THE DEVELOPMENT OF A PROCEDURAL ANALYSIS FOR QUANTIFYING SAFETY HAZARDS ENCOUNTERED IN NON-REPETITIVE, EXTENDED TIME WORK CYCLES

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PREFACE

It has been said "All the books ever written concern knowledge that we have. These would make but a small part of the true library of total knowledge. The books yet to be written cover an infinite amount of knowledge."

It is my belief that the present knowledge of safety is very small compared to the amount yet to be uncovered. This dissertation attempts to uncover a bit more of that hidden knowledge. By pushing the horizons of knowledge in industrial safety, I feel that all areas of safety -- in the home, on the road, at play -- will be served.

The members of the committee for my work are acknowledged with sincere thanks: Dr. Earl J. Ferguson, who gave detailed direction, encouragement, and aid whenever needed; Doctors James E. Shamblin and Paul E. Torgersen, who provided the necessary critique of certain areas to help improve the study; Dr. Rudolph W. Trenton, who gave constant encouragement and a progmatic view, and Dr. Luther G. Tweeten, who gave his interest and encouragement at all times.

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Finally I must recognize: my father, now deceased, for his ever-present and cherished influence; my mother, whose continual encouragement has ever been an aid over obstacles; and my wife, Jeanette, whose willigness to sacrifice her time, effort, and our financial well-being was

and will continue to be inspirational. This dissertation is respectfully dedicated to all these people who have had such an accumulating influence on this work.

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CHAPTER I

INTRODUCTION

Safe practices in all areas of daily living have received an increasing amount of publicity since the middle-1940's (1, p. 2). Complex appliances and equipment using power sources, which are potentially lethal, become necessities both at home and on the job. Because a man's livelihood depnds on his earning capacity, and thereby his health, safety on the job becomes of vital concern to the individual personally and collectively as a member of the group. Because people from all walks of life become closely associated in an industry, their interrelationships can affect a large population. Industrial safety is in one sense a cornerstone to a man's livelihood and safe behavior an important part of the individual's relationship to others. This study encompasses these worker interrelationships as manifested in the occurrence of safety hazards on the job.

Purpose

The purpose of this study is to establish a research procedure whereby industrial safety hazards may be analyzed and their significance applied on the basis of photographic studies. The research is fundamentally experimental as there are no statistical data concerning safety hazard frequency in industry except in the most general terms (21, pp. 21-30). Traditional research in the field of industrial safety has been devoted to accidents with injury and has concentrated on analysis of historical data. An apparent necessity is the development of research procedures to determine safety hazards prior to accident occurrence and, thereby, concentrate on the elimination of danger to the human beings involved. The elimination of danger is a positive approach to accident prevention. The problem was presented to the author during a research for thesis subject material by the staff of the School of Industrial Engineering and Management at Oklahoma State University in the Spring of 1965.

Safety is an intangible but, if practiced diligently, can result in substantial cost savings in the areas of maintenance, absenteeism, insurability, lost production, and production unit cost (2, p. 110). These factors, plus other considerations, will show cost reductions when equated with improved safety records. In addition, there are intangible areas such as better personnel morale, higher personal efficiency, and reduced supervisory time -- savings which are immeasurable in terms of actual dollar figures (12, p. [illegible]).

The approach to improving a safety record must be on an organized basis as must any program for cost reduction within industrial organizations. The goal of any safety program must have at its nucleus the welfare of the human beings involved in the day-to-day operations; and a safety analysis, therefore, must center upon human acts or their results.

> Safety in the broad sense of the term is wholeness of life; in the narrow sense, wholeness of physical life, implying the avoidance of accidents. ... the knowledge, skills, and attitudes that make for safety. Accidents do not just happen. They are caused (3, p. 112).

Much of the research on safety has concentrated on the repetitive work cycle where, the National Safety Council (4, p. 128) states, "Habits and carlessness causing unsafe acts are the major causes of accidents." In this study, the research has concentrated on the non-repetitive work cycle in an attempt to uncover areas of potential safety hazards not immediately apparent in a static evaluation or in an analysis of historical accident data.

Most present day accident analyses depend on historical reports to highlight the hazardous situation (5, p. 113). The individual accident is simulated, reenacted, and disassembled into the component elements so that an analysis can state why the accident occurred. This is an after-the-fact study and is not a positive means to prevent accidents or highlight hazards of a similar nature unless the same general environment is present each time. An accident does not occur each time a hazard occurs. However, the number of situations where accident potential is present must, logically, be some multiple of the accident figure.

The study attempts to document, by means of a film record, the potential accidents that occur in common materials handling situations and relate them to the over-all safety program as envisaged by the personnel responsible for safety.

Specific Objectives

The specific objectives of this study are as follows:

1. To demonstrate the usefulness of the memo-activity camera as an industrial safety tool to be used in implementing and evaluating safety programs.
2. To establish a procedure in categorizing unsafe acts.
3. To calculate the frequency of unsafe acts in an area in a particular time period.

4. To delineate actions which will reduce accident frequency and/or severity.

Scope

The data were gathered in three industrial locations in Oklahoma City, Oklahoma: the Federal Aeronautics Agency, Aeronautical Center, Storage Management; the Tinker Air Force Base Engine Maintenance Branch; and the Western Electric Company, Inc., Oklahoma City Works. These three work areas were selected on the basis of their alleged 'heavy' use of fork lift truck equipment and the similarity in use of the equipment at the three areas in transporting materiel to the using agency within the confines of a covered area. Data are not available as to how frequent the fork lift vehicles are involved in accidents. Records of the required detail are not kept by industry; however, the accident frequency over-all is high enough (see Table IX) to warrant study.

The study encompasses the evaluation of a means of research on safety hazards using camera equipment in time lapse photography. The areas of interest covered are: camera mounting to vehicular equipment, data gathering, film analysis and evaluation, and a critique as to the use of the research procedure in safety analysis for industrial application. The limitations to the study are based on the inherent limitations of the tools and equipment used plus the lack of concrete starting points in the areas of safety due to the nebulousness of the subject matter. Safety as a subject for finite study has not been explored industrially with the quantitative analytical approach as used in the tangible profit-making areas; thus, supporting and background data are difficult to obtain and place in a workable format (6, p. 2).

Methodology

This study begins with a survey of the evolution of safety in industry and the attempts to reduce accidents. Then by means of an empirical experiment, a research method is proposed to focus attention on safety hazards and, thereby, to aid in preventing accidents.

Procedure

A camera (see Chapter III) was mounted on fork lift trucks used in non-repetitive work cycles. The trucks then proceeded on normal duties throughout the work day. The camera operated in two ways; i.e., continuously and in random hourly increments over two separate time periods. Film was exposed on a time lapse basis of one frame every twelve seconds. In addition, the camera was mounted stationary over a high density traffic aisle and film was exposed at a slightly faster rate. This was done to evaluate potential accident frequency along aisles with high density pedestrian and vehicular traffic at one location. This then allows an evaluation from two aspects -- the potential accident situations encountered by a moving vehicle and the same type situations encountered at a single location.

The writing approach begins with a survey of safety in industry and the background that led to the present-day attitudes. The costs associated with safety, or the lack of it, and the benefits to be derived from good safety are considered. The study continues with a detailed relating of the experiment and the data collection on film. The films are discussed and analyzed by means of statistical techniques. A qualitative discussion is presented based on the frequency of pedestrian or vehicular hazard occurrence and how this knowledge can lead to more effective safety programs. Finally, the usefulness of the research is discussed in relation to present-day industrial needs. On the basis of the lack of literature and/or research on safety in the particular area, this study is independent (2, p. 112).

This first chapter covers the general plan of writing the thesis: the purpose of the writing, the specific objectives, the scope of the paper, the methods used in gathering data and approach to the writing, and the significance of the study.

The second chapter contains background and supporting information on safety and a discussion of the need for greater safety hazard awareness in industry.

The third chapter describes in detail the equipment used during the experiment.

The fourth chapter details the quantitative analysis, the concept of a control chart, and the means of categorizing and quantifying the hazards photographed.

The fifth chapter discusses the application of the results quantified in chapter four.

The final chapter gives the summary, conclusions, and the suggested areas for further study.

Sources

A literature research of the field of safety was made and correspondence with the leading companies in the field was initiated to gather data on the particular area of research and to determine what had already been done or what background was available. The returns from the correspondence with Mine Safety Appliance Company, Hyster Corporation, and the Maynard Research Council, Inc., indicated that the research in this area was nil. Information was obtained from periodicals on safety, a survey of the available texts covering the subject, the U. S. Government periodicals concerning accidents, several industrial and government employees interviewed, and the actual research by the author. The Bibliography lists the available literature used and, as can be noted, the literature is lacking. Much data exists on accident frequencies and the associated costs, but there is effectively no reference to the hazard -- its frequency or an analysis of it.

Safety is a popular subject, but the particular means of analysis used by the author seems not to have been used elsewhere (7, p. 20). Time lapse photography has not been fully exploited by industry although it is often used for 'effect' photography. There are few indications that this technique has been used in the field of Safety Engineering. Isolated incidents of experimentation in public transportation using time lapse photography are inconclusive.

Definition of Terms

There are various terms used by the author throughout this study which require standardizing and clarification for the reader. The following are definitions of the terms used:

Safety - The condition of being secure from undergoing or causing loss or injury.

Accident - Any unplanned, unexpected occurrence that interferes with or interrupts the orderly progress of events. In industry, the word 'events' becomes 'work'. An accident may involve men, materials, machinery and tools, equipment, and time or any combination of these elements.

Incident - A subordinate category of 'Accident' where no injury or substantial monetary loss is involved.

Fork Lift or Fork Truck - A truck chassis carrying a channel mast on which is mounted an adjustable cantilevered fork which can be hydraulically or mechanically actuated in the lifting of materiel. It is designed to lift, support, and carry loads of materiel.

Hazard - A situation encompassing a direct source of imment danger if personnel or equipment do not alter their apparent actions. The situation may have accident or incident potential, the cause for which can be traced to the actions of one or more human beings. These actions may be intentional or unintentional, the commission or omission of an act.

Time Lapse or Memo-Motion Photography - Motion picture photography with a time interval between film frames such that when projected a slow motion appears rapidly speeded up.

Significance of the Study

Mr. H. M. Somers (4, p. 5) stated in 1954 in his book, Workmen's Compensation:

> ... in the course of an average workday (in the period 1942 through 1952) ... sixty-two workers will have been killed, 350 will have suffered some permanent impairment, and 7600 will have suffered injuries which will keep them from work on an average of eighteen work days. In other words, one American worker is killed or maimed every three minutes and another is injured every eleven seconds.

Based on the Bureau of Labor publication, Monthly Labor Review, in the years 1962, 1963, and 1964, the statistics quoted above are reduced by a mere two to three per cent (8). The potential reduction in human suffering by increased emphasis on safe conduct appears obvious. This potential, plus the associated costs of accidents in all areas, monetary and humanitarian, certainly justify research in the area of safety and the means to promote and evaluate the efforts expended.

The repetitive work cycle has received a great deal of attention from the people responsible for safety, chiefly due to the number of accidents in repetitive work and the feasibility in pinpointing responsibility for the accidents. In non-repetitive work cycles, however, the variety of safety hazards is much wider in scope and involves many more people. The normal means of safety analysis in non-repetitive work cycles is based on a subjective analysis of past accidents and, thereby, the establishment of procedures to prevent similar type accidents in the future.

No one, however, can mentally forsee all the potential accidents and the safety hazards that are encountered in daily operations. The use of time lapse moving pictures taken from an operational vehicle is a means to analyzing the hazards encountered. There is still an element of subjectivity in the analysis, but there is photographic evidence to justify an interpretation. These films are direct, reusable evidence of safety hazards occurring locally and can be used by management to establish the areas or personnel which are most susceptible to hazardous conditions. The establishment of this susceptibility will then give positive guidance for the emphasis of safety programs and give specific purpose to the efforts of personnel responsible for safety. This provides safety personnel areas of positive action; whereas, in the past, they normally awaited the accident and then acted to prevent the same type of accident recurring.

There may be a relationship between safety hazard frequency and accident frequency as alluded to by Heinrich in his theories on the subject concerning one man (9, p. 26); however, this relationship has not been established and any conclusions are not possible by means of this study. The relationship possibilities are discussed in Chapter IV.

CHAPTER II

Industrial safety

PROBLEM FOUNDATION

Industrial safety is a nebulous thing in its history. It is vitally concerned with people and the vagaries of the human being in the industrial world; yet its evolution has been eclipsed until recent years by the demands of production improvements. The procedures and conclusions in the field of safety, as presently applied, are based on the evolved practices of industry and have little basis in rational continuous thought.

Background

When the Industrial Revolution took place before the turn of the Century, habits of the individual and the group in the area of safe practices were difficult to inculcate with the necessary now equipment![1] (10, p. 20). Leading authorities in safety education state:

> Public consciousness of the need for accident control was first awakened by the terrible working conditions prevailing in the industrial centers of Europe. ... The revolutionary changes in ... manufacturing processes ... brought men and women flocking from the farms to the cities. ... Many who had formerly plied their trades and skills in their homes or in small shops now worked in factories under conditions so crowded and hazardous that accidents ... took a tremendous toll (5, p. 8).

As time passed, management, reluctantly it seemed at times, began to realize that loss of experienced men and valuable equipment due to accidents made the pragmatic approach to safe working conditions and attitudes not merely humanitarian but also profitable. (10, p. 28), (5, p. 16). The advent of Workmen's Compensation laws did a great deal to promote safer procedures, techniques, and working conditions. In the book, Accidents and Their Prevention, by H. M. Vernon (10, p. 38), the author states:

> ... the pressure of reduced profits due to the injury awards based on Workmen's Compensation laws and public opinion were effective instruments in forcing industry to design and process with safety in mind.

Attitudes

Safety has long been looked upon as the 'stepchild to common sense' -- whatever 'common sense' is in a strict definition (9, p. 96). The acceptance of accidents as acts-of-God to test the character of the victim, as in the Biblical story of Job and his persecution by the Devil, or as retribution for past sins, was long a superstition held even by the intellectual elite. This superstition is still quite prevalent a misconception in these days of an advancing society in the recent years of the Twentieth Century. Safety was thought to be an individual thing which was almost personal in nature. Safety programs were instituted on this idea of common sense and there was almost no means of evaluating a program's effectiveness except on the basis of a subjective judgment and the accident trend over long time periods. In 1941, Mr. Vernon Schaefer (10, p. 156) stated that up to that time superstition has been a 'formidable opponent' in safety programs and that his only means to evaluate his own efforts was his experience of some three decades in the industries as a Safety Man.

As the machines became larger and more complex, the interrelationship of workers was realigned so that one worker's unsafe activities due to carelessness or lack of common sense effected his co-workers. Management and the Government of the United States became interested in safe practices and their encouraged or enforced use by the working force as minimum acceptable standard behavior. Employer Liability Laws were the first attempt in the latter part of the Nineteenth Century. Workmen's Compensation laws, initiated by the individual State here in the United States, began effectively in New Jersey in 1911 (11, p. 18). The National Safety Council was formally begun in 1915 with a group of manufacturers and insurance companies (12, p. 11). Since then, the American Society of Safety Engineers and the President's Industrial Safety Conference have, among others, sprung up to become active in promoting 'accident free industry'.

The promotion of safe practices by management or any authority, however, was often construed as the restriction of individuals and their behavior[2] (13, p. 192). The preventing of the local clown from playing practical jokes on fellow workers was considered by the employees as management becoming overly restrictive and 'bossy'. When an injury occurred because of the clown's actions, it was only an accident or an act of God. The victim was oftentimes merely an object of pity while the clown suffered little or no chastisement.

The Case Study and Accident Investigation

Case study examinations of safety and accident records changed the attitude of that portion of management responsible for safety[3] (14, p. 185). The case studies indicated methods in materials handling, machine operation, use of hand tools, minimum standards of behavior on the job, and all of the areas of production wherein safer activity would make production more efficient and reduce the accident rate. The case study is, however, an expensive and time consuming method of analysis. The causal factors for individual accidents are oftentimes individual in themselves and difficult to categorize for general application. A subjective element is always present when individuals examine historical data written by other human beings. The interpretation of secondhand accounts leads to possible serious error. The case study method, therefore, has serious disadvantages for use as a continuing method for improving present day concepts of what safety is and how to encourage and enforce it.

The medical profession has developed a great store of data in the epidemiological field which has assisted the Safety Engineer[4] ~~(18, pp. 196-258)~~. Unfortunately, the data do not lead to any definitive 'cause-effect' conclusions because of a lack of adequate and sufficient data on the particular individuals involved in the accidents. The psychiatric field has also done a great deal in discovering the defects in human character traits which affect the individual's attitudes toward safety. But, the data are again inconclusive and, therefore, do not lend to general application.

The unsafe act is the first local step in any accident and is the strategic factor upon which the entire scope of industry can operate. The medical, psychiatric, and legal aspects of the accident must be left to the professionals in their particular field where they can develop background for the accident or compensation criteria. Industry is professional in its own field and can, thus, operate most efficiently where its efforts show the greatest return. The case study has been of value, but a more quantitative generally applicable method of analysis must be developed which is relatively inexpensive and can be implemented without the requirement for highly technical skills.

Accidents: Cost and Severity

Although safety programs in industry have significantly reduced accidents in comparison with highway and home environments, there is still a large area for improvement (5, p. 109). The dollar cost alone amounts to over five billion dollars for each of the years 1962, 1963, and 1964 including compensation, lost production time, and equipment damage losses (15, p. 10).

Medical expenses in 1964 amounted to six hundred million dollars; an increase over 1963 of fifty million dollars (15, p. 10). This amount does not include additional costs of uncompensated wage losses. Other costs in terms of human suffering and lost future potential of the injured worker's capability are immeasurable in terms of money.

The highway fatality rate is approximately one for every thirty-five reported accidents 5 (15, p. 6). The industrial accident fatality rate is one for every one hundred accidents with the home fatality rate falling between these two extremes (9, p. 8). From previous studies by H. W. Heinrich (9, p. 26) for his book, Industrial Accident Prevention, injury and non-injury accident rates involving the same person occur according to an exponential function of 1:29; 300, i.e., major injury to minor injury to non-injury accidents. These data concern only fatalities or accidents involving the same person. No data are available on the hazardous situations occurring in a time period where many people are involved and cross relationships are a geometric progression of the number of persons.

Accidents and Compensation

A less idealistic reason for industry to be concerned about safety is in the urging on the part of the courts through Workmen's Compensation awards. The financial awards by the individual state judiciary to the injured parties have shown a marked rise since 1945. The increasingly liberal interpretation and legislative modifications of the State laws take the view that industry and the state should take an active responsibility in the interest of the accident victim (11, p. 210). 6

In 1961, this cost amounted to one and three-tenths billion dollars and was estimated to be principally caused by unsafe acts on the part of employees or unsafe conditions allowed to exist by both employees and management (15, p. 14). This is a direct effect on the profit and loss account and, as indicated by the above figures, can be a signficiant amount even when the accident frequency is as it has been held to in the last several years. The spending of only relatively few dollars on safety can effect substantial savings. As an example, the installation of inexpensive 'dead-man' controls or two handed switches has saved countless limbs in the use of machine tools in industry (16, p. 18). 7

Other Benefits From Safety

When an employee is reassured by machine safety devices, clean and well lighted work areas, and specific personnel who show an interest in safety, the employee turns out better and faster work. When interest in the individual is shown by the company, the individual will return this interest through his more efficient attitude. This returned interest will be indicated in a reduction of unit costs and unit man-hours required 8 (17, pp. 1-10). Other costs which can be reduced by safety emphasis are in the areas of maintenance of equipment and capital assets, medical expenses, administrative burdens in clerical costs to process the paperwork initiated by accidents, and, of course, the compensation for the victim.

Indirectly, there is also a large area of benefits from successful safety programs. Personnel morale, the individual employee attitude towards the company and his job, the reduction in required supervisory time devoted to investigating the lack of safety and accidents, and a very nebulous thing -- the benefits derived from good public relations and the public's opinion of the company -- are all indirect benefits which can be derived from an effective safety program.

Accident Situation Sequence Dependency

Accident frequency is reduced to a minimum if unsafe acts, equipment, and situations are ferreted out and eliminated. The accident sequence, as defined by Heinrich (5) begins with the social environment of the worker and progresses through the worker's character flaws, unsafe act, the accident, and the injury itself. As Heinrich stresses, the removal of any one of these steps prevents the accident and injury just as the removal of one domino in a group of closely aligned standing dominoes will make overturning of preceding dominoes in the group ineffective on the later ones. The interrelationship of the five steps is very important to this study or any study of safety.

There is not a great deal that industry can manipulate as far as the social environment of the worker's ancestry or family today is concerned. Through motivation and education, industry can do some limited work in manipulating the worker to improve or modify his attitude and character traits.[8] ~~(17, pp. 435-470)~~. In this area, there is danger, however, where the psychology of man must be considered. The effect of manipulation may very well show undesirable traits being manifested in other areas than the one being concentrated upon. This area of manipulation of man's character is, therefore, left in the main to the psychiatric field of medicine.

Industry can concentrate its efforts on the unsafe act as the strategic factor to prevent accidents. This area is fairly well defined and industry is well within its jurisdiction in attempting to modify the worker's attitude and behavior within the limits described.

Because industry is capable of disciplining individuals and enforcing procedures through supervisory functions, it is in a unique position for safety effectiveness evaluation. Highway and home safety programs depend to a large extent on the goodwill and willingness of the individual for proper implementation and recording of results in an attempt at evaluation. Industry is in a better position to require cooperation, and impose penalties when the cooperation is not forthcoming.

~~Management and Safety~~

The larger companies with large capital investments are the principal leaders in safety emphasis. The Government agencies are closely following these large industries and the small companies are rather poor in their safety records by comparison.[5] ~~(15, p. 5)~~. The reasons for this are probably many and varied with exceptions to both extremes and individual extenuating circumstances making the delineation rather blurred. However, in general, the larger companies have a sufficiently large number of employees that 'fringe' services become a necessity and the cost considerations involved establish an emphasis on safe conduct. Larger companies are also much more susceptible to the individual's suit in a court of law and substantial awards for allowing unsafe conditions are quite common today. Economic considerations are probably the greatest impetus to safety and its enforcement by management.

The small company is the struggling one, usually close to the local people and employees in an emotional way. As such, the small company is not as vulnerable to accident compensation awards as the larger company. As a 'family' or team member, there is an intimate closeness and, in most cases, the employees assemble to care for their own with the assistance of their management. The safety programs are less formal as is the general attitude of smaller organizations. This is unfortunate as the small company suffers a disproportinately high rate of accidents (4, p. 210). Whether or not the high accident rate is due to informality is open to argument.

Examples of organizations with excellent safety records are E. I. duPont deNemours Company, Goodrich Tire and Rubber Company, and United States Steel Corporation (2, p. 111). In its latest report to stockholders in July 1965, U. S. Steel claims to have an accident record one-third that of the steel industry and the steel industry has an accident record one-seventh that of the national average for all industry (19). Depending on the exact limits of the definitions of accident, the means of calculating the data, and other parameters, this statement would tend to make U. S. Steel a leader in the practice of good safety.

There are several companies involved in the Safety Engineering field but the accepted leader is in Pittsburgh, Pennsylvania. The Mine Safety

Appliance Company began its business in the area of coal mine safety but quickly expanded into the general industry with emphasis on personal protective devices.

Safety and Equipment Maintenance

There are few statistical references for the amount of money spent on repair or replacement of equipment due to accidents or incidents. Normally, accident statistics reflect only injury data (8). Maintenance and repair accounting accumulate material repairs in a general maintenance category which does not delineate the cause for the repair. There is some justification for this approach in that the accepted definition of 'accident' by the American Standards Association specifically limits accidents to areas of personal injury (20, p. 2).

The attitude is understandable, however, as statements by management concerning dollar costs in equipment in conjunction with safety emphasis could lead to misunderstandings as to the company's standards on human value. The noting of costs in the areas of equipment repair and human recovery or medical expenses must then be handled with tact. The amount of this cost can be estimated and it would seem that, based on the cost estimates which are high, its significance would receive greater emphasis in safety program managing.

Area of Research

The research in the area of industrial safety has, in general, taken the more rigidly confined area of personal equipment. The establishment of techniques and procedures for safety policy in the use of hand tools, machines, and other equipment has received close scrutiny using the case study method on available data. The use of safety glasses, protective shoes and hats, 'dead-man' switches, and many other points are examples of the results of this type of safety research.

There is, however, a large area of potential industrial accidents that has been largely overlooked. Because of the possible overlap with data developed in the repetitive work cycle studies, or the large scope of the non-repetitive work area, safety analysis for this type work has been too often limited to generalities. This paper is a step in the direction of establishing research procedures for the analysis of long time non-repetitive work cycles. There is great difficulty in quantifying the hazards encountered without reaching an unusable number of itemized categories very quickly. However, the problem is not insurmountable and, as discussed in this ~~chapter~~ paper, can be the basis of considerable savings.

CHAPTER III

DATA GATHERING

This chapter gives detailed information on the environment encountered in the data gathering. The equipment used, an analysis of the industrial sites chosen for the research, the establishment of camera lense and light relationships, and the problems encountered in the actual gathering of data are covered in detail.

Camera Equipment

The major equipment used in the development of data for this paper was a camera system developed by Professor H. G. Thuesen at Oklahoma State University under a National Science Foundation Grant awarded in 1961 (24). The camera is rather bulky being 8.5 inches by 7.0 inches by 12.0 inches and weighs eighteen pounds (see Figure 1). The 'memo-activity camera' is an electrically operated sequence camera taking pictures of standard size on 16 mm motion picture film with absolute time recorded on each frame at the lower left corner. The timer is enclosed in the camera with its own power source. The timer dial shown on each frame indicates .01 minutes, minutes, and hours.

The camera exposes film at preselected constant intervals of .005, .04, 0.2, 1.0, and 2.0 minutes with the additional option of a random interval mechanism. The 0.2 interval was used for the data gathering in

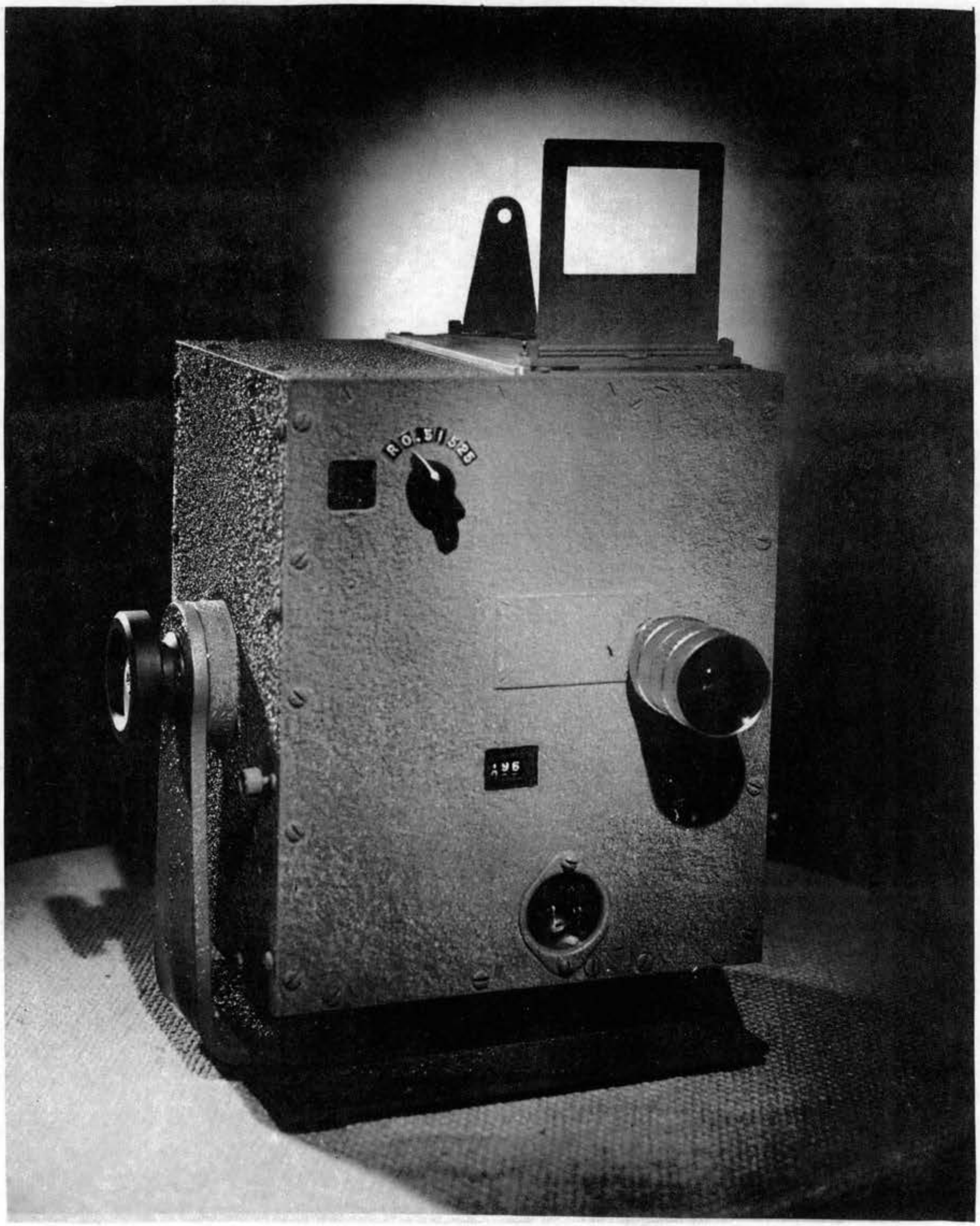


Figure 1. Memo-Activity Camera

this research. This gave one picture every twelve seconds and, using one hundred foot rolls, a time span of some thirteen hours per roll. Each frame is exposed for one-thirtieth of a second and is standard for all intervals in the timing mechanism.

A ten millimeter focal length lense was selected, after a pilot study using several lenses, because of the wide variance of activities in the area of the camera requiring coverage in the research. The lense opening used was also varied in the pilot study and based on the light extremes encountered, a 4.0 setting was used for all data gathering.

The electrical source for the camera is either 110 volt AC, 60 cycle, power at a stationary location from the commercial source provided in the building, or, in a mobile situation, a motor generator system is provided. A Carter Motor Company Rotary Converter, B-1060-CB, weighing 30 pounds and sized four inches by seven inches by ten inches long, is used to convert a 12 volt DC input to 110 volt AC, 60 cycle, power for the camera. A twelve volt DC, wet cell storage battery provides the necessary DC power to the converter.

Vehicle Equipment

The camera equipment was mounted on several vehicles to record data. A four wheeled tug was first considered due to the type of work involved. A tug normally pulls equipment and the majority of its traveling is in the forward direction relative to the driver's position. A problem arose, however, in that the fenders, which were to serve as the base for the camera equipment, are too exposed to obstacles and personnel. Also, the field of view is highly restricted due to the camera position being too low for effective area coverage. This type vehicle was eliminated for the above reasons.

Fork lifts used in areas where there is overhead activity are usually equipped with what is termed the "headache rack" or a metal protection device to protect the driver from falling objects. As the rack is above the driver's head, the elevated position provides excellent forward and peripheral views of the vehicle environment for camera equipment. The mast for elevating loads offers some view restriction for the camera but also affords some protection against possible contact with overhead objects. A secondary advantage to the fork lift mast is that elevated fork activity is viewed and can, therefore, be evaluated as to operator safe practices in conjunction with environmental safety. The decision to use fork lifts as the research vehicle was reached based on the inherent advantages in this type of equipment (see Figure 2).

The fork lift used at two of the industrial locations had protective devices mounted to the fork lift body; whereas, the third vehicle used a rack cantilevered off the mast of the truck. This latter camera mounting platform gave no elevation problem as normal travel for the mast pitch is limited to a four to six degree movement. However, the cantilever construction did cause some vibration which was indicated by several frames of film being blurred.

Industrial Sites

The three industrial sites chosen are all located in Oklahoma City, Oklahoma. Each of the three gave access to a particular truck usage in that one used the fork lift strictly in a receiving and storage situation where truck travel is mainly restricted to the storage area. The second site involved the travel of the fork lift servicing a production line area with material from storage. The third site used the fork lift for

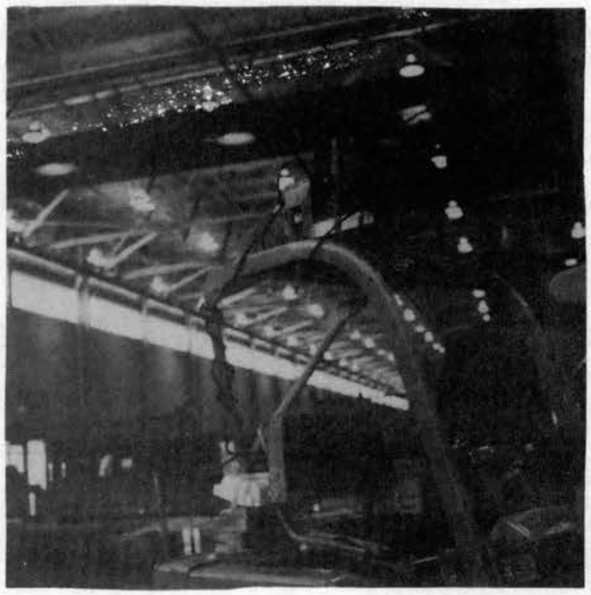


Figure 2. Camera Equipment
Mounted on
Fork Truck

interdepartmental transfer of materials within the production area. It was felt that this gives an adequate coverage of basic uses for the fork lift within industry. Two of the sites are government installations and the third produces a producer product for use in a further step in consumer goods production.

In the Oklahoma City area, there is a sufficient use of the industrial truck ranging from two or three large government and private industry facilities to the wholesale grocery situation. The cooperation and assistance by the management of all the concerns contacted were excellent and lends credence to earlier remarks by the author concerning growing management concern in the field of safety.

The sites chosen for the research are among the elite in the ratings by the National Safety Council as to best safety records (7). Industries in the communications and aircraft fields are well known for their continued emphasis on safety and, thereby, their excellent safety records. The National Safety Council rates both of these industries at the top of their list in lowest injury and lowest injury severity rates. This could well be a disadvantage as the accident rate in other industries is higher and film analysis might well show substantially more frequent hazard occurrence. However, the locations were convenient and the personal contacts available for obtaining the necessary approvals to perform the research.

In obtaining approvals to enter the plants and take photographs, the immediate attitude of the higher echelon personnel was enthusiasm. At the next lower echelon, extreme conservatism was met; and, on the lowest echelon, where the work was to be performed, there was an almost complete acceptance of the idea. In general, at the first two levels, these attitudes were likely due to the interest in safety and the cognizance of the cost data available concerning the individual company's safety record. At the lower level, any program which tends to add novelty or new conversation to the daily work is welcomed and this was probably the basis for the enthusiasm.

The selection of the sites used was, therefore, somewhat arbitrary as there was no data to use as background to prove the method. As it turns out, because the firms used are among the better ones, by National Safety Council evaluation, the justification in favor of the research procedure is increased when considering other industries. A research method of value where few accidents occur will, by intuition, be of greater assistance where accident frequency is higher.

Some alternative sites for evaluating the procedure were a department store or mail order store warehouse, a wholesale grocery outlet, and a commercial utility power company. These were eliminated for several reasons - the basic one being lack of personal contacts at the time.

Film and Associated Equipment

The film used in the research was Kodak, Tri-X, TX R449, Reversal Movie Film for 16 mm roll cameras. Five rolls of film were used with each roll having one hundred feet of film.

One roll of film was exposed as a pilot study to determine the feasibility of the mounting, the selection of lense and lense opening, and the extent of inconvenience to the vehicle driver. This first roll was then developed, analyzed, and evaluated as to whether or not to continue the research. Due to the clarity and coverage of the film, plus the clearly defined unsafe acts noted in this pilot film, the research was continued.

During the course of this pilot study, several lenses and lense openings were used. Ten millimeter, fifteen millimeter, and twenty-five millimeter lenses were used and openings of 2.4, 4.0, 5.6 and 8.0 were tried on the two smaller focal length lenses; i.e., ten millimeter and fifteen millimeter lenses. It was determined that the twenty-five millimeter lense was not feasible as the peripheral view was restricted and the advantages of clarity at a distance using the lense were cancelled by lack of contrast at the lense depth limit.

Lighting and Vibration Problems

The ten millimeter lense was finally selected using a 4.0 lense opening. This gave a good photograph in over 90 per cent of the film. The environmental view with this lense is good and no problems due to lack of clarity were encountered. Because the vehicular equipment was required to operate several times near exits where strong sunlight was admitted, some of the photographs are over exposed and look washed out. However, this did not materially affect the safety hazard analysis. At the other extreme, when the vehicle entered storage areas where lighting is poor and storage is high, some photographs are dark and images are not as clear as is perhaps desirable. Here, there is also no significant effect on the hazard analysis.

One aspect of the filming procedure which did show up on the photographs was periodic blurring of the film. In one case, the rough surface, over which the vehicle was traveling, caused blurring. In the second case, where the overhead protection for the driver was cantilevered off the mast, a definite increase in blurred photographs appeared. This would appear to be normal based on the weights and moments involved and the small amounts of movement which are magnified at the end of the lever. In the third case, there was no significant blurring of the photographs except in cases where the vehicle was entering raised areas and encountered ramps of some sort. The blurring here was not sufficient to destroy the images in the immediate area photographed.

Miscellaneous Problems

Probably the most annoying of problems was the time element. The author would plan and negotiate for a meeting of necessary personnel to clear the project; or a time would be designated for the mounting of the equipment. These two items took a seemingly excessive amount of time and seldom was the plan met within the limits established. This was, of course, to be expected but it can be annoying.

A second minor problem was the continuing efforts of local supervisory personnel to expand the scope of the project. Based on the individual's background and experience, each had a personal addition to make to "round out" the project. Several of these ideas had merit and are discussed in the final chapter to this paper as areas for further study.

There were other minor annoyances, but these could not be directly attributed to the research project.

Sequence of Filming Operations

As discussed above, the pilot film was obtained first during the early portion of August, 1965. The equipment was installed and run continuously from mid-morning to the end of the day shift at 4:00 o'clock in the afternoon. Throughout this period, lenses and lense openings were varied as was the frame exposure interval. As was further discussed, a ten millimeter lense with a 4.0 lense opening was decided upon with the camera operating at one frame every twelve seconds.

Three weeks after the first, or pilot, study the camera was set up for an eight hour operation at Site No. 2. Film was exposed all day. Research was begun at 8:45 A. M. and continued until 12:00 noon at an increased exposure rate -- 0.4 minutes or one frame every 2.4 seconds. This was a mistake by the author made during the mounting of the camera. The roll of film was then used up in three hours and a second roll was installed for the afternoon work period. The interval was reduced to the desired 0.2 minutes for the afternoon work period.

Several days later, the third roll of film was used again at a third industrial site. No further problems were encountered. The last thirty feet of this third roll of film were used with the camera mounted on a bridge crane positioned over a high density traffic aisle at the site of the pilot film study.

The fourth roll of film was run at Site No. 2, accumulating one week's data. Due to the significance of the data gathered in August, the staff at the Industrial Engineering School felt that a random sample of work hours would give a better statistical foundation for conclusions drawn. Random periods of one hour increments were selected and a designated man, detailed by the management, started and stopped the camera on this schedule. This procedure was followed at two of the sites to get some statistically based sampling of the work rather than one day's continuous film. The procedure was not followed at the third site as the original film indicated insufficient activity to warrant additional study. The film based on a sampling of one week's activity gave excellent results to further validate the preliminary data. The fifth and last roll of film was also used in this sampling manner.

The film was developed by a local radio station, Station WKY, which had the only commercial facilities for the development of 16 mm movie film. Using a Kodak "Analyst" sixteen millimeter movie projector, Model BP 16AR as modifed by L. W. Photo., Inc., Van Nuys, California, the film was projected at a slow rate and the safety hazards itemized. A rate of about five frames per second allows sufficient time to absorb the photograph and react to stop the projector on a single frame when further study is desired.

Safety hazards were then categorized by defined class and an analysis made as to the success of the research and the value of the procedure.

The subsequent chapters to this study give the details of the analysis and the conclusions drawn.

CHAPTER IV

QUANTITATIVE ANALYSIS

This portion of the study presents the methods used in analyzing the data gathered. The use of statistics to organize the data, the categorizing and charting of data, and the analysis of the results are included in this mathematical portion of the work. The conclusion to the chapter discusses a possible relationship for accidents and hazards.

Control Chart Concept

Life exists within an environment of many variables. These variables may act randomly or conform to a pattern. Some are chance and others are caused by controllable factors. The chance categories of variables are subject to statistical isolation with a view to establishing limits within which these chance variables may operate and not cause undue alarm the majority of the time. Chance causes are not predictable with certainty, but limits may be established on the basis of probability. Those areas of variation which are due to controllable factors are designated the 'assignable cause' variables. These are due to such elements as careless or unskilled workmanship, substandard raw material, equipment breakdown, or any of a number of other reasons. These are preventable or correctable and are not due to chance.

Statistical quality control methods employ 'control limits' between which the measured parameters of a sample must fall to consider the sample 'in control'. This control area accounts for the chance variables occurring randomly in any situation about which nothing can effectively or economically be done. The over-all summation of chance variables causes a dimension to vary, a defect to occur, or a safety hazard to be caused on a random basis. When a sample measurement falls outside the control limit area, it may well be due to randomness; however, there could be a definable fault requiring the reaction of the responsible authorities to get the situation back 'in control'.

A control chart is a chronological history of samples as measured according to the desired parameters. The establishment of control limits for the chart are based on the experiences of management, an arbitrary selection, or the economic relationships involved. Close control limits are more costly because each sample outside the limits set requires investigation as to why it is different. The reason may be due to the chance variables accumulating to give an out of control situation rather than a definable cause. The closer the limits, the more often this will happen. Wider limits, on the other hand, cause acceptance of samples which are slightly defective due to definable faults. The economics of the limits are, logically then, a factor in setting their extent.

Statistical Approach

The wide area and scope of activities photographed in the research indicated that an attribute inspection or number of hazards noted was the statistical measurement parameter required for this analysis. In a quality control analogy, this analysis would correspond to the method of summing the defects noted as opposed to the fraction defective method where the total number of possible defects is known. No one could possibly determine with accuracy the total number of possible hazards that occur in one time period where a working force of several thousand are employed. Because of this, the analysis could not enumerate the hazards noted by photographing and state that the number was a percentage of the total number of hazards possible. The number of hazards increases with the number of man-hours and employees and, therefore, a parameter of the man-hours involved is the common denominator for the analysis.

Duncan (25, p. 350) states that experience with numbers of defects in a sample unit of a universe will closely follow the Poisson distribution form. The basis for assigning this mathematical form to hazard occurrence is strictly on intuitive grounds because it is impossible to collect data to establish the form on an empirical basis. The formula for the Poisson distribution is $P(c) = \frac{c'^{c} e^{-c'}}{c!}$ where c is the number of defects in a sample consisting of a single unit and c' is the average number of defects per unit for the universe. When the total universe cannot be defined from the view of possible defects, the Poisson form may still be used on the empirical basis that it apparently describes situations adequately to justify its use. Each of the research sites is considered to be a population as of itself. This is based on the fact that no two industrial sites have the same environment and though human nature may act in an over-all similar manner, the varying environment of the industry sites will effect a significant difference in the resulting human actions. Differences such as climatic conditions, lighting conditions, aisle dimensions, equipment use, and location will affect a delineation into separate populations. As a statistical proof of this, see the chi-square tests below.

The inspection universe then is the individual research site where data was gathered. Within each organization, however, this unit must be defined further on the basis of a common denominator or unit of measure. The truck may travel a certain number of miles within the plant, or remain within specific area boundaries, or encounter specific similar situations. As the primary interest in this study is the actions of people, the natural common denominator is the person and the number of hours he or she works during the research. Each site is, therefore, defined on the basis of the number of thousands of man-hours worked in the departments through which the truck traveled; and where the camera might, therefore, photograph an unsafe act. The site breakdown by labor force and man-hours is listed in Table I.

TABLE I

OPERATIONAL MAN-HOURS DURING THE RESEARCH

	Man-Hours		
	Continuous Photography	Random Photography	Stationary Photography
Site No. 1 - - - 1,500 employees	9,000	15,000	4,500
Site No. 2 - - - 1,100 employees	7,700	11,000	
Site No. 3 - - 100 employees	700		

As noted in Table I, the three industrial sites used for the research, and photographic sampling methods did not involve the same size sample of personnel and did not involve the same period of time (see Table V). Therefore, since samples are not equal, a $\overline{U}$ chart is indicated as the required recording technique to establish guidelines for each universe or population (25, p. 356). The $\overline{U}$ chart has the advantage of comparing unequal samples through the use of a common mean, $\bar{u}$, and individual control limits for each sample size.

Upper and lower control limits (UCL and LCL) are established by formula (25, p. 355):

$3\sqrt{\bar{u}/k}$

$$UCL = \bar{u} + \sqrt{3\bar{u}/k}$$

$$LCL = \bar{u} - \sqrt{3\bar{u}/k}.$$

By definition, the Poisson distribution variance is equal to the mean of the population being analyzed. If control limits are established on the basis of three times the square root of this variance added to or subtracted from the population mean, less than one per cent error will be made in detection of defective out-of-control samples. There will be a corresponding large probability of accepting a sample which is slightly defective due to cause, but not accepting a good sample will be at a probable minimum. The selection of the limits can be based on any desired multiple of the variance, but it is common practice to use the third multiple. In this way, 50 per cent of the chance variations will fall above or below the mean based on randomness. Limits may be established in the above manner or on the basis of probability of error such as one per cent error chance, five per cent error, or any figure chosen by the using authority. For this study, however, the common practice of three times the square root of the variance will be used to determine the control limits.

The term 'k' is used to place the samples at any one site on a common basis. In this study, the 'k' is based on the number of man-hours worked at the site for which the control limits are being established. Thus, the 'k' varies for each site and research period, and is the factor used to weigh unequal samples in order to establish a common reference for purposes of comparison.

The $\bar{u}$ is common to all samples at one site and based upon the sum of hazards noted divided by the number of hazards for some unit of measure - in this study, the number of hazards for each one thousand man-hours worked during the time period. The control limits are then established as listed in Table VI using the above formulas. Because the data was gathered in three separate methods; i.e., individual eight hour periods of photographing at each site, ten randomly chosen one hour periods of photographing at each site, and a stationary camera location, tables are listed for each method. Charts are drawn for the individual site, however, and not drawn for the individual method of photography.

Category Definition

The defects noted in a quality control situation are analogous to the safety hazards in this study. A defect is anything causing a deterioration in the operation of a product. The safety hazard is a personal act or existing situation encompassing a source of danger. (See Chapter I, Definition of Terms.) The definition is necessarily broad and the establishment of specific subordinate categories is necessary in order to facilitate the enumeration.

The establishing of categories requires a qualitative analysis as to the lack of safety involved in a personal act or situation. In many instances, such as traffic rule violations, the categorizing of unsafe situations is facilitated by already established criteria. These criteria could be State and/or Federal laws or regulations imposed on the basis of analyses of past performance in similar situations. The difficulties in defining the safety hazard are manifested in the cases of marginal situations where perhaps the degree of jeopardy is minimal. An example of this would be an object projecting into the aisle right-of-way a small amount versus a large object protruding into the aisle a sufficient amount to alter the flow of traffic. This particular hazard is discussed below. The point here is that often the qualitative evaluation causes the major impediments in defining category guidelines.

The unsafe practices causing safety hazards were divided into three categories:

1. Static conditions - An existing situation where safe practices are being violated and personnel or vehicles in motion are not directly involved.
2. Vehicular motion - Vehicles violating traffic rules established by vehicle manufacturers, local company policy, or other accepted authority.
3. Personnel actions - Actions by individual personnel violating safe practices not involving operation of vehicles.

These categories are then further sub-divided into areas directly associated with this research study (see Table II, page 42).

In the first category, the static condition would exist for some time and personnel are not in evidence as attempting to modify or prevent the hazard from causing an accident. An example of this would be an object projecting into the aisle. The object could be anything from the lip or a portion of a trash receptacle to a loaded skid or pallet standing in the aisle right-of-way. There is very likely a distinction to be made here for minor and major hazard potential. However, a trash receptacle could be struck, fall over, and roll across or strike an employee's limb and cause a major injury; whereas, a loaded pallet could be struck a glancing blow and little or no injury result. On this basis, then, all protrusions into the aisle were considered hazardous without attempting to establish a distinction as to the degree of hazard.

A distinction as to hazard degree could possibly be made on a measuring scale. The object's protrusion into the aisle could be defined on the basis of quantity on a line normal to the aisle limit line. The establishing of degree of jeopardy would again be an arbitrary decision and an endeavor towards this end is outside the scope of the work.

In the second category, above, the violations of traffic rules involving moving traffic are based on accepted standard traffic rules-of-the-road as specified by the National Safety Council, safety rules as published by the "American Standard Safety Code for Powered Industrial Trucks", ASA B56.1 dated 1959, and any special rules published by the individual research site governing the movement of traffic. An example of this latter rule occurred at Site No. 2: Vehicle drivers are instructed not to travel through areas where other employees are on 'coffee-break'. The photographs indicated that violations of this rule are not uncommon.

The unsafe acts of employees whose work is not associated with vehicular operation are listed in the third category. Even though several of these hazards would probably involve vehicles if an accident occurred, the hazard was attributed to the person performing the unsafe act. A specific example of this is the case at Site No. 2 where a janitor had his cleaning equipment and a trash receptacle cover sufficiently arrayed in a traffic aisle to cause a traffic hazard. The subordinate or detailed groups under each of the three categories are as in Table II.

The groupings (on the following page) are based on the research performed and apply to the industries photographed only. In other industries, the specific groups may require additional delineation or modified definition for inclusion of specific data.

Calculations and Charts

The frequency of the individual hazard as defined above is noted in Tables III and IV. Table III lists the Safety Hazard Frequency based on the individual one shift photography at each site with the final column of the table listing the Hazard Frequency when the camera was mounted in a stationary position over the high density traffic aisle. Table IV lists the Safety Hazard Frequency for the random interval photography at each site.

Table V lists the accumulated frequencies from the above mentioned tables plus the number of employees at each site, the number of hours research done at each site, the number of man-hours under research, and the hazards per one thousand man-hours. The table is in three parts to distinguish the three photographic methods used. Table VI, then, breaks the Table V into the research site categories and establishes mean values of $\bar{u}$.

The Control Limit Mean, $\bar{u}$, is calculated by dividing the total of the hazards noted by the total number of hazards per each one thousand man-hours at each site.

TABLE II

CATEGORY SUBDIVISION

Category I -- Static conditions.

A. Object projecting into the aisle.
B. Items stored in racks/bins piled too high or in such a manner to be in danger of falling into the aisle.

Category II -- Violation of traffic rules.

A. Motor vehicles.

1. Improper passing of moving vehicle.
2. Traveling on wrong side of two-way aisle.
3. Failure to yield right-of-way at an intersection or 'Break Area'.
4. Traveling the wrong way on a one-way aisle.
5. Fork truck traveling an unreasonable distance with elevated load.
6. Personnel working on elevated and unprotected forks.
7. Improper loading of vehicle.

B. Non-powered vehicles.

1. Improper passing of moving vehicles.
2. Load obstructs view in direction of motion.
3. Traveling wrong way on one-way aisles.
4. Traveling on wrong side of two-way aisle.

Category III -- Personnel actions.

A. Employee obstructing aisle with the major portion of his body.
B. Employee walking with armload obstructing view in direction of motion.
C. Violation of smoking safe practices.
D. Employee obstructing right-of-way unnecessarily with tools and/or equipment.
E. Improper riding on truck.

TABLE III

SAFETY HAZARD FREQUENCY
(FILM ANALYSIS - SINGLE SHIFT CONTINUOUS PHOTOGRAPHY)

	Site No. 1	Site No. 2	Site No. 3	Site No. 1 Stationary Photography
Category I -- Static conditions causing safety hazard.				
A. Objects projecting into the aisle	10	57	5	15
B. Improper storing of items in racks/bins.		2	12	
Sub-Total	10	59	17	15
Category II -- Traffic rule violation.				
A. Motor vehicles.				
1. Improper passing of vehicle	1	1		
2. Traveling on wrong side of two-way aisle		1		
3. Failure to yield right-of-way at an intersection or 'break area'.	2	7		2
4. Traveling wrong way on 'one-way' aisle.	4			6
5. Fork truck traveling unreasonable distance with elevated load.			4	
6. Personnel working on elevated and unprotected forks.			1	
7. Improper loading of truck.			3	3
B. Non-powered vehicles.				
1. Improper passing of moving vehicles.	2	4		

TABLE III (Continued)

	Site No. 1	Site No. 2	Site No. 3	Site No. 1 Stationary Photography
B. (Continued)				
2. Load obstructs view in direction of motion.	1	3		
3. Traveling wrong way on one-way aisle.	4			
Sub-Total	16	16	8	15
Category III - Personnel unsafe acts not directly involving vehicles.				
A. Employee obstructing aisle with major portion of his body.		4		
B. Employee with armload obstructing view in direction of motion.				1
C. Smoking near fuel tank opening		3		
D. Employee obstructing aisle unnecessarily with tools and/or equipment.		1		
E. Improper riding on truck.		1		2
Sub-Total	0	8	0	3
Grand Total	26	83	25	3

TABLE IV

SAFETY HAZARD FREQUENCY
(FILM ANALYSIS - 10 RANDOM HOURLY INTERVALS)

	Site No. 1	No. 3	No. 3
Category I -- Static conditions causing safety hazard.			
A. Objects projecting into the aisle.	154	76	
B. Improper storing of items in racks/bins.	3		
Sub-Total	157	76	
Category II -- Traffic rule violation.			
A. Motor vehicles.			
1. Improper passing of moving vehicle.	4		
2. Traveling on wrong side of two-way aisle.	2	2	
3. Failure to yield right-of-way at an intersection or 'break area'.	1		
4. Traveling wrong way on 'one-way' aisle.	13		
5. Fork truck traveling unreasonable distance with elevated load.			
6. Personnel working on elevated and unprotected forks.			
7. Improper loading of truck.	1		
B. Non-powered vehicles.			
1. Improper passing of moving vehicle.			
2. Load obstructs view in direction of motion.	1		
3. Traveling wrong way on one-way aisle.	15		
Sub-Total	37	2	

TABLE IV (Continued)

	Site No. 1	No. 2	No. 3
Category III - Personnel unsafe acts not directly involving vehicles.			
A. Employee obstructing aisle with major portion of his body.	4	2	
B. Employee with armload obstructing view in direction of motion.			
C. Smoking near fuel tank opening.			
D. Employee obstructing aisle unnecessarily with tools and/or equipment.			
E. Improper riding on truck.			
Sub-Total	4	2	
Grand Total	198	80	

TABLE V

SAFETY HAZARDS PER 1000 MAN-HOURS

Site No.	Employees	Research Hours	Man-Hours Researched	Total Hazards	Hazards/ 1000 Man-Hours
	Continuous One Shift Photography				
1.	1500	6	9000	26	2.88
2.	1100	7	7700	83	10.78
3.	100	7	700	25	35.71
	Random Interval Photography				
1.	1500	10	15000	198	13.20
2.	1100	10	11000	80	7.27
3.	No Random Interval Photography done here.				
	Stationary Photography				
1.	1500	3	4500	33	7.33

TABLE VI

MEAN VALUES
(HAZARDS PER 1000 MAN-HOURS)

Site No.	Continuous Photography	Random Photographs	Stationary Photographs	Total	$\bar{\bar{u}}$
1.	2.88	13.20	7.33	23.42	7.80
2.	10.78	7.27	--	18.05	9.02
3.	35.71	--	--	35.71	35.71

Table VII, then, establishes the 'k' value and the control limits for each site or research area. The 'k' is dependent upon the number of employee man-hours worked by the personnel at the individual plant during the research time. Each one thousand man-hours is considered to be one unit of 'k'. The 'k' values are then calculated as follows for each site depending on the amount of time the research was being done:

CONTINUOUS PHOTOGRAPHY VALUES OF 'k'

Site No. 1. $k_1 = 9000/1000 = 9.0$

Site No. 2. $k_2 = 7700/1000 = 7.7$

Site No. 3. $k_3 = 700/1000 = .7$

RANDOM PHOTOGRAPHY VALUES FOR 'k'

Site No. 1. $k_4 = 15{,}000/1000 = 15.0$

Site No. 2. $k_5 = 11{,}000/1000 = 11.0$

Site No. 3. Not Applicable.

STATIONARY PHOTOGRAPHY VALUES FOR 'k'

Site No. 1. $k_6 = 4500/1000 = 4.5$

The Hazard Pattern Charts, $\overline{U}$ charts (Figure 3a through c), are then drawn using the control limits from Table VII (following page) and the mean, $\bar{\bar{u}}$, for each site found in Table VI (preceding page). The abscissa and the ordinate for the charts are the sample numbers and the number of hazards found for each one thousand man-hours under research. These Hazard Pattern Charts present, in a usable format, the relative safety of an organization. The application of this information is discussed in Chapter V.

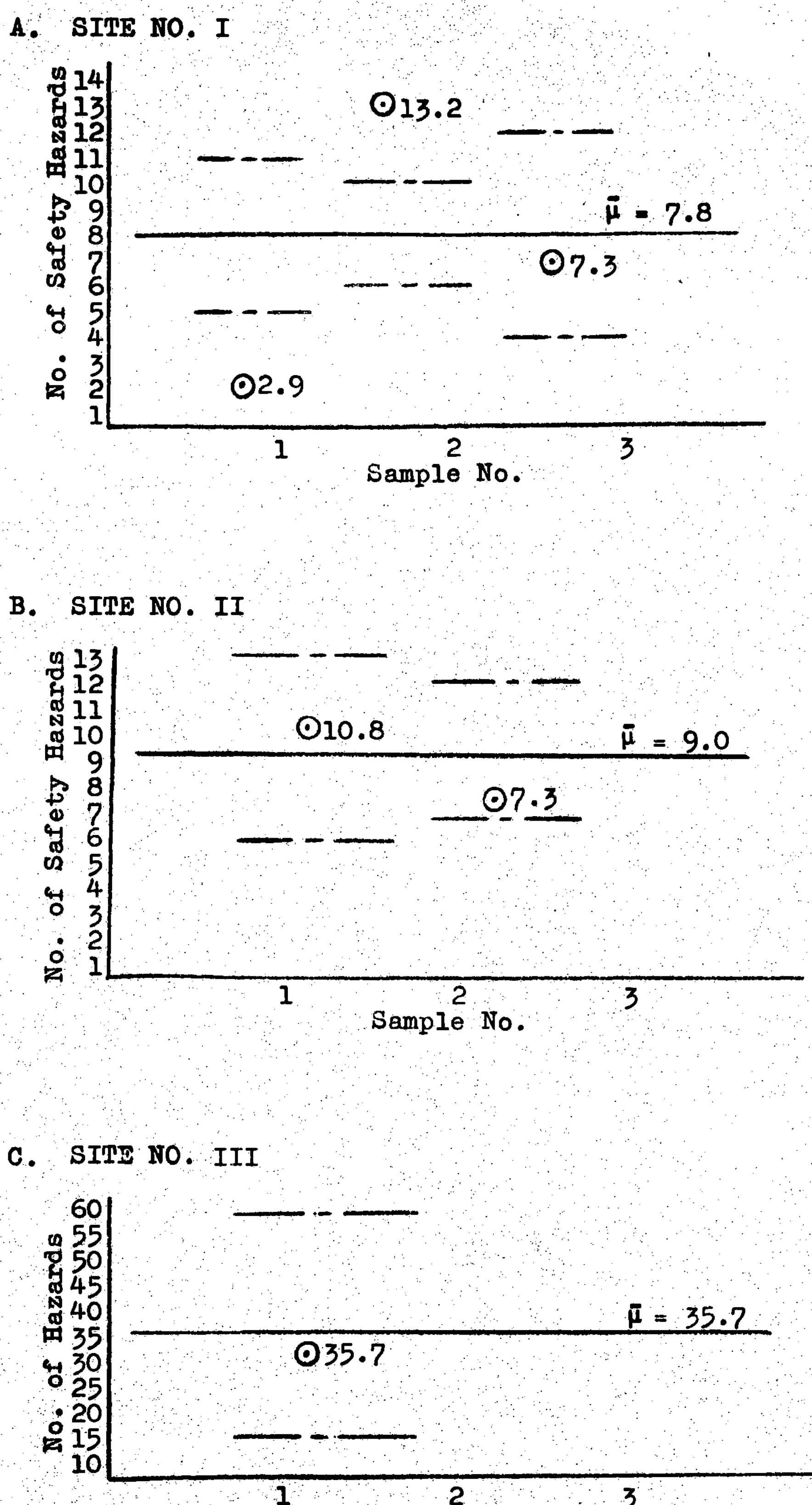


Figure 3. Hazard Pattern, $\bar{u}$, Charts

TABLE VII

CONTROL LIMIT VALUES

Research Method	k	$3\sqrt{\bar{u}/k}$	UCL = $\bar{u} + 3\sqrt{\bar{u}/k}$	LCL = $u - 3\sqrt{\bar{u}/k}$
	SITE NO. 1			
Continuous	9	2.7975	10.60	5.01
Random	15	2.1645	9.97	5.64
Stationary	4.5	3.9495	11.76	3.86
	SITE NO. 2			
Continuous	7.7	3.2544	12.28	5.77
Random	11.0	2.7195	11.75	6.31
	SITE NO. 3			
Continuous	.7	21.4299	57.14	14.28

Results

The $\bar{U}$ charts each have a central line, $\bar{u}$, which is the expected number of safety hazards during any period of one thousand man-hours of work. The expected hazard frequencies found in this research average out to: 7.9 for Site No. 1, 9.03 for Site No. 2, and 35.71 for Site No. 3.

The above are the quantitative results of the research and the first step in the research method being proposed. In order to establish a statistical delineation for these results, the chi-square testing technique has been applied to make decisions on the following hypotheses:

Ho. No. 1: The samples from all the sites and using all methods of photography are taken from the same population.

Ho. No. 2: The samples taken at Site No. 1 are from the same population.

Ho. No. 3: The samples taken at Site No. 3 are from the same population.

Table VIII lists the hypotheses by number and the decision for each based on the chi-square test.

TABLE VIII

CHI-SQUARE TEST: SIMILARITY OF POPULATION

Ho:	No. of Samples	Calculated X^2	Tabular X^2	Ho; Decision
1.	6	173.124	12.8	Reject
2.	3	6.851	5.9	Reject
3.	2	.6811	3.84	Accept

Source: (45, p. 451)

The rejection of Hypothesis No. 2 is the only one in dispute based on intuitive grounds. The first sample at Site No. 1 was taken just prior to a long holiday weekend and the safety program was emphasizing 'Be Safe'. In the author's opinion, this program materially affected the hazard frequency and further sampling during normal work times would establish a single universe at Site No. 1. No chi-square test was run on the third site as the degree of freedom becomes '0' with only one sample. The test, therefore, becomes of no value.

Analysis

There are some variations in the data for which explanations are required in the opinion of the author. This section will explain these variations and discuss the results.

In the first place, the relatively high rate of safety hazards at Site No. 3 of 35.71 hazards per one thousand man-hours is due to two things in this study. One, the establishing of hazard categories is a subjective analysis of safety and if the site authorities do not consider a practice unsafe while an evaluator does consider it unsafe, a contradiction in judgment results. In the author's opinion, this situation was most apparent at this site and the high rate of hazard occurrence is the result. A subjective analysis such as this must be submitted to proper authority for decision. Second, the environment at Site No. 3 is significantly different from the other two being limited to storage of materiel only. No production facilities are present and the labor force is much lower in number. Thus, there appear to be logical reasons for the differences in frequency.

A second area of data variation is in the number of samples. The research method requires additional data in repeated samples to establish with certainty the limits on the $\bar{\bar{U}}$ charts and the hazard frequency for the individual site. However, this study was initiated to prove the feasibility of such a procedure and not to set up definite quantities for the charts. Confirmation of control limits and hazard frequencies will require many samples if the method is acceptable as being of use to the company. The varying hazard frequency among the various sites may well be based on the relative emphasis on safety at the sites or on the attitude of the employees toward safety. This is an argumentative point and stated here as a possible explanation for this variation.

There was an expected difference in the occurrence of hazards among the several methods of photography sampling used. At Site No. 2, however, the enumeration results were almost equal for unequal time periods of seven hours for the continuous sample versus ten hours of random sampling. There is no obvious significance to this fact except that there was a decrease in safety hazards perpetrated when employees realized the possibility of being photographed in the act. This realization could make a person more conscious of his actions and modify them accordingly. Based on conversations with supervisory and Industrial Relations personnel, this reaction very likely took place.

An 'Expected Accident Criterion' Theory

In industry, there is, effectively, no recognition of the 'incident' in present-day statistics. In Heinrich's ratio of 1:29:300, as discussed in Chapter II, the incident was apparently of some concern. It follows then that if the incident is of some importance where one person is concerned, it becomes of far greater importance where personal relationships are a geometric function of the number of employees and the number of hazards are much more frequent. There is evident a void in the statistical concepts of Safety. This study has concentrated on the safety hazard which is a further step beyond the occurrence of the incident, assuming that there is a functional relationship among the accidents, incidents, and hazards. If the assumption of relationship is made and accepted as a premise, then a quantitative relationship may be proposed whereby incident statistics are circumvented and a ratio of accidents to hazards may be of value in the prediction of accident frequencies from samples of hazard frequency.

Through the use of available data at each industrial site used in the research, the accidents occurring at each site during the period July, August, and September are listed. From these data and the hazard frequency data obtained by the research, an 'Expected Accident Criterion' can be established. See Table IX (on the following page). This parameter is a ratio of the accidents per one thousand man-hours to the safety hazards enumerated per one thousand man-hours for a stated period of analysis time. A quarterly time period was selected based on the fact that the climatic environment is rather constant for the research sites and, more significantly, accident occurrence is rather infrequent. This necessitates a time period longer than a month in order to approach a 'leveling' of the data.

Acceptance of this reasoning leads to the theory that a prognostication of accident frequency is plausible. By establishing hazard frequency in a time period through the use of this research, the accident expectation can be calculated as a function of the established 'Criterion'.

A great deal of further study is required on this theory and many samples of hazard frequency are needed to correlate with accident data to prove the functional relationship and establish conclusions. However, the rationale is not incongruous with the present data.

TABLE IX

ACCIDENT-HAZARD RELATIONSHIP

Site No.	Man-Hours Worked July	August	September	Total	Accidents July	August	September	Total	Accidents per 1000 man-hours	$\bar{u}$	Criterion
1.	241,920	253,440	230,400	725,760	47	57	49	153	.2108	7.8074	1:37.04
2.	670,760	703,560	737,880	2,112,200	424	350	494	1268	.6003	9.0260	1:15.04
3.	25,200	26,400	24,000	75,600	---	17	---	17	.2249	35.71	1:158.71

CHAPTER V

QUALITATIVE ANALYSIS

The collection and organization of data is the facilitated portion of this research method in that the required judgment and qualitative analysis using the results of the quantitative analysis cause the greater difficulties. The value of the data collected depends on its use. The data itself is not an end, but a more quantified means of guiding safety program implementation and emphasis than has heretofore been used. Thus, the end is a better means to safety program guidance. This chapter discusses the uses of this quantitative data in consideration of specific objectives.

The Safety Program

The preceding chapter proves the feasibility of enumerating the safety hazards in any industry. Through the use of established analysis techniques, a chart may be devised which graphically demonstrates the historical relationship of the hazard frequencies. In this manner, safety program frequency and emphasis may be adjusted more readily than by awaiting accident statistics to show trends.

For example, a plant safety group in using this procedure may note that the Hazard Pattern Chart records the latest samples as consistently above the mean, $\bar{u}$. An analysis of this time period may reveal an excessive number of objects in aisle right-of-ways, or vehicle operators continually operating in violation of some traffic rule. The safety personnel then place particular emphasis on these two hazards in the program of safety until the hazards reduce in frequency.

The specificness of the safety program in its emphasis on particular hazards, as compared to a general "Be Safe" program is the importance of this method.

The safety program has had, in the repetitive work cycle, a statistical record of specific injuries due to rather easily defined hazards. Many of these resulting "Safe Practices", such as hard hats and safety glasses, are applicable to the long work cycle, but there is a large area of hazard where the Safety Engineer has depended upon generalities in the program of safety emphasis. The safety program can be specific in the long time nonrepetitive activity cycle by means of this research method.

The Individual

The personnel photographed are normally recognizable as to name and department. Therefore, individuals responsible for unsafe acts or responsible for the area where an unsafe condition exists may be identified. This photographic evidence can be used by supervision to realign the individual's attitude as necessary or apply penalties where required. Photographic evidence is, by its very nature, difficult for an offender to contradict or evade.

An individual who consistently is responsible for unsafe behavior is very likely to have a record of accidents. Photographic evidence may lead to causes and the assistance necessary to help the individual.

The individual, on seeing himself in photography, is his own best critic. It is known that the individual feels a detachment and sees himself as a part of the whole when he views himself in pictures (20). If the film from this method is shown to groups of employees, they can better critique the hazards and much can be gained from the employees themselves.

Evaluation of Safety

In industry, the majority of innovations to the organization, the production process, or any of the various facets of industry are evaluated on the basis of efficiency increase or reduction in actual cost to the company. The evaluation is on the basis of operations prior to and after the innovation. Thus, efficiency or the dollar saved is the criteria for judgment.

Safety program evaluation differs from this in that the criteria is a decrease in accidents, though accident frequency reduction can be equated to dollar value. Normally, a safety program takes effect over a long period of time and the trend in accidents cannot be directly attributed to the safety program alone. Over time, there are other parameters which could affect a change in the accident frequency. As examples of other parameters, people seem to be more safety conscious in winter time or just prior to a holiday period. To get the value of a safety program under present criteria, then, takes a long period of time. In automotive traffic safety, for example, the safety program evaluation takes several years.

Because of the intuitive relationship of unsafe act and accident, a reduction in the hazard frequency would appear to effect a reduction in accidents also. The use of the research method, herein evolved, could establish a hazard frequency prior to a safety program initiation.

Immediately subsequent to the program or after a period of program operation, a second survey to re-establish the hazard frequency would, with all other things being equal, tend to the conclusion that the program had a deleterious or beneficial effect on the attitude of the employees. The need to initiate such a program during 'normal' times to, as far as possible, prevent biasing of the results is apparent. In this manner, other parameters, which could bias the outcome based on time, are reduced to a minimum since they have little time to take effect.

The frequency of safety programs and their emphasis can be established by their effect on the employees. Since the time element is reduced to a minimum by taking immediate measurements, an effective evaluation can be made.

Accident Agencies and Causes

Nowhere in industry or other phase of society has there been a direct relationship proven between accident frequency and hazard frequency. There may well be a completely different mathematical distribution of accidents superimposed on the assumed Poisson distribution of hazards. Intuitively, it is felt that accidents are a direct function of hazards, but it is unproven.

No accidents were photographed during the course of this research work and, thus, no cause or agency of accidents can be alluded to with certainty. Though on the basis of the "Law of Averages", a person will suffer injury if endangered in the same manner, frequently, there is insufficient data in this work to establish this and analyze accident agency or cause. The 'Expected Accident Criterion' developed in Chapter IV is a theory which, though intuitively rational, requires a large amount of data to prove conclusively.

Therefore, no firm application of this criterion can be alluded to in this research except on the theoretical basis of potentiality.

Multiple Hazard Pattern Charts

As an extension of the present concept, control charts could be established for individual hazards such as objects projecting into the aisle or a particular unsafe act noted often enough to warrant individual treatment. The individual treatment would be initiated when accident trend analyses indicated a high accident rate apparently due to one or more hazards. The establishing of these charts would require justification on the basis of accident trends because of the multiplicity of possible hazards and the potential paperwork resulting from a chart for every hazard.

Inherent Conditions of Hazard

The photographic study indicated an important corollary to the discussion. This corollary concerns the situations created by the architect, engineer, or planner for a site which are inherently unsafe. Layout of machinery, location of equipment, or service equipment which force the operator to perform his work in an unsafe manner are examples of possible 'built-in' hazards. At one of the research sites, pay telephones are provided for the employees. They are not enclosed, but are in a shell arrangement which forces the user to stand in the transportation aisle. This is an inherent hazard though, as yet, there are no accidents recorded due to the hazard. This last statement is not confirmed by a research of the accident reports, but stated on the basis of conversation with the safety personnel.

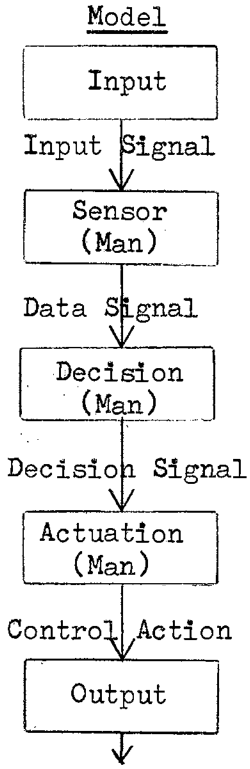
The film records establish the hazard and how it occurs without members of management having to be present at the moment a hazard is evident. This type of hazard is manifested clearly and management can then concentrate on how to eliminate it.

Information Models

Symbolic or schematic models have been used extensively by many fields of study to represent reality. Their value lies in representation of reality in cooperation with the abstract for illustrating relationships. Information models illustrate the relationship and use of information as it first is recognized in raw data form and proceeds to be digested for the decision making process and finally put to use in modifying reality over time.

Comparative models of the flow of safety information, considering input and output of data, indicates the value of quantifying as permanent evidence the safety hazard reports as proposed in this study. In the first model, input information is recognized through subjective judgment of personnel evaluating the occurrence of safety hazards or accident report analysis. The observance of a safety hazard is not recorded except by individual observation and no record is kept as to any frequency of occurrence. Under present normal industrial operations, this safety hazard data may or may not be used to guide safety program implementation. Much of the safety program direction is a result of accident trend analysis; thus, the programs may well lag accident trends over time. Thus, the data output in the present situation model may be of little value depending on the time and subjective judgment parameter throughout the time constant of a safety program.

SAFETY MOTIVATION SEQUENCE
MODEL I

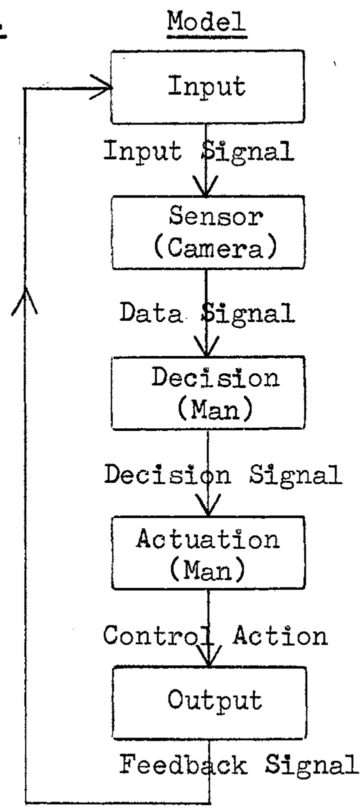


Step No.	Description
1.	Hazards or accident reports.
2.	Individual sees hazard or reads accident report.
3.	Deduces potential accident or causes of reported accident.
4.	Knowledge of hazard frequency unavailable and other parameters then effect choice of Safety emphasis.
5.	No positive method for evaluating efforts.

The above model indicates that the second, third, and fourth steps are activated by mental processes of safety personnel and are, thus, subject not only to the individual's experience and performance, but also to the individual's highly variable mental response to external stimuli. There is no 'feedback' signal to the input which would serve as an evaluation of any effort expended in areas of particular unsafe conditions.

A model of information flow for the procedure proposed in this study illustrates the contrast from the existing situation.

SAFETY MOTIVATION SEQUENCE
MODEL II



Step. No.	Model	Description
1.	Input	Hazards or accidents.
2.	Sensor (Camera)	Photographic data and enumeration, categorization of hazards
3.	Decision (Man)	Decision on emphasis of safety program.
4.	Actuation (Man)	Modified safety program as required.
5.	Output	Changes in hazard frequency.

The substitution of an objective quantitative step in the model for the subjective sensing of hazards reduces the probability of human failure to overlook problem areas by a significant amount. The addition of a 'feedback' signal to the model as proposed in completion of the communication cycle gives a positive evaluation of the man-man linkage found in the promotion of safety at the industrial operation.

CHAPTER VI

SUMMARY AND CONCLUSIONS

In this last chapter, a summary of the research and results is presented along with the conclusions reached and areas of possible further research which appear to need study.

Summary

The study, herein, performed under the direction of Dr. Earl J. Ferguson, at Oklahoma State University, establishes a basis for analyzing safety hazards and their frequency. An industrial fork truck was used as the vehicle from which time lapse motion, or memo-motion, pictures were taken during several time periods of industrial operations. The unsafe practices photographed were categorized into three general areas and, thence, into subordinate detailed groups in order to standardize and define the specific unsafe practices.

The totals of these hazards were translated into a frequency per one thousand man-hours based on the number of hours of research and the number of employees at the research site. These frequencies were then used to establish a mean and control limits for a charting technique used to graphically display safety relativity. Each research site has an individual chart. The charts, then, indicate a hazard frequency per one thousand man-hours of labor for each research site. These are expected hazard frequencies of 7.90, 9.03, and 35.71 for Sites No. 1, No. 2, and No. 3, respectively.

This data can then be applied by safety personnel to modify the periodic safety program emphasis or frequency and in the extreme to modify the philosophy of safety personnel as to concentration of their efforts. The data can also be of importance in evaluating the effectiveness of the safety program as it is used periodically throughout a time period.

Conclusions

The research work establishes a method by which the periodic safety program and a safety philosophy can be evaluated and indicate necessary modifications. In the first chapter for this study, the hypothesis is stated that the non-repretitive, extended time, activity cycle is subject to feasible safety analysis whereby unsafe acts can be determined qualitatively according to established categories and serve as the basis for safety program implementation and evaluation. By means of basic statistical techniques and a modification of established useful work sampling techniques, a method of combining the statistics reduced from the photographic raw data with qualitative analysis was developed. This method is feasible and economical enough for any moderately sized industrial concern to use in evaluating the degree of safety among its employees and the effectiveness of the local safety program frequency and emphasis.

Because of the photographic evidence of unsafe practices in the real situation, the interpretation and subjectivity inherent in most safety evaluations can be eliminated or reduced to a minimum. When a question arises as to the practice photographed being safe or unsafe, the photographs are the actual evidence which, after study, are the proof in the decision.

The establishment of a Hazard Pattern Chart will give personnel responsible for safety a means of quantifying the evidence and indicating to management the relative safety of the local work force. In this day of quantitative techniques, the author feels that this is one of the primary features indicating the value of the method presented.

A great many more samples of unsafe practices at the sites used in this research and at other sites is necessary to verify the usefulness of this research method. However, this study was intended to establish the feasibility of the method and show a direction of philosophical concepts. It is felt that this goal has been achieved.

The additional samples of unsafe practices at the research sites used may well modify both the $\bar{u}$ means and the control limits established by this study. However, the method of arriving at these concepts as presented in this study has been proved to be feasible.

The accuracy of the accident to hazard ratio will take many samples and several years of historical data on accident statistics. Accidents occur infrequently when compared to the frequency of unsafe practices and, therefore, much work is required to establish statistics and empirical conclusions as to the relationship of ideas. Based on the cost data as detailed in Chapter II, however, the required work seems well worth the effort.

With the safety improvement methods used in today's complex industry being so nebulous and subject to interpretation based on widely separated criteria, this research should help indicate a more quantitative means to the goal of accident prevention.

Recommendations for Further Study

There are several areas of study which occurred to the author during the research work which appear to be tangent to but not directly related to this work. These areas when developed would hopefully add to the structure presented. Several of these areas are as follows:

1. From a quantitative standpoint, a study on whether or not the Poisson distribution actually fits the situation could be helpful.
2. An increased scope of industries must be investigated to get sufficient data for general application of the method in various types of industries from general contracting one-time-only work to production line repetitive work using all types of large and small equipment.
3. The research method presented here could be used in a study of safety involving pedestrians at crosswalks such as at a University or any school level where large numbers of people crowd crosswalks at repeated time intervals.
4. In the same type of study as in 3 above, this research could be applied to the study of motor vehicle traffic intersections or circles where accident frequencies are of interest to traffic authorities.

The above areas of further study indicate the wide area of possible use for time lapse photography. This method of data collection has almost unlimited potentialities.

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