modified by adding a white styrofoam tip for help in identifying the top of the cone. The cones were adjusted, using this white tip, to a common height of 2.7 feet. Repeated measurements in the field at different times yielded a maximum deviation of .05 feet.

3. Film and prints

Kodak Plus-X pan film was used with both cameras. Its ASA rating is 125 which is classed as a medium speed film. It offers a very high degree of sharpness and, because it has a better resolving power than higher speed films, it does not lose that sharpness as quickly when making enlargements. This is a fairly versatile film and can be used with a hand held camera under almost all daylight conditions.

It should be noted that a higher speed film (on the order of ASA 400) could be used to increase the usage in darker conditions. Since both cameras were able to go as high as 1/1000 of a second in shutter speed, daylight photography would still give an acceptable quality print.

The Iowa State University Photo Service processed all film and also did all the work for the enlargements. It was found that a convenient way to help in locating and keeping track of specific photographs was to have a contact print made for each roll of film developed. The contact print is made by laying the negatives on a piece of print paper and exposing the print paper. In this way, the negatives can be viewed as miniature photographs on a single sheet with the advantage of having the frame number available for reference.

Normal enlargement of 35 mm prints to fully utilize an 8 x 10 inch piece of print paper affords the most convenient and economic method of enlargment. This gives an enlargement factor of just over 7x. By comparison, the enlargements found in this thesis are very nearly 6x. In terms of ease of operation, it was found that the 7x enlargement was preferable. Detectable difference in sharpness of images was negligible between these two powers of enlargement.

4. Photographic procedure

A testing area was established on the driver's education course of Iowa State University. This area included a four way intersection with turn lanes, turn arrows, and curbs. Although they were somewhat deteriorated, the street markings and curbs were in sufficient repair to make use of them.

An initial area was set up to test the capabilities of the perspective grid system. This consisted of marking off 4-foot increments in depth and width. Masking tape was used to make the increments which were determined with the use of a 100-foot steel tape designed for surveying purposes. The left front edge of the masking tape was located precisely, however, the trailing edge was not and was used only to help in identification. These marks are accurately located to within ± .05 feet. Distances between the vertical pieces of masking tape are taken from the leading right edge. Fig. 5b shows the location of the masking tape in this test area.

Two different procedures were used in photographing this test area. The first is a single photograph procedure and the second is a procedure for obtaining stereo coverage.

The single photograph procedure is very simple. The template is laid down so that the sides are parallel to the direction through which a series of photographs is desired. The photographer then backs up a sufficient distance to obtain good focus of the template and the scene in front of the template, centers the camera axis through the center line of the template, tilts the camera so that the bottom of the viewfinder is parallel and almost flush with the closest edge of the template, and snaps the photograph. Fig. 5b is an example of this procedure.

After evaluating the process of taking single photo perspective grid photographs, the testing was expanded toward the development of stereopairs. This expansion is seen as being desirable for the enhanced realism and interpretive value that a stereoscopic model provides.

Given the proper conditions, a pair of photographs can be placed under a stereoscope and a three dimensional representation is seen. Given this added ability of depth perception, a viewer sees the scene as if he were at the location of the camera at the time it took the photographs. This development would seem extremely useful to any investigator that was unable to be at the scene of the accident when it happened.

Because perspective grid photography deals with single photograph coverage, there has been no documented attempt to develop a simple procedure for stereo coverage integrated with this theory. Such a procedure would give a small, but tangible, link to stereometric operations which depend upon stereo coverage. No attempt is made to totally replace the single photograph method, only to supplement it with the extremely advantageous ability to view an accident scene in three dimensional perspective.

This procedure was developed around the perspective grid template so that there would be no loss in the ability to use the template in preparing the grid pattern. Also, this procedure preserves the simplicity of the single photograph method by not requiring any precise measuring nor does it significantly increase the amount of time needed for photographing the scene.

Photographing a stereo pair was done by centering the camera as described for single photographs, then taking one sidestep to the right of approximately two feet. By aligning the bottom portion of the viewfinder with the template, the camera will be approximately parallel with the center line of the template. Although the camera axis should be as parallel as possible to the centerline, it is very difficult to not obtain some convergence or divergence with a hand held camera. For recording the left photograph of the stereo pair, two steps are taken to the left from the right hand position. This will place the photographer about one step (or two feet) to the left of the template centerline. The camera aligning procedure is repeated and the scene photographed. Fig. 4 is a schematic diagram of this procedure.

B. Photogrammetric Analysis Stage

The preparation of the overlay grid pattern is the first part of the photogrammetric analysis stage. The second part would be the preparation of a scaled diagram from the data obtained as a result of this grid pattern. This section examines the procedures for developing the grid pattern from single photograph coverage and stereo photograph coverage as well as the procedure for developing a reference system for height determination.

1. Single photograph procedure

The procedure for developing the grid pattern is not at all difficult and can be done rather quickly. Reference can be made to Fig. 5a which is an example of this procedure. First, extend the edges of the template until they intersect. This point is termed the vanishing point. Next, extend the bottom edge of the template horizontally to the limits of the photograph. Determine the scale distance of the bottom edge of the template and mark off equal spacings of this scale distance along this bottom line from both the left and right corners of the template. Since all parallel lines will vanish at the same point, simply connect

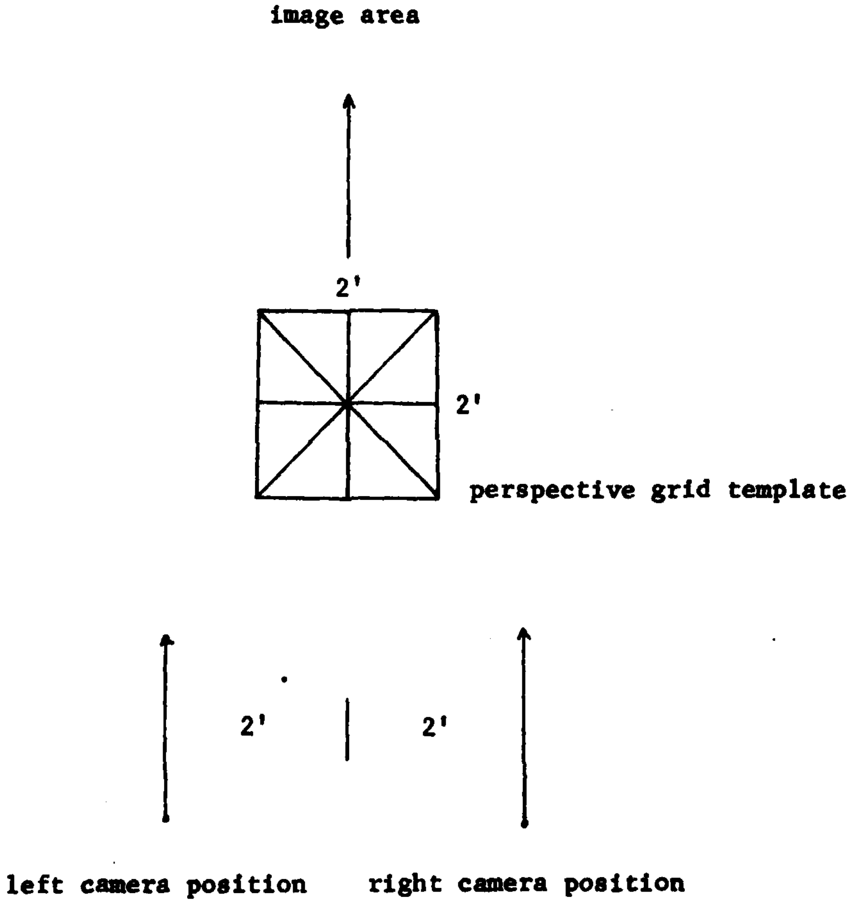


Fig. 4. Schematic for obtaining stereo pair coverage

the increment marks on the bottom line to the established vanishing point. These lines will be called grid meridians.

Consider again the example of the square road network. If another road was added at 45° from an intersection, it would pass through each intersection on that diagonal and at an angle of 45°. This would also be the case for a 45° diagonal line on the photograph. The template already contains the diagonal lines needed to add the horizontal lines. Extending them to the left and to the right, they will cross the grid meridians at the intersection points. Then, simply connect the corresponding left and right intersection points.

The template will conveniently allow for preparing quadrilaterals representing sections two feet square. It can also be extended to four feet sections or, alternatively, to sections as small as one foot square.

2. Stereo photograph procedure

Fig. 6b is an example of a grid system prepared from an off center photograph. This example is a right hand image of a stereo pair.

Upon careful examination of Fig. 6a, it can be seen that the template is no longer imaged as a quadrilateral. When the template is centered in the photograph, extending the top and bottom portions of the template will result in parallel horizontal lines. When the template is off center, extension of those lines will no longer be parallel.

The following procedure was used in these cases. First extend the edges of template to determine the vanishing point, draw in the bottom horizontal line, and mark it in equal increments of template width. Then connect these marks to the vanishing point as in the single photograph procedure.

Using the top corner of the template closest to the center of the photograph, connect that corner to the first left increment mark and also to the first right increment mark. The extension of these lines will intersect the grid meridians at 45° angles, and the horizontal lines can be added. These initial horizontal lines will represent 4 feet depth lines.

3. Height determination procedure.

Fig. 7a is an example of an overlay prepared to determine a height value using the traffic cones as control. Any number of cones may be used in different orientations, however, two is sufficient. The traffic cones were used in conjunction with the perspective grid, since lines of equal depth (or distance from the template) were needed to establish points for reference to the height scale.

First, a rudimentary technique is applied to the bottom of the traffic cone to locate its center. In other words, the location of that point directly below the white tip of the cone. This is done by connecting the diagonal corners or centers of opposite sides and using the intersection point.

Then connect the white tips of the two cones and extend them through the entire photograph. Doing the same thing to the center points of the bottom of the cones, establishes two perspective parallel lines which represent 2.7 feet of height.

Next, find the appropriate horizontal line of depth for the object to be measured. By extending this horizontally, it will strike the perspective parallel height lines at the appropriate scale reference. Knowing that the scale distance between the two height lines at the depth represents 2.7 feet, it can be compared to the scaled height of the object in question, and the actual height then calculated.

Fig. 5a (overlay). An example of the sectioning process. The sections are all 2 feet wide, with the front sections being 2 feet in depth and the rear sections being 4 feet in depth

Fig. 5b. An example of a perspective grid photograph. This is approximately a 7x enlargement

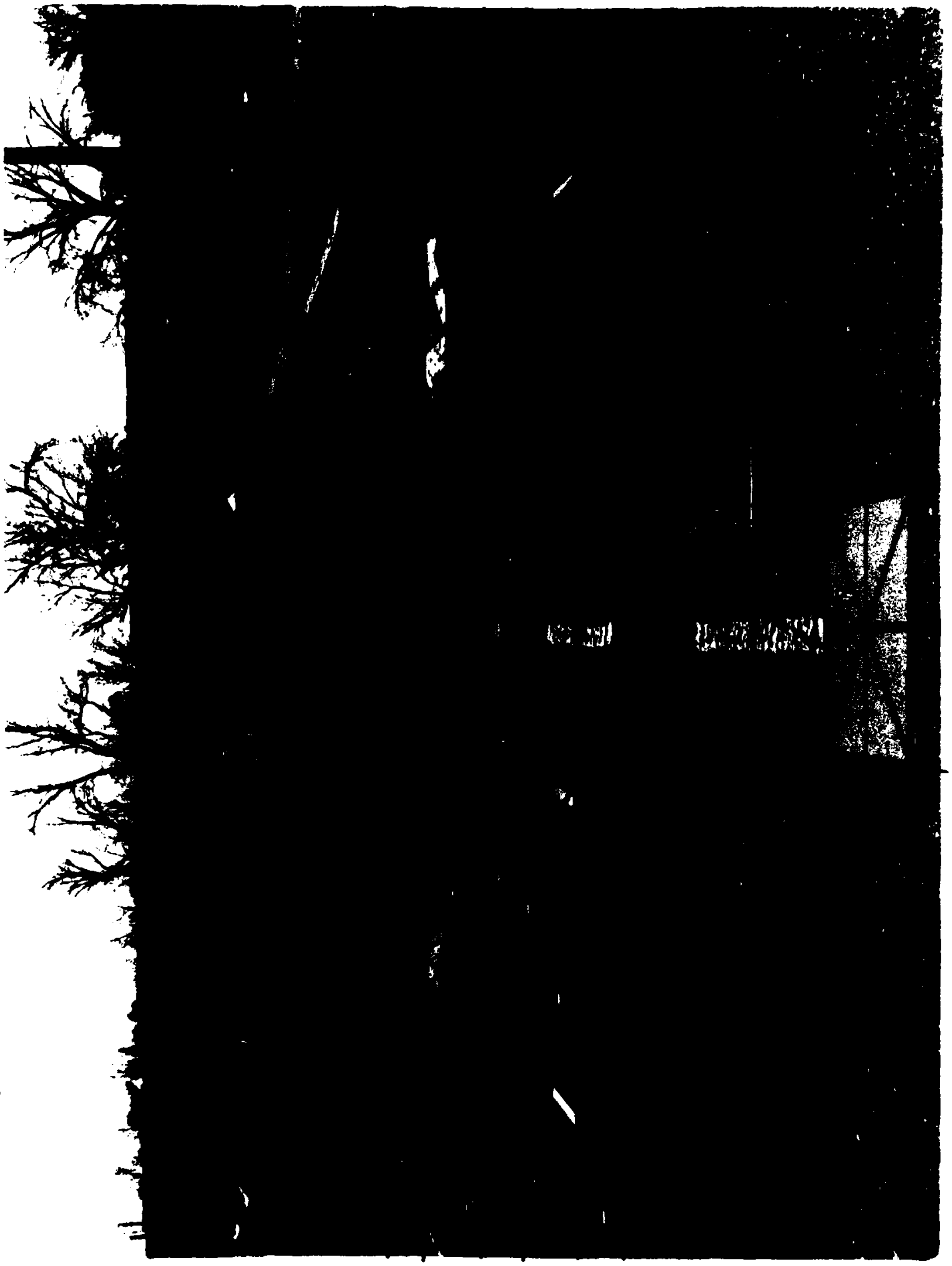


Fig. 6a (overlay). An example of off center sectioning. All sections are 2 feet wide and 4 feet deep

Fig. 6b. The right hand portion of a stereo pair. The camera axis of this photograph is to the right of the perspective grid template

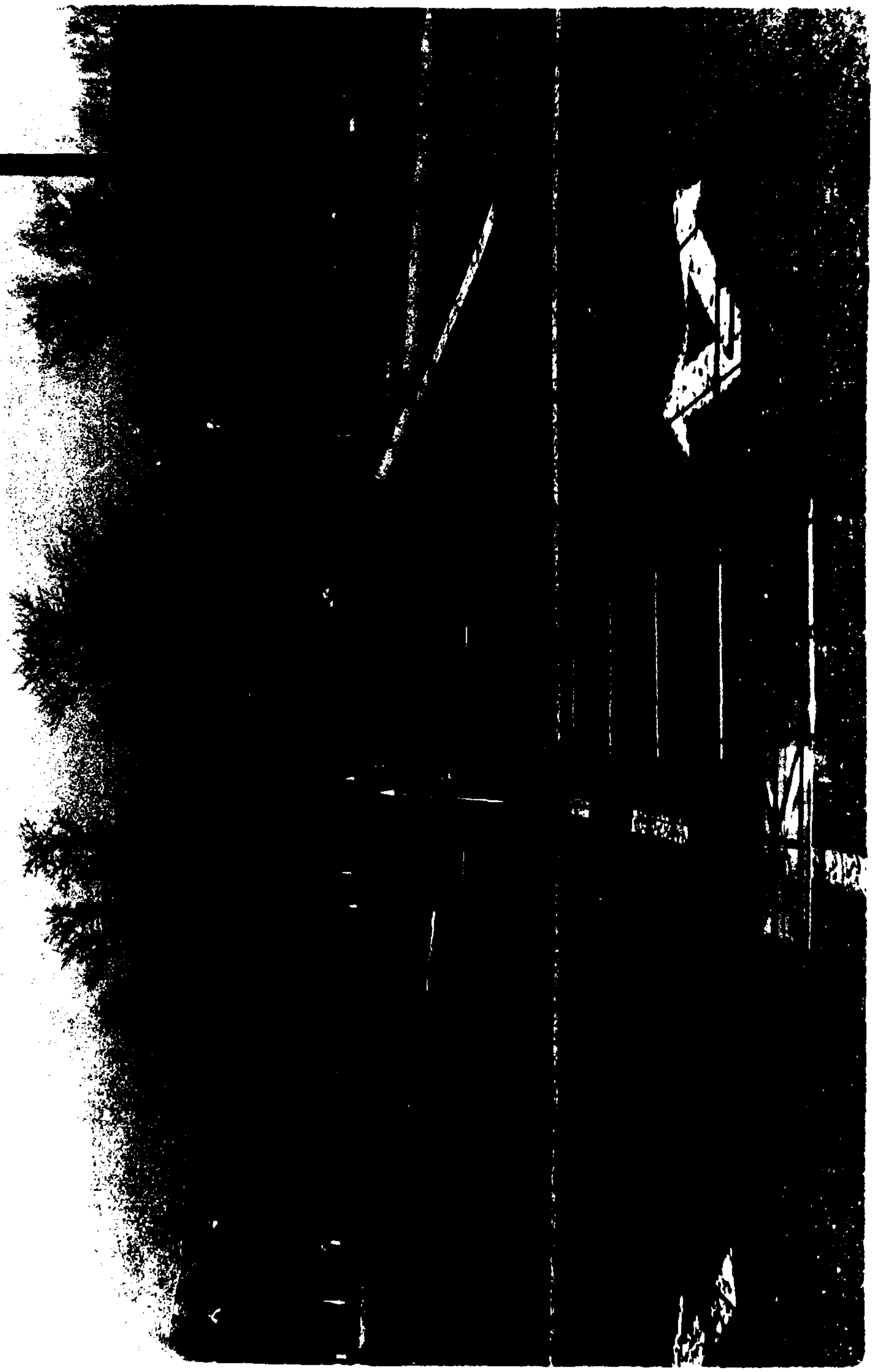


Fig. 7a (overlay). Determining the height of the car. The traffic cones are used to determine the scale at various depths within the photograph. In this photograph, the scaled height and taped value were equal at 4.5 feet

Fig. 7b. An example of supplemented perspective grid photography. This photograph contains sufficient control to determine lengths, widths, and heights

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IV. PRESENTATION OF THE RESULTS

A. Single Photograph System

Data acquisition presented absolutely no problems. Photographs were taken under varying daytime light conditions with no loss of points due to over or under exposure. This is attributed to the simplicity that both cameras afforded for determining the proper shutter speed. Photographing the template, and the scene in the background, required only the time necessary to focus and align the camera. This required less than one minute. It was found that, after becoming familiar with the procedure, fewer photographs were taken in covering the same amount of area.

Learning to properly apply the grid system to the photograph required several trials. This was simply a matter of familiarization and, once confidence in the system was established, it went smoothly and quickly. Each photograph required 20-30 minutes for grid overlay preparation. A compass and protractor were found to be helpful in checking the geometry.

A single photograph, such as the one shown in Fig. 5b was used initially to determine the limits of the system. This was done on the established 50-foot test range which is also seen in Fig. 5b.

As shown in the figure, the parallel lines of depth appear to remain accurate to a depth of 40 feet. However, at that depth, determination of the scale distance will not give the accuracy needed. In fact, at 20 feet of depth, it can be seen that the width of the fine pen line covers the masking tape totally. This means that the width of the line represents 2 inches. Using an accurately constructed grid system, a fine pin prick, and a good scale, measurements at 20 feet will be accurate to within 1 inch on an 8 x 10 enlargement. At 40 feet, accurate location of objects is no better than ± 4 inches.

The test range was constructed to be 50 feet in length. A series of two photographs and then a series of three photographs were taken along this test range. The center line length of this test range was determined using both series of photographs. The series of two photographs gave a value of 49.8 feet and the series of three photographs reduced to 50.1 feet.

Baker (1975) suggests that the greatest degree of accuracy required using conventional techniques is ± 0.1 foot. Considering the use of the three photograph series along the 50-foot test range, this photographic system does meet the accuracy of conventional techniques.

Based on the accuracy of point location at different depths in the photograph and the results of the test range, 20 feet was chosen for the maximum distance that one photograph should cover.

B. Stereo Photograph System

The general objective of achieving stereoscopic coverage without disrupting the simplicity of the single photograph perspective grid system was obtained. There are, however, certain conditions in this application that require attention.

The data acquisition stage provided no difficulties. It took from 2-3 minutes to obtain a stereo pair at any given template location. It did require more time to orient the camera, especially in keeping the lower edge of the viewfinder parallel with the leading edge of the template. Fig. 6b is an example of one side of a stereo pair. The camera separation of 4 feet gives an overlap of photographs of about 80 percent.

The photogrammetric analysis stage does require more care than with the single photograph system. The fact that the template does not represent a trapezoid can be overcome by the procedure described earlier. At 20 feet, the results of data reduction are equivalent to those obtained by the single photograph methods. Fig. 6a is an example of a perspective grid overlap prepared by the described procedure. In this figure, the taped distance between the tip of the arrow pointing forward and the heavy white line just in front of it was 10.5 feet. From this template, a value of 10.6 feet was obtained.

Photographs were also taken at greater camera separation distances than 4 feet. It was found that, at these greater distances, it became increasingly difficult to construct the grid system. The reference grid needs to be as close to the lower center of the photograph as possible. Therefore, the 4-foot distance was established. Separations are not going to be the same for each station photographed, but, as long as the distance was less than four feet, the grid system was able to be accurately constructed.

The big advantage of this system is in the ability to obtain stereoscopic coverage of the scene. Figs. 8a and 8b are examples of stereo pairs obtained by the described procedure. If viewed with a pocket stereoscope, a three dimensional image will be seen.

Fig. 8a. Example of stereo pair. Note the relationship of the trees to the fence when viewed in stereo

Fig. 8b. An example of a stereo pair. These two photographs were not recorded at equal distances of depth from the template

Stereoscopic viewing was achieved for all pairs of photographs taken. Divergence of the camera axes may require the viewer to focus his eyes at a given depth to obtain stereovision. In most cases, this did not present a problem. This problem can be corrected quite easily by forcing the camera axes to a slight convergence when photographing the scene.

This ability to view the scene in stereo was especially useful when working with the enlargements. Using a mirror stereoscope, the evaluation of different parts of the scene was made much easier.

Since the entire scene can be viewed from one stereo pair, it was not necessary to take stereo photographs at each 20-foot station. For the case of this intersection, one stereo pair taken from each of the four roads was ample coverage. This represents the advantage of having stereoscopic coverage available while using the even simpler method of the single photograph system to prepare the scaled diagram.

C. Reduction of Height Data

The traffic cones were used as object space control for the scale in the z direction (mainly height). Figs. 7a and 7b represent the method used in determining the height of an object. In this particular example, the height of the chrome railing on the roof of the larger car is being determined.

Fig. 7a shows what could happen if careful consideration is not given to the location of the midpoint of the cone on the ground. If, for example, the corners of the two cones were connected, it can be seen that the bottom line would have a sharper inclination angle with respect to the top line. This would result in an incorrect determination of scale distance at any given depth.

In Fig. 7b, the taped height to the top of the chrome on the roof was 4.5 feet. The reduced height from Fig. 7a is also 4.5 feet to the nearest 0.1 foot. Results from other photography were just as good. In photographs where the curb was visible, the height scale was extended to its location. The taped height of the curb was 0.5 foot. The maximum deviation was 0.1 foot and this occurred at an extreme corner of the photograph.

This procedure is also viewed as a distinct advantage in supplementing either the single photograph or the stereo photograph perspective grid systems. According to Sally (1964), photographs are severely limited when only two-dimensional measurements can be taken from them. The method of using cones is simple, gives moderate accuracy, and is flexible enough to be applied in almost any circumstance.

D. Comparison of Survey Methods

Fig. 9 is a scaled diagram of an intersection surveyed by standard taping procedures. Fig. 10 represents the same area, however, this diagram was scaled using perspective grid photography. Both diagrams were prepared at a scale of 1 inch to 12 feet.

Since the primary purpose for obtaining the taped distances was for comparison against photographic reduced measurements, Fig. 9 is more detailed than that which would probably have been prepared for an actual accident at this location. The time required to prepare the minimum field notes was 15 minutes. This included sketching the scene, taping the roadway widths and accurately locating the vehicles within the intersection. In order to complete this survey with lane widths, an additional 10 minutes were required. Two people were employed in this process.

The intersection was photographed from 8 camera stations with alternate use of the single photograph and stereo pair methods. It required a single individual 20 minutes to complete the photography of the intersection.

In terms of man hours, the photographic procedure required 33 percent less time than that needed to record the minimum taped distances. For the complete survey, 60 percent less time in total man hours was required. No attempt was made to obtain the taped measurements by a single individual. Considering the case of the traffic accident investigator operating alone, this time requirement increases in significance.

The diagram prepared from the photographic reduced data is almost an exact duplicate of that prepared from taping notes with respect to dimensional quality. The maximum difference between points of known taped distance compared to photographic data was 0.5 foot. This maximum difference was found when locating objects in the outer portions of the photographs.

The most significant difference between the two diagrams is the amount of detail portrayed. Fig. 9 was constructed strictly from taping notes and those notes were thought to have been very detailed. Comparing this to Fig. 10, it shows that a number of items were not recorded in the taping procedure. The directional arrows on the pavement were not recorded at all and two lane widths were omitted. The detail in Fig. 10 is further improved by noting the more accurate representation of the lengths and widths of the dashed and continuous white lines. Also, two of the corners were inaccurately recorded in Fig. 9.

It did require more time to prepare the diagram by the photo reduction method. About one hour was required to scale the diagram from taping notes compared to about three hours for the photographic method. An overlay grid was prepared for each photograph and overlapping sections between photos were double checked. Although this increased the time required, it also increased the accuracy of the diagram. In those cases where results between photographs differed, the measurement taken closest to the template was used.

In general, the results of the two survey methods offer the following comparisons:

--the scaled diagrams are essentially equal in accuracy,

--the photographic method required less time for data acquisition, and represents a greater degree of detail, however,

--it required more time to prepare as a scaled diagram.

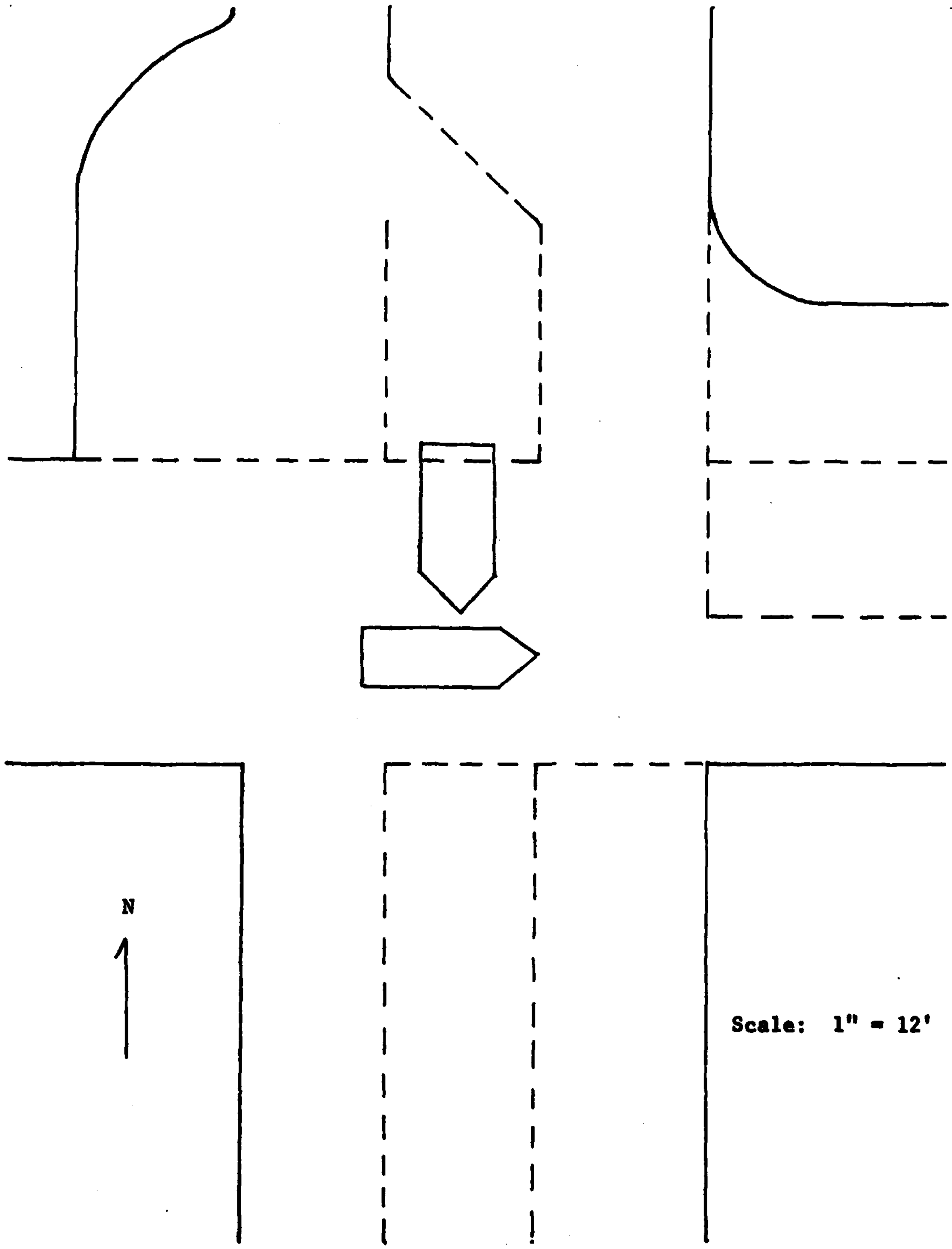

Fig. 9. Scaled diagram from taping data

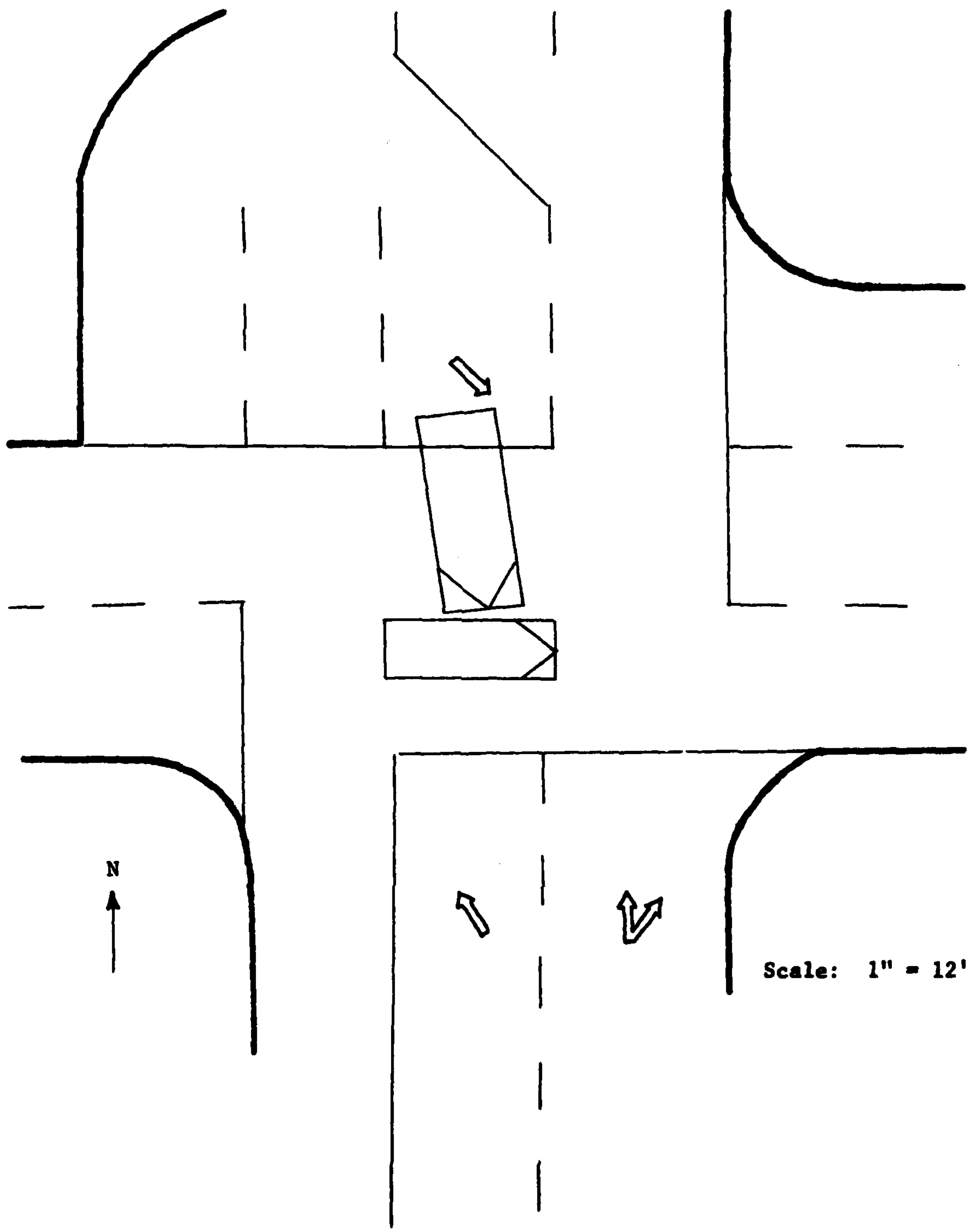

Fig. 10. Scaled diagram from photo reduced data

V. CONCEPTION OF A PILOT PROJECT

A. General Project Development

In this section, a conception for the administration, training, funding, and routine procedure for application of a photographic system to traffic accident investigation within the state of Iowa is offered. This conception is based on an analysis of the available literature and interviews with concerned personnel. Evaluation of this material indicates that this project conception is valid for implementation within the state of Iowa.

1. Selection of a system

There is no doubt that a stereometric system would improve the accuracy and detail of the traffic accident diagrams. Documentation by Sally (1964), Berling (1970), Lillesand and Clapp (1971), and Hardegen (1974) amply confirm this. For an initial system, indications are that a stereometric system would not be receptive within the Iowa police community primarily because of the large expense involved in procuring the cameras and plotters. It is also felt that these systems would necessitate reorganization, training, and policy revision requirements that would be unacceptable to administration officials. For these reasons, stereometric systems do not seem appropriate for use within the state of Iowa at this time.

Perspective grid photography is seen as the best alternative for initial application of a photographic system. Used with nonmetric cameras and a grid template, this application offers beginning simplicity with potential for technological advancement. It is felt that, once the advantages of using a simple system become apparent, the demand for advancement of technology and degree of usage will steadily increase.

2. Organization and administration

This author suggests that the pilot project be organized such that there is a separation between those responsible for data acquisition and those responsible for photogrammetric analysis. The data acquisition and custody of the photographs would be administered by the law enforcement agency and the photogrammetric analysis administered by the photogrammetry section of the civil engineering department at Iowa State University.

This separation would allow for initial comparison of the photographic methods and conventional methods without overly burdening the traffic investigator. He would still prepare his accident diagrams as per current procedure, but in addition would photograph the accident. Once the analysis of the photographs is completed by the photogrammetry section at Iowa State University, the diagrams would be returned to the law enforcement agency for comparison.

The custody of the negatives would have to be the responsibility of the police agency. If there is any doubt as to the validity of the photographs used in the analysis and diagram preparation stage, the negatives could be produced and the photographs substantiated.

The separation of responsibilities would seem to be an especially ideal situation in the early stages of development. The involvement by the law enforcement agency would be limited to establishing guidelines and policies for routinely photographing the accident scene and maintaining custodial responsibility of the negatives. The photogrammetry section would be able to provide recommendations and advice for improving the field procedure of data acquisition.

3. Training

Under this conception for establishing a pilot project, the training requirements are substantially minimized. The basic training requirement would involve the operation of a camera and the procedure for obtaining the photographic evidence. The training departments internal to the law enforcement agencies could conduct this training. Advice and topical information concerning photogrammetric principles relevant to data acquisition could be obtained from the faculty at Iowa State University.

B. Contributing Considerations

1. Funding

The Minnesota State Patrol received federal funding for their pilot project, and was given a five year renewal of those funds, under section 402c of Public Law 89-564 which is administered by the Department of Public Safety. The Governor's representative for federal funding would be able to offer advice on the details of submitting a joint proposal for establishing a procedure as previously discussed. If funds were made available, this would assure emphasis was given to the technical capabilities of the system as opposed to cost considerations.

2. Diagram improvement

There would be no reason to suggest the photographic system as outlined if it was not felt that it would offer improvement to current procedures. Figs. 1 and 2 are referred to as examples of current procedure. These are diagrams extracted from actual accident reports. Upon examination of either diagram, there are certain questions that can be raised which may be relevant since they concern the scene at the time of the accident. In Fig. 1, there are two references to distances along the path taken by the cars, a reference to road width, and nothing more. Several misconceptions are given by this diagram. The curve of the road must be exaggerated since it is only 24 feet wide, but the distance traveled before going off the road was 103 feet. If the car struck the first building on the side, how did it manage to push it perpendicular to the direction of force? What damage was done to the buildings and what type of buildings were they?

Fig. 2 was obviously a better prepared diagram. It is actually a supplementary diagram extracted from an actual accident report. Upon examination, the following is noted. The diagram indicates that points A and C are approximately the same distance from the reference base line. However, the table of data indicates point C was actually 7 feet west of point A. The reference distance for point D from the RP does not make sense as written in the table.

In both cases, there are questions which could easily be answered if a photographic process would have been applied. It must be assumed that these diagrams were prepared for someone's benefit and that they would be receptive to complete and accurate portrayal of the accident scene. A photographic process would allow the individual desiring this information to relook at the photographs and answer questions or discrepencies as they arise.

3. Photographic efficiency

Crawford (1978) states that the perspective grid system as used in Minnesota saves time during at-scene investigations. This supports the contention that, as the investigator becomes confident in his camera work, he will become less reliant upon conventional methods and the system as proposed will also represent a savings in investigation time. This increased efficiency is viewed as an obvious advantage in terms of the daily activities of the police investigator.

Further efficiency is obtained by the photographic process since the investigator is not required to make any value judgment concerning what type of diagram will be needed. The photogrammetric analysis can be applied on an as needed basis. As long as the scene was photographed, it can be diagrammed at any time, at any scale, and to any degree of completeness.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

Based on an analysis of the available literature, interviews with concerned personnel, and the results of experimentation, the following conclusions concerning a photographic system applied to traffic accident investigation have been reached.

1. A simple system for data acquisition and photogrammetric analysis consisting of nonmetric cameras and perspective grid theory can meet or exceed the quality of survey diagrams prepared by conventional methods.
   a. This simple system is capable of mensuration in all three dimensional planes and is capable of stereoscopic representation.
   b. By separating the functions of data acquisition and data reduction, the simplicity of this system is magnified, since data acquisition becomes an operation requiring little more than the knowledge necessary to operate a camera and leaves data reduction to the photogrammetrists.
   c. This simple system is technically and economically feasible for implementation within the State of Iowa, and is especially advantageous in its potential for ease of expansion.
2. Use of a simple system is advantageous to the use of stereometric systems for the initial stages of a photogrammetric application.
   a. Stereometric systems currently represent a degree of sophistication beyond the needs and capabilities of the accident

investigation communities.

b. The use of a simple system affords easier understanding of photogrammetric principles, which in turn, helps alleviate misconceptions and misunderstandings.

B. Recommendations

This thesis has been the product of an initial study and investigation concerning use of close range photogrammetry applied to traffic accident investigation. The following recommendations appear feasible and worthy of merit, based on this initial study. 1) A comprehensive pilot project, closely resembling the conception as given, should be established within the State of Iowa. 2) The Iowa State Patrol should be given priority as the participating law enforcement agency, as they have expressed the greatest amount of interest in this general subject area.

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