NATIONAL BUREAU OF STANDARDS

NBS SPECIAL PUBLICATION 482

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Rare Event/Accident Research Methodology

NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

[2] Located at Boulder, Colorado 80302.

Rare Event/Accident Research Methodology

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Edited by
V. J. Pezoldt

Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary
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Thanks are also due to Kim Howard for secretarial assistance both in the preparation of this document and during the workshop.

ABSTRACT

This volume contains the formal papers presented at a Workshop on Rare Event/Accident Research Methodology sponsored by the Human Factors Section of the Center for Consumer Product Technology, National Bureau of Standards held at NBS May 26-28, 1976. The topics addressed at the workshop and reflected in the papers in this volume include system safety engineering, hypothesis generation in accident research, epidemiological approaches to injury research, observational techniques for studying complex tasks, accident simulation, and methodological considerations being forced by the law.

Key Words: Accident research; human factors; methodology; rare events; safety; system safety.

Introduction

The National Bureau of Standards (NBS) has long been involved in research and standards development activities in the areas of product performance and product safety. The Bureau's commitment to these activities was increased when, in 1974, the Institute for Applied Technology established the Center for Consumer Product Technology (CCPT). The Center's mission is:

> to perform research and development toward establishing and advancing measurement techniques and test methodology necessary to evaluate safety and other performance characteristics of consumer products.

In support of this mission, the Human Factors Section, a unit of the Product Systems Analysis Division within CCPT, sponsored a Workshop on Rare Event/Accident Research Methodology. The purpose of the workshop was twofold: (1) to further familiarize Section staff with a variety of methods currently being applied to safety problems, thereby improving the Section's capabilities; and (2) to provide a forum for the exchange of information and ideas among a small group of safety practitioners and accident researchers.

The workshop was held at the National Bureau of Standards' Gaithersburg, Maryland facility May 26-28, 1976. Eight invited participants from outside NBS made presentations to the workshop and acted as discussants in sessions devoted to their particular specialities. This volume includes the papers prepared by each of the eight presenters which served as the basis for their presentations to the workshop. A broad range of topics pertinent to rare event, safety, and accident research were presented. The topics addressed at the workshop, and reflected in the papers here, included systems safety engineering, hypothesis generation in accident research, epidemiological approaches to injury research, observational techniques for studying complex tasks, accident simulation, and methodological considerations being forced by the law.

SYSTEM SAFETY ENGINEERING AS THE INTEGRATOR OF ACCIDENT PREVENTION ACTIVITIES

Willie Hammer
Hughes Aircraft Company

WILLIE HAMMER has held a wide variety of engineering positions. Since 1961 he has been involved entirely in safety engineering, with the Air Force, a consulting engineering firm, and now Hughes Aircraft Company. Mr. Hammer has taught product and systems safety courses at UCLA, the University of Wisconsin and abroad. In addition to numerous published articles on various subjects, mostly safety, Hammer has written the highly regarded Handbook of System and Product Safety (Prentice Hall, 1972), and Occupational Safety Management Engineering (Prentice Hall, 1975).

Hammer's workshop presentation provides an overview of the discipline of System Safety Engineering and a brief review of the philosophy and methods of System Safety. Central to his discussion is the principle that accident prevention activities involving any product or system must be initiated with the earliest concept of that product or system and be maintained throughout its life cycle. As suggested in the title of his paper, Hammer considers this discipline a prime candidate for the task of integrating the contributions of many specialities into a comprehensive program of accident prevention. The analytic methods of System Safety, as presented by Hammer, provide a logical framework for applying the results of research and experience to the very real safety problems faced by industry.

Accident prevention is an activity involving many considerations, managerial activities, and technical disciplines. This workshop was called because of this and to familiarize each participant with the areas of interest, methodologies, and capabilities of the other participants.

I am a system safety engineer. For those of you who are not familiar with system safety engineering, some background information may be of interest.

After World War II, personnel concerned with prevention of aircraft accidents began to express their view that safety must be designed into airplanes like any other required characteristic. Some aircraft companies formed safety organizations to this end, but it was not a concerted effort throughout industry.

The concerted effort began in the early 1960's because of Air Force concern for safety with highly lethal intercontinental ballistic missiles. The missiles were capable of causing horrendous injury and damage. If one was lost catastrophically no blame could be put on a pilot, as in an aircraft accident, since there was none on board a missile. In addition, Air Force operating units were being given vehicles powered by exotic fuels and oxidizers with highly dangerous characteristics. The philosophy developed that safety programs had to be initiated almost as soon as the new system was conceived, and carried on through all phases of development, production, and operation.

To mitigate some of these problems requirements were written into contracts which required safety efforts to be undertaken during development of missiles. These requirements were generally limited to those contracts for which there was serious concern for safety, and for which someone in authority was knowledgeable and forceful enough to have them imposed. In 1962 work was initiated on an Air Force specification which would require all missile contractors to undertake system safety programs. This was soon extended to aircraft and other Air Force equipment. The concept was soon caught up by the Army (especially for helicopters) and the Navy so that the Department of Defense issued directives requiring system safety programs be undertaken for systems to be developed or modified. Six years ago, perhaps one of ten contracts for military systems had requirements for a system safety program; now the rate is about eight of ten.

System safety programs were being called for but there was a lack of methodologies for accident prevention which could be used for complex systems. There is no school, technical society, or other large organization at which research in system safety engineering is being conducted. Therefore, we who work in this discipline must sometimes do our own research in order to meet the requirements of our jobs. We have adopted, adapted, and developed methods. We have been forced by necessity into an organized approach to accident prevention by:

- Evolving new concepts and methodologies.
- Refining old concepts and methodologies.
- Adapting techniques from other scientific, technical, and management disciplines to our needs.
- Eliminating erroneous, invalid, or unnecessary data, concepts, requirements, methods, or equipment.
- Integrating related management and technical activities.
- Programmed, systematic determination of hazards and their elimination or control.

To accomplish our jobs we had to know something about program management, and about the activities of other engineering disciplines, their objectives, techniques, and capabilities. There are many disciplines whose practitioners were (and are) concerned with safety and accident prevention but who were almost always also interested in additional considerations. System Safety and reliability engineers share a concern regarding malfunctions which could lead to accidents. If a malfunction cannot cause an accident, we safety engineers are not concerned. Reliability engineers are interested in any malfunctions and in quality control of all operable items. Maintainability engineers are interested in malfunctions which require repair; they are also concerned with logistic support of a system or product. System Safety engineers are concerned with maintainability engineering for two reasons: the lack or inadequacy of which could result in accidents to operators, and in designs which could cause injury to maintenance personnel.

We in System Safety engineering believe that a hazardous condition must exist in order to have an accident. These hazardous conditions can be due to personnel errors, mechanical failures, dangerous characteristics of equipment or material, and/or adverse environmental factors. There are numerous instances in which these overlap. For example, hazardous characteristics of equipment or material are either inherent or created by design error, one of the subcategories of personnel error. I have put the four categories and their interrelationships into a mathematical expression (Exhibit 1) to indicate simply the various factors involved.

Some of the engineering disciplines, besides System Safety, which might be interested in the four rough categories would include, but not be limited to:

- Personnel errors: human factors engineers, psychologists, design engineers, and procedures and manual writers.

- Mechanical failures: design engineerings, reliability engineers, metallurgists, quality control engineers;

- Hazardous equipment or material: design engineerings, chemists and chemical engineers, materials engineers, industrial hygienists, biochemists;

- Environmental factors: design engineers, meteorologists, industrial hygienists, structural engineers, sound engineers.

Note the fact that design engineers are cited in each case. An objective study would undoubtedly reveal that many injuries and much damage could have been, and can be, avoided by better designed equipment. Safeguards against accidents should be designed into equipment as much as possible, and little reliance placed on procedures to be followed by users. I said there is no school at which research in system safety engineering is being conducted. The situation is only slightly better when it comes to teaching system safety engineering to undergraduate engineers. The courses in existence teach safety engineering to students aiming to be safety engineers, but unless they have been instituted very recently, I don't believe there is a school which teaches safety to engineers who will go into other fields, especially design. Yet, these are the ones who will be designing the equipment which turns out to be unsafe.

What have we System Safety engineers done so far which could be considered noteworthy?

. This discipline is predicated on the principle that accident prevention activities involving a system or product must begin with the initial concept of that system or product and be maintained throughout its life cycle. Tasks have been developed to be carried out during each phase of the life cycle. The erroneous idea that safety engineering during development before a product is unnecessary before it is built and tested must be eradicated. A list of safety tasks, the outputs and potential problems in carrying out a product safety program are presented in Exhibit 2.

. One of the first and most important tasks listed in Exhibit 2 is the preparation of safe design criteria to be observed by designers. Good standards for safe design must be provided as soon as the system or product is conceived. There must be means for ensuring that the standards are observed. But even with the best standards, hazards can still exist in a product. There must therefore be means for analyzing the system or product to make certain that these potential hazards have been eliminated or controlled.

Safety criteria in most product standards are generally lacking, inadequate, or ineffective. The A.N.S.I. standards for products are not only wanting in respect to safety, but because they are voluntary are often ignored. Admiral Hyman Rickover's comments regarding standards are noteworthy:

"To forestall intrusion of Government, the industry concerned will usually propose voluntary safety requirements. These requirements represent the minimum all are willing to accept. This is not enough. There are more accidents. Only after the lapse of much time are laws finally enacted. Much harm will have been done in the interval--harm which could have been prevented.

The typical industry-controlled code or standard is formulated by a committee elected or appointed by a technical society or similar group. Many of the committee members are drawn from the manufacturers to whom the code is to be applied. Others are drawn from engineering consulting firms and various Government organizations. However, since near unanimous agreement in the committee must generally be obtained to set requirements or to change them, the code represents a minimum level of requirements that is acceptable to industry.

In a subtle way, the use of industry codes or standards tends to create a false sense of security. Described by code committees and by the language of many of the codes themselves as safety rules, they tend to inhibit those legally responsible for protecting the public from taking the necessary action to safeguard health and well-being. Many States and municipalities have incorporated these codes into their laws, thus, in effect delegating to code committees their own responsibility for protecting the public."

If we compare safe criteria stipulated in industry standards with those in government-prepared documents, such as in military specifications and standards, we find the government criteria more stringent for the same hazards. In addition, they are wider in scope. Yet these military requirements are for personnel whose mental and performance capabilities and training are far higher than the general public who are to be protected by industry standards. If the Consumer Product Safety Commission has industry develop its own standards, as it has been attempting to do, it will recreate the same unhappy situation Admiral Rickover has described.

One possible solution is the use of a new system which at Hughes Aircraft Company have recently developed and are still refining. We call it SCRAT, for Safety Criteria Retrieving and Tabulating. It is predicated on the idea that any system, product, subassembly, or material can have only certain hazards and that the safe design criteria for these hazards can be prepared to apply in general terms to all items which have potential hazards. We have, therefore, put safe design criteria for our products into a computer. When we want the criteria for any item, we can retrieve them at will for the specific design being undertaken. A safety engineer then reviews it and adds any other safe requirements that may have been stipulated for observance in a contract. We are still refining the system but even the early usages we have been beneficial.

The process could be expanded for use by the Consumer Product Safety Commission to satisfy most of its needs for developing product safety standards. (The criteria we use are for the products we produce and limited in scope. In addition, our criteria are derived from military specifications and standards.) The computer readout can also be used by C.P.S. engineers as checklists to evaluate whether a product appears to be safe.

There are numerous other uses to which SCRAT can be put. If any of you are interested and want further information, please let me know.

The "Fly-Fix-Fly" methodology of determining potential hazards which might exist in a product only by reviewing the causes of accidents or presentations in lawsuits cannot be justified logically, economically, operationally, or morally. To determine and control the potential hazards which could exist in a system, product or operation, new methods of analysis have been developed. The best of these, Fault Tree Analysis, was originated by Bell Telephone Laboratories under an Air Force contract. The Air Force was much concerned that the Minuteman ICBM could be launched or the nuclear warhead detonated either inadvertently or by an unstable person. A means for assessing the possibilities qualitatively and quantitatively were wanted. The techniques of reliability analysis were inadequate for the purpose: the effects of multiple failures were not considered; personnel error and other actions were not considered; possibilities of single point failures could not be established.

For those who are not familiar with Fault Tree Analysis, a very brief description may be in order. A specific adverse event or condition to be investigated is selected. All the factors which can contribute directly to this event or condition are then shown on a logic diagram. The causes of these secondary factors are then added, developing downward like the roots (although they are called branches) of a tree. Following the tree downward indicates the causes of an event; following it upward indicates the effects.

The Fault Tree can be used for qualitative purposes to indicate diagrammatically the cause and effect relationships, or it can be prepared so that probabilities of the top, specific adverse event can be calculated. By means of Boolean algebra, mathematical equations can be written and simplified which will express the top event in terms of the basic causative factors. Simplification of the equation will eliminate redundancies. In addition to providing an expression for the top event, the simplification will indicate where potential single point failures exist. Probabilities of occurrence of the basic causative factors can be inserted in the equation and the probability of the top adverse event calculated.

Because it was the prime contractor for the Minuteman system, the Boeing Company became the first major user and proponent of Fault Tree Analysis. Bell Telephone Laboratories personnel had indicated symbology to be used; Boeing personnel added to it. (Symbols generally used are indicated in Exhibit 3; a simple Fault Tree in Exhibit 4.) There are many variations in symbology, generally to simplify usage. Notation are used to permit computer calculation and preparation of fault tree diagrams for complex systems.

The method is being used for purposes other than safety. Reliability engineers are using it. The top event selected is one indicating that successful accomplishment of an event (only material failures are included). The probability of successful accomplishment is, by definition, reliability.

Other applications of Fault Tree Analysis have been in accident investigation, where the top event is the injury or damage which occurred. Management Oversight and Risk Tree (MORT), developed by Aerojet Nuclear Company, endeavors to establish logically the contributory management events which could or fail to produce a specific management objective.

Fault Tree Analysis is an excellent method but is not usable for all accident prevention analyses. Its basic premise is analysis of a specific event. Factors which do not contribute to that event are not included in that tree. If they are to be considered, another tree with a suitable top event must be developed. The lower levels of the tree frequently cannot be developed until after the product is designed. System Safety engineers, therefore, use other types of analysis, from simple analytical reports to more complex mathematical studies. For example, at the beginning of a development program a Preliminary Hazard Analysis if usually prepared which provides an initial assessment of hazard which would be present in a new product or operation as proposed. Corrective action could be taken immediately.

. Another area in which we have been working is in quantitative measures of safety. I pointed out that the inadequacy of reliability methodologies to this end was a compelling reason the Air Force went to Bell Telephone Laboratories, leading to the development of Fault Tree Analysis. There are other reasons for interest in quantitative measures:

+ Risk assessment. Many companies would like to know the risk which use of certain equipment or conduct of certain operations would entail. Decisions can be made based on economic justifications determined this way. Insurance companies are interested. To determine potential losses it is necessary the probability of an accident or accidents be known. It is frequently undesirable, especially with new products, to obtain probability values from accident statistics.

+ Establishment of acceptable safety levels. A regulatory agency, such as the Consumer Product Safety Commission, can require that products meet stipulated safety levels before they can be put on the market. The British Civil Aviation Authority is already doing this with aircraft to be certified for flights into the British Commonwealth.

+ Comparisons. Quantitative levels can be used to compare two or more designs to see which is safer. Safety analysts in nuclear power design activities have done this.

We have been running into problems in this area. Some of the solutions will depend on activities in other disciplines. For example, we need good, valid data on probabilities of human error. There have been abuses in the use of quantitative goals, but little by little the problems are being eliminated.

The philosophies of System Safety, the concept of life-cycle program planning, and the techniques of SCRAT and of hazard analysis can be applied universally in accident prevention. A good System Safety engineer will be knowledgeable in all of these. He may not be as well qualified in highly specialized disciplines from which it is necessary to obtain esoteric information. Where data on probabilities of human error are required he must step aside for the human factors engineer or the psychologist. On the other hand, System Safety methodologies can be used to determine how the efforts of specialists can best be utilized in an effective course of action. System Safety engineering methodologies can be used to integrate accident prevention programs.

That, to a limited extent, is what we System Safety engineers do. I hope that one of the outcomes of this Workshop will be a recommendation for accident prevention research programs over a long term. I hope that we System Safety engineers are invited to participate in the development of the programs and in specific research activities. We have the people, the methodologies, the capabilities, and the experience.

PRODUCT SAFETY PROGRAM
By Willie Hammer

SAFETY PROGRAM ACTIVITIES

CONCEPT PHASE	DEVELOPMENT GO-AHEAD EVALUATION PHASE	PRODUCT DEVELOPMENT PHASE	PRODUCTION GO-AHEAD EVALUATION PHASE	PRODUCTION PHASE	OPERATIONS AND SUPPORT ACTIVITIES PHASE
1. REVIEW PREVIOUS SIMILAR PRODUCTS FOR SAFETY CONNOTATIONS. 2. DETERMINE PAST PROBLEMS WITH SIMILAR OWN PRODUCTS OR THOSE PRODUCED BY OTHERS. 3. DETERMINE POTENTIAL HAZARDS IN PROPOSED PRODUCT: . INJURIES TO USERS AND MAINTENANCE PERSONNEL . DAMAGE TO OTHER EQUIPMENT AND FACILITIES. . DAMAGE TO COMPANY PRODUCT BY ITS OWN OPERATION. . DAMAGE TO COMPANY PRODUCT FROM OUTSIDE SOURCES . COMPANY PRODUCT INVOLVED IN ACCIDENT BECAUSE OF FAILURE OF OUTSIDE EQUIPMENT OR UNCONTROLLED ENVIRONMENTAL FACTOR. 4. ASSIST DESIGNERS IN PRELIMINARY PLANNING. 5. ASSIST AND PARTICIPATE IN TRADE STUDIES. 6. PREPARE A PRELIMINARY HAZARD ANALYSIS. 7. PREPARE SAFE DESIGN CRITERIA: . REVIEW EXISTING REQUIREMENTS (SPECS, STANDARDS, CODES..) . DETERMINE ADDITIONAL NEEDS WHERE EXISITNG REQUIREMENTS ARE NONEXISTENT OR INADEQUATE 8. MAKE PRELIMINARY DETERMINATION OF SAFETY DEVICES WHICH MAY BE REQUIRED. 9. DETERMINE SAFETY TESTS WHICH MAY BE REQUIRED FOR MATERIALS, SAFETY DEVICES, AND OPERATIONS. 10. ESTABLISH SAFETY REQUIREMENTS TO BE IMPOSED ON SUBCONTRACTORS AND VENDORS. 11. ESTABLISH SAFETY REQUIREMENTS WHICH MAY BE IMPOSED ON USERS. 12. ESTIMATE COST IMPACT OF SAFETY PROGRAM.	1. CONTINUE TO GATHER INFORMATION ON HAZARDS, PERFORMANCE AND SAFEGUARDS. 2. CONTINUE TO CONDUCT SAFETY TESTS ON CANDIDATE MATERIALS AND DEVICES. 3. EVALUATE RESULTS OF TESTS TO DETERMINE FEASIBILITY OF DESIGNS, EQUIPMENT CHARACTERISTICS, OR MATERIAL PROPERTIES. 4. EVALUATE SAFETY ASPECTS OF PROPOSED CHANGES. 5. UPDATE SAFE DESIGN CRITERIA AS NECESSARY TO INCORPORATE CHANGES AND ADDITIONAL FINDINGS. 6. PREPARE "GET-READY" PLAN FOR DEVELOPMENT PHASE: DETERMINE INTERFACES WHICH WILL EXIST AND INFORMATION REQUIRED TO COORDINATE SYSTEM/SUBSYSTEM AND MANUFACTURER/SUBCONTRACTOR/VENDOR SAFETY ACTIVITIES. PREPARE DIRECTIVE TO INITIATE THE PRODUCT SAFETY PROGRAM; IDENTIFY THE PRODUCT SAFETY ENGINEER OR OTHER PERSON RESPONSIBLE FOR SAFETY, HIS RESPONSIBILITIES AND FUNCTIONS; AND RESPONSIBILITIES OF OTHER ACTIVITIES FOR SAFETY. INSTRUCT COMPANY PERSONNEL IN OBJECTIVES AND METHODOLOGIES OF PRODUCT SAFETY ENGINEERING. INITIATE MEANS TO MONITOR SAFETY PROGRAM DURING FOLLOWING PHASES. ESTABLISH INTRA-COMPANY LIAISONS, AND WITH SUBCONTRACTORS, AND OTHER PARTIES CONCERNED WITH PRODUCT SAFETY. 7. PREPARE BUDGET FOR COSTS OF SAFETY PROGRAM AND EQUIPMENT	1. CONTINUE TO ASSIST DESIGNERS IN SAFETY MATTERS. 2. PARTICIPATE IN TRADE-STUDIES AND PROPOSALS FOR DETAILED DESIGNS AND ENGINEERING CHANGES. 3. PREPARE SAFETY ANALYSES EITHER REQUIRED BY GOVERNMENT AGENCIES OR BY THE CUSTOMER, OR TO ENSURE THAT THE MARKETABLE PRODUCT WILL BE SAFE. 4. ESTABLISH MEANS BY WHICH DESIGN PROBLEMS AND THEIR SOLUTIONS CAN BE REPORTED. ENSURE THAT CORRECTIVE ACTION IS TAKEN ON EACH DEFICIENCY. MAKE A RECORD OF ACTION TAKEN OR REASON ONE IS NOT TAKEN. 5. DETERMINE WHETHER DESIGNERS ARE OBSERVING SAFE DESIGN CRITERIA. NOTIFY RESPONSIBLE PERSONNEL OF ANY DEFICIENCIES SO THAT CORRECTIVE ACTION CAN BE TAKEN. 6. KEEP APPROPRIATE MANAGERS INFORMED AND ALERTED TO ANY SIGNIFICANT SAFETY PROBLEMS, POTENTIAL OR ACTUAL, AND TO ANY SAFETY ACCOMPLISHMENTS. 7. DETERMINE WHICH PRODUCTS, ASSEMBLIES, COMPONENTS, OR PROCEDURES ARE SAFETY-CRITICAL SO THAT SPECIAL PRECAUTIONS CAN BE TAKEN DURING MANUFACTURE, TESTING, ASSEMBLY, HANDLING, SHIPPING, AND OPERATION. 8. REVIEW SUBCONTRACTOR AND VENDOR DESIGNS AND PRODUCTS TO DETERMINE WHETHER ANY PROBLEMS EXIST WHICH COULD AFFECT THE SAFETY OF THE COMPLETE PRODUCT. 9. REVIEW PROTOTYPE TEST PLANS TO ENSURE (a) SUITABLE PRECAUTIONS ARE TAKEN DURING TESTING TO AVOID INJURY OR DAMAGE; (b) TEST GOALS FOR SAFETY ASPECTS WILL BE ACHIEVED. 10. REVIEW PROCEDURES TO ENSURE MAN-MACHINE RELATIONSHIPS ARE OPTIMAL TO PROVIDE THE SAFEST PRODUCT POSSIBLE. REVIEW OPERATORS AND MAINTENANCE PROCEDURES AND MANUALS BEFORE PUBLICATION TO ENSURE THEY ARE CLEAR, DO NOT INVOLVE ANY HAZARDOUS TASKS, AND CONTAIN NECESSARY WARNINGS AND CAUTIONS. 11. DOCUMENT ANALYSES, STUDIES, TEST RESULTS AND OTHER SAFETY RELATED INFORMATION. 12. ENSURE ALL TASKS AND TESTS REQUIRED BY GOVERNMENT AGENCIES, CUSTOMERS, OR STANDARDS AND CODES ARE ACCOMPLISHED. DOCUMENT THESE ACCOMPLISHMENTS. 13. IDENTIFY SAFETY AND PROTECTIVE DEVICES AND EQUIPMENT TO BE PROVIDED. 14. INDICATE ACCOMPLISHMENTS AND PROBLEMS TO ANY SAFETY REVIEW BOARD, COMMITTEE, OR OTHER ACTIVITY CONCERNED WITH SAFETY OF THE PRODUCT. 15. DETERMINE WHETHER CUSTOMER'S FACILITIES PRESENT ANY HAZARD.	1. UPDATE ANALYSES OF PRODUCT AS DESIGNED AND BUILT. 2. EVALUATE SAFETY ASPECTS OF PROPOSED CHANGES. 3. EVALUATE PROTOTYPE PERFORMANCE FOR SAFETY CONNOTATIONS. 4. PREPARE "GET-READY" PLAN FOR PRODUCTION AND OPERATION PHASES. 5. INSTITUTE MEANS TO: . INFORM PRODUCTION AND QUALITY CONTROL MANAGERS WHICH ITEMS ARE CONSIDERED SAFETY-CRITICAL AND WHICH PARAMETER ARE ESPECIALLY SIGNIFICANT. . ENSURE THAT PRODUCTION PERSONNEL WILL MAKE NO CHANGES IN SAFETY-CRITICAL ITEMS WITHOUT EVALUATION BY SAFETY PERSONNEL. . ENSURE THAT ANY INSPECTION OR TEST-FAILURES OF SAFETY-CRITICAL ITEMS ARE REPORTED TO THE SAFETY ENGINEER. . REPORT AND EVALUATE CUSTOMER COMPLAINTS AND FIELD SERVICE REPORTS. 6. TRAIN FIELD SERVICE PERSONNEL IN SAFETY RELATED SUBJECTS: . EXISTENCE OF HAZARDS AND PRECAUTIONARY MEASURES. . AREAS WHICH WERE INVESTIGATED BUT FOUND TO BE NONHAZARDOUS. . SAFEGUARDS INCORPORATED. . USE OF SAFETY EQUIPMENT. . NECESSITY FOR STRICT OBSERVANCE OF PRESCRIBED PROCEDURES. . ERRORS WHICH COULD LEAD TO ACCIDENTS. . NECESSITY FOR IMMEDIATE REPORTING OF SAFETY PROBLEMS, POTENTIAL OR EXPERIENCED. . PROBLEM, COMPLAINT AND ACCIDENT REPORTING PROCEDURES.	1. ENSURE THAT PRODUCTION AND QUALITY CONTROL MANAGERS AND PERSONNEL ARE GIVING SPECIAL CONSIDERATION TO ITEMS WHICH ARE SAFETY CRITICAL. 2. ENSURE THAT PRODUCTION PERSONNEL ARE MAKING NO DESIGN CHANGES IN SAFETY-CRITICAL ITEMS WITHOUT EVALUATION BY SAFETY ENGINEERS. 3. ENSURE THAT INSPECTION AND TEST FAILURES OF SAFETY-CRITICAL ITEMS ARE BEING REPORTED TO SAFETY PERSONNEL. 4. ENSURE THAT WARNING AND CAUTION LABELS WHICH SHOULD BE ON EQUIPMENT ARE ACTUALLY PLACED THERE AND ARE IN PROPER LOCATIONS. 5. ANALYZE CUSTOMER COMPLAINTS AND FIELD PROBLEM REPORTS FOR SAFETY CONNOTATIONS. RECOMMEND MODIFICATIONS WHERE SAFETY CAN BE IMPROVED. 6. ENSURE THAT COMPLETE QUALITY CONTROL, CUSTOMER COMPLAINT AND FIELD PROBLEM REPORTS, AND RECORDS ON MODIFICATIONS AND ACCIDENT REPORT FINDINGS ARE MAINTAINED.	1. ENSURE THAT COPIES OF FIELD PROBLEM REPORTS, CUSTOMER COMPLAINTS, AND ACCIDENT INVESTIGATIONS AND FAILURE REPORTS ARE SUPPLIED SAFETY PERSONNEL FOR EVALUATION. 2. PROVIDE ASSISTANCE TO COMPANY FIELD SERVICE PERSONNEL AND CUSTOMERS ON POTENTIAL SAFETY PROBLEMS, FAILURES OF SAFETY CRITICAL ITEMS, OR ACCIDENT INVESTIGATIONS. 3. MAKE FIELD VISITS TO CUSTOMERS OR TO FIELD SERVICE PERSONNEL TO ENSURE OPERATIONS AND MAINTENANCE ARE BEING CONDUCTED AS STIPULATED IN PROCEDURES AND MANUALS.

EXHIBIT 2

PRODUCT SAFETY PROGRAM
By Willie Hammer

SAFETY PROGRAM OUTPUTS

CONCEPT PHASE	DEVELOPMENT GO-AHEAD EVALUATION PHASE	PRODUCT DEVELOPMENT PHASE	PRODUCTION GO-AHEAD EVALUATION PHASE	PRODUCTION	OPERATIONS AND SUPPORT ACTIVITIES PHASE
DOCUMENT SAFETY ACTIVITIES AND ACCOMPLISHMENTS BY PREPARING A SAFETY STATEMENT WHICH INCLUDES: . THE RESULTS OF TRADE STUDIES WHICH HAD SAFETY COHOTATIONS. . THE PRELIMINARY HAZARD ANALYSIS WHICH DESCRIBES THE HAZARDS WHICH REMAIN IN THE ADOPTED CONCEPT. . SAFE DESIGH CRITERIA TO BE OBSERVED DURIHG PRODUCT DEVELOPMENT. . THE RESULTS OF TESTS ALREADY ACCOMPLISHED WHICH HAVE SAFETY CONNOTATIONS. . TESTS TO BE UNDERTAKEH SPECIFICALLY FOR SAFETY REASONS; AND THOSE TESTS TO BE TAKEN FOR PERFORMANCE EVALUATIOH WHICH HAVE SAFETY CONNOTATIOHS. . ANY OTHER DATA RELATING TO SAFETY OF THE PRODUCT, ESPECIALLY POSITIVE FEATURES. . BUDGET FOR ACCOMPLISHMENT OF SAFETY PROGRAM AND FOR PROVIDING SAFETY FEATURES.	1. "GET-READY PLAN FOR SAFETY PROGRAM. 2. REVISE AND ADD NEW INFORMATION WHICH BECOMES AVAILABLE TO SAFETY STATEMENT. 3. PRODUCT SAFETY PROGRAM MONITORING SYSTEM. 4. REPORTS ON SAFETY PROBLEMS (POTENTIAL AND ACTUAL).	1. EXTENSION OF SAFETY STATEMENT, TO INCLUDE (BUT NOT LIMITED TO): . TEST RESULTS WITH SAFETY CONNOTATIONS FROM THE MANUFACTURER, SUBCONTRACTORS AND VENDORS. . ADDITIONAL TRADE-STUDIES AND RESULTS. . SIGNIFICANT SAFETY FEATURES DESIGNED INTO THE PRODUCT. . SAFETY PROBLEMS ENCOUNTERED AND THEIR SOLUTIONS. . ANALYSES UNDERTAKEN AND THEIR RESULTS. . LISTS OF CRITICAL COMPONENTS AND ASSEMBLIES. . ASSURANCES THAT SAFE DESIGN CRITERIA HAVE BEEN MET. 2. PRESENTATIONS AT DESIGN REVIEWS AND SAFETY REVIEWS. 3. DOCUMENTATION FOR GOVERNMENT AGENCIES AND CUSTOMER. 4. SAFETY INPUTS TO PLANS FOR TESTING PROTOTYPES. 5. FEEDBACK TO COMPANY SAFE DESIGN CRITERIA.	1. LISTS OF SAFETY-CRITICAL ITEMS. 2. PROCEDURE FOR PREPARING AND SUBMITTING ENGINEERING CHANGE REQUESTS. 3. "GET-READY" PLAN FOR PRODUCTION PHASE. 4. RESULTS OF SAFETY TESTS AND SAFETY RELATED TESTS ON PROTOTYPES. 5. SYSTEM FOR REPORTING AND EVALUATING CUSTOMER COMPLAINTS AND FIELD SERVICE PROBLEM REPORTS. 6. INPUTS ON SAFETY TO CUSTOMER AND FIELD SERVICE OPERATORS AND MAINTENANCE PROCEDURES AND MANUALS. 7. INPUTS TO FIELD SERVICE PERSONNEL TRAINING COURSES. 8. UPDATED ANALYSES. 9. APPROVED WARNING AND CAUTION LABELS.	1. QUALITY CONTROL REPORTS, ESPECIALLY ON SAFETY-CRITICAL ITEMS. 2. PRODUCTION TEST REPORTS ON SAFETY-CRITICAL ITEMS. 3. LOT IDENTIFICATION RECORDS. 4. ENGINEERING CHANGE REQUESTS.	1. CUSTOMER COMPLAINT AND FIELD PROBLEM REPORTS. 2. RECORDS OF ACTIONS TAKEN ON COMPLAINTS AND PROBLEM REPORTS. 3. ENGINEERING CHANGE REQUESTS. 4. BULLETINS TO FIELD SERVICE PERSONNEL AND CUSTOMERS WHICH: . REMIND THEM OF HAZARDS AND PRECAUTIONS TO BE TAKEN. . MAKE THEM AWARE OF NEW PROBLEMS, HAZARDS, AND CORRECTIVE MEASURES. . INDICATE OPERATING AND MAINTENANCE CHANGES IN PROCEDURES.

PRODUCT SAFETY PROGRAM
By Willie Hammer

SAFETY PROGRAM
PROBLEMS

PROBLEMS

CONCEPT PHASE	DEVELOPMENT GO-AHEAD EVALUATION PHASE	PRODUCT DEVELOPMENT PHASE	PRODUCTION GO-AHEAD EVALUATION PHASE	PRODUCTION PHASE	OPERATIONS AND SUPPORT ACTIVITIES PHASE
1. DESIGNERS' AND MANAGERS' ATTITUDE THAT CONCEPT PHASE IS TOO EARLY TO WORRY ABOUT SAFETY. 2. INADEQUATE OR NO STANDARDS FOR A PRODUCT TO BE MARKETED (PRODUCT SAFETY); INADEQUATE OR NO SAFETY REQUIREMENTS BY THE CUSTOMER (SYSTEM SAFETY). 3. HARDWARE PROCUREMENT SOMETIMES DOESN'T GO THROUGH THIS PHASE.	_ES DEPARTMENT WANTS _ST TO BE REDUCED TO MAKE _RODUCT COMPETITIVE; SAFETY PROGRAM OFTEN CURTAILED OR WIPED OUT. 2. ATTITUDE THAT DESIGNERS WILL PRODUCE A SAFE PRODUCT EVEN WITHOUT A SAFETY PROGRAM. 3. DEVELOPMENT GO-AHEAD EVALUATION TOO HASTY, WITH LACK OF ADEQUATE PLANNING, FAILURE TO ACCOMPLISH SAFETY TASKS, AND FAILURE TO PREPARE GET-READY PLAN WITH ITS SAFETY TASKS. 4. IN A CUSTOMER SPONSORED PROGRAM (SYSTEM SAFETY), MANUFACTURER GENERALLY WAITS UNTIL HE RECEIVES A FIRM CONTRACT BEFORE HE INITIATES THESE ACTIONS. THEN HIS ORGANIZATION IS TOO BUSY TO ACCOMPLISH THEM. 5. NEGOTIATIONS WITH CUSTOMER REGARDING CONTRACT COST OFTEN RESULT IN SAFETY PROGRAM BEING CURTAILED OR WIPED OUT.	1. SAFETY ACTIVITIES OF PREVIOUS PHASES WERE NOT UNDERTAKEN. 2. ADVERSE ATTITUDES OF DESIGNERS AND MANAGERS TOWARDS SAFETY EFFORT. 3. SAFETY REQUIREMENTS ON SUBCONTRACTORS AND VENDORS WERE NOT CONTRACTUALLY IMPOSED OR WERE NOT IMPOSED EARLY ENOUGH 4. FAILURES TO TAKE CORRECTIVE ACTION ON SAFETY PROBLEMS: . FAILURE BY SAFETY ENGINEER TO FOLLOW UP NEEDS. . ADVERSE MANAGEMENT DECISION. . COST OF CHANGE. . LACK OF TIME FOR ACCOMPLISHMENT. 5. PROGRESS OF SAFETY ANALYSES IS GOVERNED AND SLOWED BY: . PROGRESS OF DESIGN AND DEVELOPMENT. . LACK OF AVAILABILITY OF INFORMATION. . LACK OF COOPERATION OF OTHER ACTIVITIES.	1. SAFETY FEATURES MAY BE ELIMINATED TO REDUCE PRODUCTION COSTS. 2. FAILURE TO IMPLEMENT SAFETY REQUIREMENTS ON SUBCONTRACTORS AND VENDORS. 3. SAFETY TESTS NOT COMPLETED PRIOR TO "GO-AHEAD." 4. FAILURE TO HAVE SAFETY PERSONNEL EVALUATE OPERATOR AND MAINTENANCE PROCEDURES AND MANUALS. 5. FAILURE TO PREPARE LIST OF SAFETY-CRITICAL ITEMS AND PARAMETERS. 6. FAILURE TO INITIATE PROCEDURE TO HAVE SAFETY PERSONNEL EVALUATE PROPOSED ENGINEERING CHANGES. 7. MANAGEMENT AND SALES OBJECTIONS TO USE OF WARNING AND CAUTION LABELS ON EQUIPMENT.	1. SAFETY ENGINEERING OPERATION IS GENERALLY ELIMINATED BY THE TIME PRODUCTION PHASE BEGINS. 2. CHANGES MADE TO REDUCE PRODUCTION COSTS WITHOUT EVALUATING IMPACT ON SAFETY. 3. POOR QUALITY CONTROL. 4. MANAGEMENT ACCEPTANCE OF SUBSTANDARD QUALITY TO MAINTAIN PRODUCTION RATE. 5. FAILURE TO MAINTAIN ADEQUATE PRODUCTION AND QUALITY CONTROL RECORDS ON SAFETY-CRITICAL ITEMS.	1. BELIEF THAT ACCIDENTS ARE ALMOST ALWAYS DUE TO OPERATOR ERROR. 2. FAILURE TO HAVE TRAINED SAFETY PERSONNEL EVALUATE CUSTOMER COMPLAINTS AND FIELD PROBLEM REPORTS. 3. FIELD PROBLEM REPORTS NOT ACCOMPLISHED ADEQUATELY. 4. CUSTOMER COMPLAINTS NOT FOLLOWED UP. 5. LACK OF FIELD REPORTING SYSTEM AND OF FEEDBACK TO: EVALUATE WHETHER A FIELD PROBLEM ACTUALLY CONSTITUTES A HAZARD, INITIATE CORRECTIVE ACTION, AND TO IMPROVE SAFE DESIGN CRITERIA FOR FUTURE PRODUCTS.

INVESTIGATIVE METHODS USEFUL IN SAFETY

William G. Johnson
Energy Research and Development Administration

This paper was prepared by WILLIAM G. JOHNSON and discussed at the workshop by ROBERT EICHER. Mr. Eicher has worked closely with Johnson at the Energy Research and Development Administration (ERDA) (formerly AEC) where he is Special Hazards Engineer in the Division of Safety, Standards, and Compliance. Mr. Johnson, retired general manager of the National Safety Council, is the author of MORT - The Management Oversight and Risk Tree, which he prepared for the U.S. Atomic Energy Commission, Division of Occupational Safety.

MORT is a major output of ERDA's continuing development of a safety management methodology for reducing accident rates. Application of MORT has been primarily in occupational safety, however, many of the techniques and methods employed can be useful in consumer product technology as well. The paper presented here serves, in large part, to introduce and annotate MORT for the workshop participants.

For the past six years ERDA (formerly AEC) has been developing a safety management methodology to augment its basic physical research goals. AEC had had safety programs and records equal to the best practices of private industry and government. Nevertheless, the goal of the development work was stated as "an order of magnitude reduction in rates and risks."

The investigative method used in the developing "superlative safety assurance systems" for ERDA was as follows:

1. Conceptual framework -- development of a trial synthesis from the best organizational practices, aerospace system safety methods, safety related research, and behavioral, organizational and managerial sciences;

2. Further development from analysis or reinvestigation of accidents;

3. Trial in an organization (Aerojet Nuclear), and then restatement of the synthesis;

4. Application, training, and technical assistance agency-wide;

5. Ongoing development, especially at Aerojet, but also as numerous laboratories and production facilities.

The primary outputs have been two:

MORT - The Management Oversight and Risk Tree, U. S. Atomic Energy Commission, February 12, 1973, SAN 821-2.

Accident/Incident Investigation, Energy Research and Development Administration, August 1, 1975, ERDA-76-20.

In progress is Workbook on Measurement of Safety Assurance Programs. A review draft is scheduled for May and a pilot training draft for the Fall, 1976. The Workbook will offer numerous examples of the measurement data believed needed, augmenting the hundreds of specific questions already posed in MORT. A method cumulating many specific measurements into assessment of eight broad system criteria will be proposed.

A growing number of supportive publications are coming from System Safety Development Center at Aerojet:

Occupancy-Use Readiness Manual,
Human Factors in Design,
A Contractor Guide to Advance Preparation for Accident Investigation,
MORT User's Manual (to be published shortly).

In addition a variety of training aids and experimental forms are of interest as to methodology.

Organizational research in safety has the following obstacles:

1. The rarity of major events,

2. Difficulty of cross-context comparisons of complex organizations,

3. Paucity of basic research or relevant data,

4. Lack of research orientation among safety practitioners.

The synthesis has supplied a conceptual framework wherein investigation becomes more searching and testing of control programs is more nearly possible.

In the course of the six-year project a wide variety of research and investigation methods have been assimilated, and some new methods have been developed.

The three years subsequent to publication of MORT have included widespread examination and use of the systems by managers and scientists of many disciplines. The usage has confirmed the basic 1973 report, and resulted in extension and development rather than drastic change.

* * *

The relevance of the "superlative safety systems" for consumer product technology lies in two areas:

1. Product safety up to the point of consumer use is amenable to the same control processes (given the substitution of appropriate use and user data, consumer rather than employee);

2. Some elements of the system may have relevance or usefulness in the consumer use phase, but because of the obvious differences between controllable employee behavior and typical consumer behavior, the use phase requires separate evaluation of any given study method for a control or technique.

* * *

For the convenience of Workshop participants, a reprint on MORT from the Journal of Safety Research, March 1975, is attached as Appendix A. Also, ERDA has made available copies of the above publications to Workshop participants.

This paper could be called a "Smorgasbord of Investigative Methods." The intent is to call out the developments within the project briefly. Then, if the reader is interested, the texts or references can be consulted. Many specific measurements and experiments are described in the text.

The order of listing, with a few exceptions, follows the order of the MORT text.

I. Introduction. Among other concepts, the significance of codes, standards, and regulations is presented. They are minima. Useful and necessary to put a floor under performance, but not the route to the optimum performance desired by all.

II. What Procedures Hazards

1. Accident/Incident definition. An essentially new definition is presented (p. 25). It was developed for functional use in design of safety measures. (Short definitions may be superior for tabulating events, but do not lead into essential preventive aspects.) Also Hazard and Risk are defined.

2. Energy and Barriers. The Gibson-Haddon concepts are simple and objective, and have many advantages for prevention analysis. Systematic, sequential analysis of possible barriers has repeatedly produced innovative safety devices of superior efficacy.

3. Frequency-Severity Matrices. Different accident sources typically have different slop lines. A slop less than the 45° line of balance is a danger sign, and appears to have catastrophe prediction value.

4. Error as Accident Cause. The substantial literature on error measurement and error reduction methods can be brought to bear on safety.

   a. Rigby's "error tolerance limits" (p. 52) useful in studying degrees of control, provide macabre humor when a limit turns out to be "forensic."

   b. The Surry decision model (p. 54) has been under careful observation. While it seems conceptually correct, its practical significance seems limited under circumstances of typically subtle danger buildup often conditioned by changes remote in time, and the blinding speeds of accident occurrence. If non-injury errors or unreviewed changes were seen as danger signals, the Surry scheme could be useful. (See McKie, p. 61, for a natural history note.)

   c. The extensive reliability and error prevention work of ERDA's weapon production program is essentially product safety. Much in the way of useful concepts and data on error-provocative situations has emerged. A key point in the work of Sandia Lab is the need for error rates of the general form: errors/opportunities, i.e., the need for user data as well as accident data.

5. The Role of Change in Accidents. This is one of the most important MORT developments. The basic concept of Kepner-Tregoe--in a stable system, change is the cause of the trouble--was initially studied by NSC and has been under intensive study by ERDA. Change analysis is a most powerful technique for identifying obscure causes. It is particularly useful in product quality assurance.

(The form on page 67 is not a form to be filled out. The left hand tabs are intended only to be indicative of the event-related factors to be inserted.)

Most (perhaps all) serious accidents have one or more changes, usually detectable.

Equally powerful as a preventive medium is "Change Based Potential Problem Analysis." (The form on page 69, as now used, has a column "Effects of Change" inserted before "Preventive Counter-Change.")

This analysis could be significant in design of a revised model of a product. Call out all differences (e.g., as irrelevant as color), then analyze Effects of Change. It often turns out that so-called irrelevant changes have significance. This inexpensive, perceptive form of analysis should be a requirement on every project and for every significant change.

The effects of changes are directional and exponential--quite a challenge!

6. Sequences in Accident Causation. MORT (1973) is essentially just descriptive of a phenomenon of lengthy sequences.

The use of sequence as an analytic device was developed by Benner and Wakeland for NTSB. Following their leadership the ERDA Accident/Incident Investigation Manual (AIM), pages 4-3 to 4-8, and Appendix I, discuss the method, "Events and Causal Factors Sequence Diagram," and show illustrative cases. The sequence diagram is the usual focal point of analysis.

Sequence diagrams, coded by MORT codes, now seem a realistic possibility for causal information coding and retrieval.

7. The Role of Risk Management. The scientific literature is summarized, but provides little practical material. The concept which associates risk with the profitable, creative, and "fun" side of a line of balance is articulated. The simplest useful model of risk assessment is described.

III. How to Reduce Hazards

8. Integrating System Safety with Present Best Practices. System safety, as developed in aerospace and nuclear industries, is project related. Insofar as product safety is a project by project effort, system safety can be a recommended approach. The text provided by Willie Hammer* (a Workshop participant) is a valuable guide.

The need to integrate system safety with the best organizational practices arises from the ongoing, continuous operation of the organization, not usually seen as merely as series of projects.

The MORT synthesis incorporates system safety with numerous references (Hammer's text was not then available). However, by now MORT also incorporates many methods and criteria not customarily found in system safety, e.g., change analysis, independent review, procedure criteria, the full spectrum of human factors concerns, ongoing monitoring and audit systems, and the basic management policy and implementation factor.

The basic position is that MORT and project system safety are noncompetitive. Start with whichever one seems appropriate for an ongoing organization or a project and then add the other.

9. Method vs Content. Analytic or observational method (with good people) has repeatedly shown that it is Fast and Cheap, and that it can find some deficiencies not usually revealed by hardware, technical or process specialists. Examples again are error, change, and sequence analysis.

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*Hammer, Willie, Handbook of System and Product Safety, Prentice Hall, 1972.

10. Safety, Efficiency and Performance are Congruous. This tenet can be illustrated with anecdotes and strong beliefs in some business circles. It is not scientifically proven. This carries over to consumer products which commonly have energy use or conservation methods of performing work.

If organizational safety program is redefined as those elements likely to improve safety and performance, the mutual reinforcement is enhanced. Increased positive emphasis on safety is then supported by management. Emphasis solely on codes, standards and regulation will not suffice, nor does it tend to build management support.

An inherent relation between energy, control, and performance (p. 109) underlies much of what we undertake in modern society. When control is not in scale, performance suffers and accidents result.

11. A Safety System as a General Management System. We reinvent nature's biological safety mechanism with essential feedback as a "safety system," or a wide variety of managerial systems.

The beauty of the simple, six element system (p. 113) is that under it we can tree (successive elaborations of essential detail) everything that must be said about safety methodolgy. For example:

Simple - six elements - p. 113

Next level of detail - p. 114

Congruous with general management - p. 128

More detail - MORT

Note a tree is a sequence - left to right and top to bottom.

A tier in a tree is a process - p. 194.

Additional trees can give more detail, e.g., Independent Review tree, Exhibits 8 plus 4-7 and 9-12, or for other subjects, Exhibits 3 and 12.

12. General Safety Program Theses. A simple set of propositions reflects what has gone before and what will follow.

IV. MORT. The appendix to this paper provides the necessary discussion. If MORT seems complex, remember that it must be "necessary and sufficient," and also provide redundant controls.

V. Management Implementation of the Safety System. Ten elements susceptible to measurement and evaluation are listed and described. The elements are correct and basic if the product is a reactor, a process facility, or a product used by others (industry or government) with a strong concern for safety.

The management criteria have not been tested on a consumer product organization. Product safety specialists have opinions that the management elements for product safety are similar, if not identical. A study of product-related management systems could bring about major improvements in product safety. This thesis will be repeated in the Hazard Analysis part.

21. Risk Assessment System. Models varying from simple to complex are presented. Probability goals for safety are now feasible and practical.

ERDA now has several active investigations in analyzing risks in transportation of hazardous materials, using the NTSB model. This model, converted to general organizational problems, is shown (p. 219).

VI. Hazard Analysis Process. The Hazard Analysis Process must be conceptualized and defined. The failure to do so is probably the most glaring single weakness in present-day professional safety work.

22. System Safety and Hazard Analysis. Two concepts, Life Cycle and Safety Precedence Sequence, were well articulated by NASA (but not AEC at the time).

System safety costs (perhaps 5% of engineering costs, and a tiny fraction of total production costs) are essentially small. Managers and engineers commonly see them as expensive; this has never been shown. What can be expensive are the hardware or control systems shown necessary by analyses; then trade-off studies may be necessary and well based.

23. Hazard Analysis Process Defined. The listing referred to on page 235 is "MORT IV," an improvement over the MORT charts in the text, but similar to the large chart which accompanied the Safety Research Journal (MORT V).

The need for the elements in this process has been confirmed in spilled blood and piles of rubbish and ashes. Lack of articulation of such a process is the grave weakness in product and other design.

To facilitate initiation of an improved process, the simplification shown as Figure 1 was developed. It shows the "big six" of hazard analysis which will merit brief comment here:

a. Information search

(1) Codes, standards and regulations;
(2) Accident/incident data. Without any desire to relieve manufacturers, the difficult matter of nationwide product data collection and retrieval may be a valuable service for government action.

b. Change Analysis, already discussed.

c. Failure Mode and Probability/Consequences analysis of residual priority problem lists.

d. Human Factors Review, covered in MORT chapter 26. The MORT tree analysis shown follows common practices, but has demonstrated no efficacy in upgrading investigations or reviews by untrained personnel. We fell back on a classification of skill levels, a low threshold of a "cookbook" or a sensitizing course such as the Aerojet manual cited at the outset. The skill applied to product design is easily classifiable, and the threshold should be a minimum requirement in modern society. Here standards for design will not suffice.

e. MORT analysis.

f. Nonnormal operating modes--start up, shut down, repair, failure, anomalies, etc.--search is a test of imagination.

The final level of required system safety analysis is negotiable from a scaling mechanism--big problems, big analysis--and for a major system safety effort. Hammer is, again, the best guide.

We can now return to some of the other major elements in Figure 1. Good Design Organization (Chapter 27). Strangely, a general format of a design process, onto which a safety process can be easily fastened, is apparently lacking. The points of interactions, particularly early safety input, should be defined.

The role of reliability and quality assurance are understated in MORT (1973), especially for product safety.

What is called for is a three-level investigation or audit of a product design function:

a. Basic design organization.

b. Quality assurance aspects (p. 281).

c. Hazard analysis process (p. 235).

Only the three in combination could give assurance of an error-free design process.

Independent Review. This concept was apparently invented by the AEC, and it is a powerful factor in detecting oversights and omissions.

Trade-offs are not a functional point of design clearly called out in MORT. Safety is a frequent loser in trade-off sessions because the predictive safety data for cost/benefit comparisons are weak relative to other concerns. Therefore, the injuction to always put in the values is made, which will be clear when serious accidents occur (p. 256).

Historical Note. The automobile industry can under excrutiating pain in Senate hearings in 1963 and 1964. Its management policies and implementation, its safety research, its hazard analysis process, and its trade-offs (style for safety) were found less than adequate (LTA in MORT). One company president has said he wishes he knew prior to 1963 what he now knows. The lesson for other manufacturers seems clear--audit and measure processes against ideals, or public agencies will.

VII. The Work Flow Process

Operational Readiness is a test not covered in MORT, but not has the Aerojet guidelines listed above. The process therein shows analytic trees which, with slight adaptation, could be used to determine that a manufacturer was ready to produce a safe, trouble-free product.

However, a simple guideline for universal use is the Nertney Wheel (p. 254).

With one exception, Procedures, the factors of Supervision, Employee Training and Performance Motivation seem inappropriate for consumer product technology.

Procedures (chapter 32). Tested criteria for evaluating procedures are listed. (Seven of ten procedures in a well-run organization flunked the test.) It seems likely most manufacturers' procedures would show at least as high a failure rate.

New View on a Human Factors Process. MORT divides the human aspects into several pieces, remotely classified as relevant to a MORT process. To tie it all together, Figure 2 was developed. The following numbered notes explain the steps in the process. (Other steps are clear, or see MORT index.)

(1) Any number of tests and guides. See special bibliography in MORT.
(2) See Procedures above and MORT, Chapter 32.
(3) Behavior change - Appendix H, Innovation Diffusion, and Appendix I, Acceptance of Proceduralized Systems.
(4) Mager and Pipe, Analyzing Performance Problems, Lear Siegler, Inc. Fearon Publishers, Belmont, California, 1970.

It should be most fruitful to measure the Human Factors Process as it would bear on designers in an organization. They are people, and need support and assistance.

VIII. Information Systems.

The specific criteria listed 343 would likely not be fulfilled by a product data system. Again, government may have a role to fill. The manufacturer does have certain inescapable obligations.

36. Technical Information. Can be well organized and approach comprehensive change.

37. Monitoring Systems. Some can be developed.

a. Error sampling is possible by field study.

b. Failure reporting, especially from controlled groups, such as customer service.

c. Critical Incident Studies (called RSO's in MORT because they are not "critical" in a nuclear industry!). This is a powerful and perceptive tool for product design.

d. Accident/incident reporting systems.

Data reduction for management or design use is required.

38. Accident Investigation. See the new Manual. A few thorough, in depth investigations, including a manufacturer's investigations of the role of his systems, will provide more useful data than superficial investigations of many hundreds or thousands of accidents. ERDA investigations of serious events reveal on the order of forty organizational improvement possibilities per case, about half being system improvements.

Audits of design, production, quality assurance and other relevant programs by high level, independent groups (internal or external) have been shown to be powerful and searching methods of discovering needed improvements, particularly when good audit and process criteria are used.

39. The Organization's Information System. This section extends earlier comments and findings. Primary is the finding that EDP coded systems in industry have produced information of modest diagnostic value, but almost no information for action decisions.

40. National Information System. Many pieces and parts are available but not tied together. Therefore, a designer is placed under an unwarranted handicap. Governmental initiative seems necessary to make diverse information stores easily accessible to smaller organizations.

41. Measurement Techniques.

a. The Frequency-Severity Matrix is further developed (p. 420).

b. Extreme Value Predictions (p. 426) are proving to be a useful means of estimating the probability of more serious events from past "worst event" data.*

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*Gumbel, Emil J. "Statistical Theory of Extreme Values and Some Practical Applications," National Bureau of Standards, Applied Mathematics Series, 1954.

c. Simplistic rates commonly used in industry to measure industrial safety performance are of slight value (p. 432). Also see Appendix K for results of an NSC Symposium on Measurement, pertinent for many safety-related problems.

* * *

In summary, the experiences of the last six years suggest the following needs:

1. A compilation or synthesis of the best available practices to form an ideal measurement yardstick.

2. Systematic investigation of accidents in sufficient depth to modify and improve the ideal system. (A "state of the art" for the next three.)

3. Pilot tests and evaluations of the system.

4. Research and evaluation under conditions where variables are at least known, even if not quantified.

5. Implementation is a long-term project, five to ten years. However, short-term gains result from each improvement; differences can be seen within a year.

These needs apply directly to product safety and commercial transportation, and perhaps other fields as well.

Figure 1.

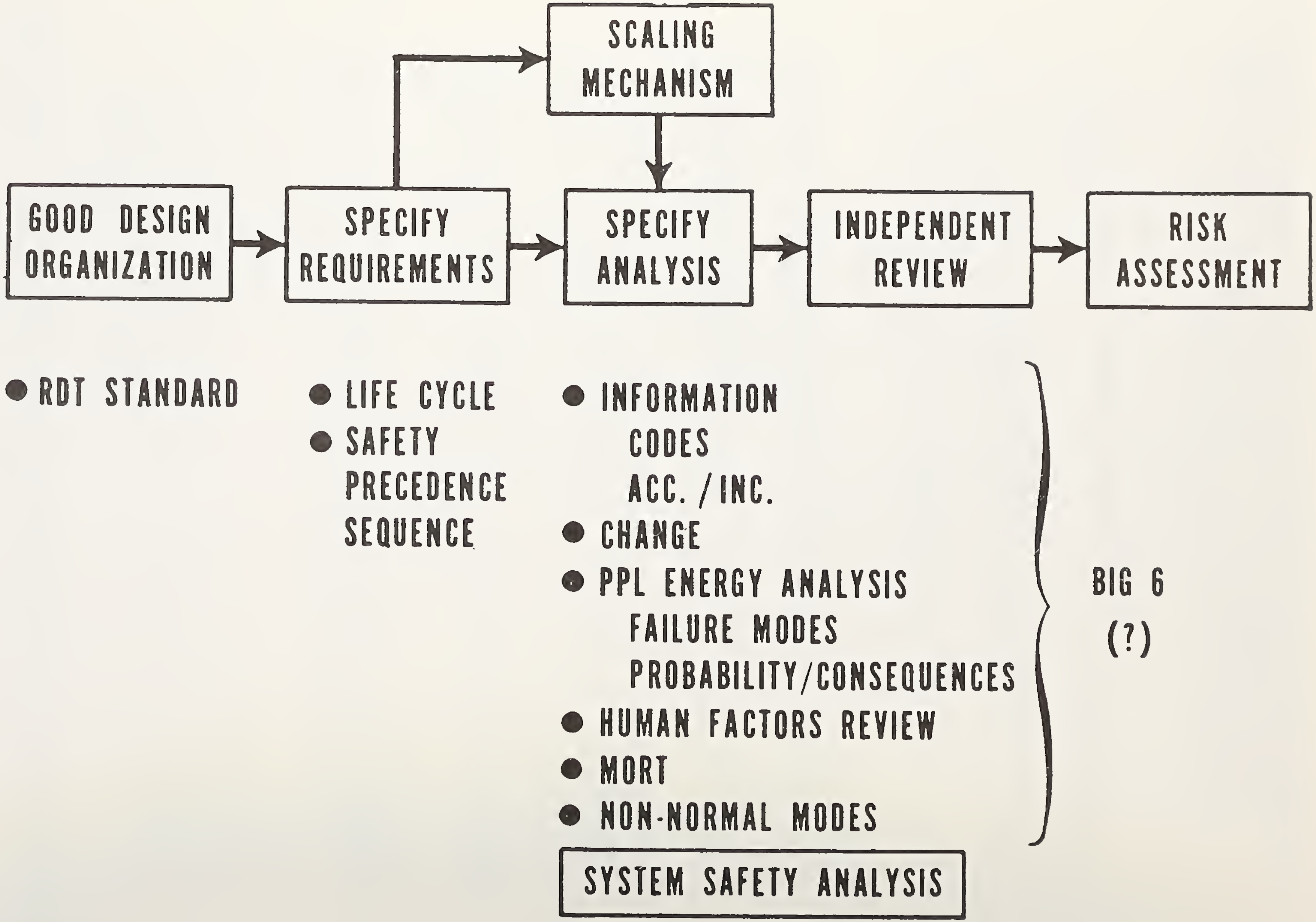
SCALING MECHANISM
GOOD DESIGN ORGANIZATION
SPECIFY REQUIREMENTS
SPECIFY ANALYSIS
INDEPENDENT REVIEW
RISK ASSESSMENT
● RDT STANDARD
● LIFE CYCLE
● SAFETY PRECEDENCE SEQUENCE
● INFORMATION
CODES
ACC. / INC.
● CHANGE
● PPL ENERGY ANALYSIS
FAILURE MODES
PROBABILITY/CONSEQUENCES
● HUMAN FACTORS REVIEW
● MORT
● NON-NORMAL MODES
BIG 6
(?)
SYSTEM SAFETY ANALYSIS

Figure 2.

HUMAN FACTORS PROCESS TO BUILD HIGH PERFORMANCE

Input	Planning and Engineering	Task Description	Preparation	Supervisory Support	Participation Feedback Reward	Performance Problem Diagnosis & Correction	Firm Control
Objectives Challenging Goals Resources Responsibility Authority Accountability	Work which is: Easy to do safely, Not error-provocative, and Minimizes injury potential	Procedure Criteria (2)	Selection Training	Attain and Maintain Operational Readiness		Mager-Pipe analysis (4) Change analysis	Problem & deviation detection Prompt correction Vigor and example
↑ (from Criteria)	↑	↑	↑	↑	↑	↑	↓ if needed
Criteria	Data	Task Support	Opportunity for Growth	Other Support	Appropriate Change Methods (3)	Generalized Mass Motivation Programs	Discipline
Research Studies Guides (1)	Accidents/ incidents Errors RSO's	Equipment Maintenance Work Conditions		Personnel Services Peer Groups Technical Services			

Applies to: Managers, Engineers, Scientists, Supervisors, Operators, Crafts, Etc., Administrative.

Note: Reliability, Quality Assurance, and Safety Assurance have varied complementary roles.

HYPOTHESIS GENERATION FOR RARE EVENTS RESEARCH

Ludwig A. Benner, Jr.
National Transportation Safety Board

LUDWIG BENNER, JR. is Chief of the Hazardous Materials Safety Division of the Bureau of Surface Transportation Safety, National Transportation Safety Board. Mr. Benner has long been involved with transportation safety in a number of capacities. His paper deals with the process of discovery, suggesting that hypothesis development in accident investigations and rare event research need not be a hit or miss proposition based primarily on "creative intuition" and "good luck." Rather, Benner proposes a multilinear events sequencing methodology to aid in the development and testing of research hypothesis. The interested reader is referred especially to Benner, L., Accident investigations: Multilinear events sequencing methods. Journal of Safety Research, 1975, 7(2), 67-73, for a more complete discussion of the proposed methods.

INTRODUCTION

This paper focuses on hypothesis generation. How does one generate propositions that can be tested by scientific methods? Popper (1959) says there is no logical path leading to new ideas--they can only be reached by "emfuhlung" or creative intuition. Polya (1957) offers a "rule of discovery" that goes about like this: the first rule of discovery is to have brains and good luck; the second is to sit tight and wait until you get a bright idea. Their views are widely held.

Surry's (1969) discussion of accident research methodology is useful if further understanding of some of the difficulties with existing accident research are of interest to the reader. But Surry does not discuss the discovery problem.

The problem of structuring discovery, especially the discovery of hypothesis, has been with us for a long time. There may be a way to do it. I would like to share with you my method for generating hypotheses, derived from my work as an accident investigator.

WHAT HAPPENED?

After an accident, every investigator is confronted with the need to answer the question "what happened" regardless of the ultimate purpose of his investigation. The usual approach is to try to "reconstruct" the accident. The method used is to try to isolate events suggested or indicated by evidence acquired after the accident. As the investigator becomes aware of events that occurred during the accident, outlines of what happened begin to emerge. As additional evidence of events comes to light, the investigator begins to speculate about possible hypotheses, that is, ways the accident might have happened. Each hypothesis is tested against the evidence subsequently developed, to arrive at the most likely explanation of what happened.

As I have observed this process, elements common to the search for understanding of any phenomenon have been noted. These observations suggest that there may be a logical path leading to new ideas, and that a general method for generating hypothesis during the study of phenomena, including rare event phenomena, may be possible. The essential assumptions and principles follow.

EVENTS SEQUENCING

My hypothesis generation method is based on the premise that the functioning of our universe and its constituent parts reflects a continuum of interacting events. Events, in this context, are used in the sense that someone or something does something (actor + action = event). Each event influences one or more events which follow that event in time. It is the precede follow logic of the related events that provides the key to the hypothesis generation method.

The accident investigation process is based on a "break down events" principle. Take "an accident" and break it down into increasingly finite events in the following manner. "An accident occurred" describes a phenomenon as a gross event. "A sliding car struck a tree" breaks down the gross event into two subevents. The car rolled onto an icy patch, began to slide, and struck a tree further breaks down the phenomenon into even more discrete events. This "break down" process can be continued for as long as necessary to gain the understanding of the phenomenon required by the purpose of the study. Each time an event is subdivided, the need for more precise understanding of the actor-action relationships arises. And each time the need arises, the last known action by an actor provides a starting point to hypothesize the next action or actions that must have been taken by that actor in order for him to arrive at the next known action supported by the evidence. Thus, the bridging of the events gaps is circumscribed by logical spatial and temporal relationships among the events as they progress through their precede/follow sequence. This method of "breaking down" the events sequence structures the discovery of unknown events required for the sequence to proceed from the beginning point to the end point of the phenomenon being studied.

Usually for someone or something to do something (an event to occur) certain enabling conditions must exist. The creation of these conditions also flows from an event sequence. That is to say, events produce changes of state or outcomes. For any phenomenon under study, the chronological flow of events provides an explanation of what happened, just as we naturally try to create mental movies when we attempt to describe events. The existence of the enabling conditions, which must have been present for each event to occur, can be traced backward in time to explain "why" the events sequences occurred.

A convention for displaying the events sequences, which further facilitates discussion and discovery, has been proposed where the events sequences involve two or more actors (Benner, 1975). This multilinear events sequencing method provides opportunity for a precede/follow logic check along both the horizontal time coordinate for a single actor as well as a vertical time coordinate for sequencing related events by two or more actors. In other words, the timing of any event by any actor can be compared with any other event by any other actor, and this chronological validation provides a method for "proving" the hypothesis that differs from traditional, statistical, or experimental approaches of the scientific method. The display has the further advantage of highlighting unknown "linking" events in the sequence. It can also structure speculations about their occurrence or guide the search for evidence to confirm these speculations.

RARE EVENTS RESEARCH

The multilinear events sequencing methodology can be useful for predictive study of rare events or accident phenomena. If one can accept that accidents are multi-event phenomena involving more than one actor, whose actions must occur in a specified chronological sequence to achieve a harmful or other outcome of interest, it can readily be seen that if any of the events occur out of sequence (or not at all) the outcome being studied will not occur. Thus the pattern of events describing the "rare event phenomenon" can be studied. It is the occurrence of the events sets in the necessary relationship which is rare, rather than the occurrence of individual events within the set.

If this concept is valid, it suggests new approaches for the accumulation of data about rare events in the form of events sets, rather than in the form of individual conditions on events constituting the phenomenon. The manipulation of chronologically sequenced events sets in process flow chart form appears to hold more promise in understanding rare events phenomena than the present approaches. In the accident field, the need for a unifying theoretical framework to organize the events sets for research purposes can be shown to be increasingly urgent. A theory which would accommodate the sequential ordering of events sets in accident and other rare events research has been proposed by the author (1975).

Summary

The sequential ordering and display of events and events sets constituting a rare phenomenon provide a reproducible method for structuring the discovery of a hypothesis explaining the phenomenon, and for testing the logic of the explanation. The application of probabilistic estimates of the frequency of occurrence of these events, both individually and in sets, provides an approach for predicting these phenomena. Time or spatial logic tests, as well as traditional mathematical or other experimental methods, can then be used to validate one's hypothesis.

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EPIDEMIOLOGIC APPROACHES TO INJURY RESEARCH

Julian A. Waller, M.D., M.P.H.
University of Vermont

JULIAN A. WALLER is a professor and chairman, Department of Epidemiology and Environmental Health in the University of Vermont College of Medicine. Active in the field of injury control since 1960, Dr. Waller is the author of a large number of research papers, articles, and books about the roles of medical conditions, alcohol and other drugs in injury, the improvement of emergency health services, product safety, and other aspects of home, recreational and highway safety.

Waller's paper begins with a brief, and excellent, overview of epidemiology and two basic designs used by epidemiologists for testing hypotheses about determinants of injury, namely, the case history and cohort methods. Waller then discusses two epidemiologic methods based on the interaction between the host (victim) and the injury agent (physical energy). The first model presented deals with determining causes while the second is concerned with identifying the range of countermeasures options.

One of the unique things about the field of injury control is that it is not a field. Rather, as best I can determine, it is a side interest or, more correctly, a nuisance issue for several different professional groups--engineers, ergonomists, psychologists, systems specialists, architects, highway and vehicle builders, designers of various types, lawyers, physicians, chemists and administrators, to mention a few. Consequently, the construction of a unified approach to research about or control over injury is something akin to building the biblical Tower of Babel. Each profession has its own concepts, terminology, and acknowledged experts, all of which are largely unknown to members of other professions who may be equally concerned about injury as a social and economic problem.

This fact has been repeatedly brought home to me as, during the past several months of a sabbatical, I have attempted with increasing frustration to write a book covering all aspects of injury control. It is almost impossible to search out all the sources where appropriate literature or information might be found, to always understand what is being said once I have obtained the data, or to translate my material into language that will be sufficiently acceptable to all groups who need to see it.

Just recently, in a long conversation with a systems safety specialist whom I have known for some years, I suddenly realized that his conception of epidemiology was quite different from the realities of the field, as was my concept of the systems approach. Therefore, I welcome the opportunity to explain to others the epidemiologic approaches, their strengths and limitations. I strongly suspect that, if all approaches of epidemiologists and other professionals are laid on the table, it will be apparent that, despite differences in terminology, they often seem to draw upon similar intellectual processes and have much in common.

I. What is Epidemiology

As one might infer, the term epidemiology comes from the study of epidemics, or disease frequencies that are significantly above the expected norm for a population at a given time. As communicable diseases began to decline somewhat as a major cause of death and disability in the western world, other uses were found for epidemiologic tools and concepts so that now the techniques are applied more often to the study of chronic diseases, environmental problems, health services, and the evaluation of countermeasure programs, all areas relevant to injury and its amelioration.

Briefly stated, epidemiology is the study of the distribution and determinants of disease or other phenomena in a population. Several aspects of this need to be emphasized. First and foremost, epidemiology is population based, getting its data not from theory or laboratory or simulation, but directly from observation of the real world, with all the concomitant advantages and disadvantages.

Second, the study of distribution implies that the epidemiologist starts with the expectation that the phenomenon to be examined may not be distributed randomly but rather follows specific nonrandom patterns, and for explainable reasons.* This also means that proper study requires examination not only of those times or segments of the population in which the phenomenon exists, but also for the times or segments in which it does not exist, i.e., the control or comparison population.

Here we already begin to get into trouble. A phenomenon may be thought not to exist in a population or at a given time simply because although present, it cannot be observed. Unlike clinical medicine, which deals predominantly with correction or prevention of health problems which are obvious, epidemiology deals with what is known as the "biologic gradient" of disease. This term simply means that, if studied carefully enough, virtually all disease will be found to vary not only in frequency but also in severity, again for explainable reasons. Thus, a disease may be present but not observable (i.e., subclinical) in some, mild,

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*Because injury events are not random they should not be called "accidents," a term which has connotations of randomness (and consequently inability to change) and also prescientific connotations of acts of God, punishment for sinfulness, carelessness, etc.

moderate, or severe in others, and also fatal on occasion. The distribution of this gradient varies with the phenomenon and the circumstances. Thus, the epidemiologist is concerned both with frequency and severity.

Third, the study of determinants involves identifying why a phenomenon is nonrandomly distributed as opposed to the previous question of how the distribution is nonrandom. Here, again, some basic tenets should be noted. In studying determinants one commonly examines the host (i.e., person or other living thing affected by the phenomenon), the agent (or factor necessary for the phenomenon to occur) and the environment which may modify frequency, severity, or both. Also of importance may be the vectors, or vehicles by which the agent is carried to the host.

Some nonepidemiologists with whom I have spoken are under the impression that epidemiology seeks out single causes. While it can be and often is used for this purpose, it is most important that one of the basic tenets is that a single cause may have multiple effects and that a single effect may be the result of several causal factors. In some cases, these causal factors may be capable of producing a single effect. In other cases, the effect may occur only if two or more factors are present simultaneously or in tandem. In the study of injury there have been far too few sophisticated studies philosophically oriented toward and capable of examining a multitude of factors simultaneously. This is a fault of the users, rather than of the capabilities of the field.

Although there have been many variations, two basic designs exist for testing hypotheses about determinants, and a brief discussion of the advantages and disadvantages of each of these designs is warranted. Both designs require examination of two populations over two time frames, the so-called 2 x 2 model.

The case history or case-control method involves comparison of a population that has the disease (in this case injury or events capable of producing it) with a population that does not have the disease. It thus starts with the second time frame, that is after the disease has occurred. Then, through questioning, study of old records, etc. this method attempts to determine how often factors hypothesized to be causal existed during the period antecedent to the disease.

Applied to injury, the researcher would compare persons fatally injured in crashes with those not involved in crashes to determine how often each group had alcohol present. The "hooker" is that since the data are from the real world the populations being compared may differ also in many factors other than alcohol, some of which may be equally or even more relevant to the occurrence of injury events. Thus, the epidemiologist attempts to match the ill and well populations for as many variables as possible, leaving unmatched only those which are subject to hypotheses.

The advantages of the case history method are that it is relatively quick, inexpensive, and can be applied to rare events. The disadvantage is that it cannot be used to describe the absolute frequency with which the disease occurs in populations with or without the causal factor in question. For this, one must turn to the cohort method which, in turn, has disadvantages of high cost, much longer time frame for completion of the study, and inability to examine rare events.

The cohort method is the exact reverse of the case history approach. The two populations identified are those with and without the variable or variables hypothesized to cause disease or to affect its severity. Both populations are then followed over a specified time, and the resulting proportions with disease or with greater severity are then compared.

Again applied to injury, using the case history method one could say that 42% of fatally injured drivers but only 3% of drivers not in crashes but with similar driving exposure have blood alcohol concentrations of .10% by weight or greater. Using the cohort method, it would be possible to say that the risk of crashing per 100,000 miles of driving is p_1 with no alcohol present and p_2 with a BAC of .10%. Of course, the cost of following two such populations using the cohort method is prohibitive, and there are very serious and insurmountable ethical issues regarding permitting persons impaired by alcohol to drive and to expose themselves and others to the risk of crashing.

II. Relation Between Epidemiologic and Other Methods

What are the relationships of epidemiologic methods to other ways of studying injury events for purposes of establishing countermeasures? Important similarities and differences exist. One similarity is the creative process. Whether the method involves epidemiology, psychology, system design, simulation, or any other approach, the result will be no better than the capability of the researcher to do modeling, that is, to identify all of the potentially relevant cells or branches, to establish cogent hypotheses, and to design acceptable methods for testing them. I would suggest that the approach to an injury problem commonly goes something like the following:

1. Hypotheses are established based on anecdote or unorganized observation.

2. The hypotheses are tested through epidemiologic, sociologic, or possibly engineering analysis of real world experience and through selected laboratory simulation.

3. Building upon data about frequency, severity, and causal factors so obtained system designing then begins to take place, identifying all possible component branches that need to be considered, dealing with types of failures that may occur, relative probabilities and likely results. Of course, one can design a theoretical fault tree involving a totally new product or situation. But even here the designer builds upon previous experience using data drawn from other potentially applicable situations.

4. Testing and further development of the system model takes place through additional epidemiologic, laboratory and other studies, including simulation.

5. Priorities for countermeasures are established based upon selection of those aspects of the problem that seem to be associated either with greatest frequency, severity, or both, and that simultaneously have greatest likelihood of feasibility. By feasibility, I refer not only to technical and economic issues but also to social, legal, cultural, and other issues that form the warp and weft of human society. For, as Henry Wakeland has aptly noted, this nation "has never been satisfied to serve only one set of values".[1] Wakeland has recently published a paper which considers 18 values related to safety and other social issues in assessing the expected success of different countermeasures.[1] These values can be further grouped into the following categories:

a) economics
b) public image and psychological motivation
c) equality and fairness
d) deservedness of protection
e) critical position in a technical system
f) timing

6. Finally, one or more countermeasures may be applied. If fortune smiles, arrangements have been made to permit adequate evaluation. Here again, epidemiologic methods may come into play.

It must, of course, be immediately apparent that the methods and concepts used by epidemiologists are not limited to this professional group, any more than methods of other professionals are used by them alone. Several of the above steps, and occasionally even all of them, may be carried out either by a single individual or professional group, or by members of a number of professions.

I hasten to note that most of the epidemiologic research in the field of injury control has been concerned with examining the distribution and determinants of injury events and of the severity of such events. This has led to proposals for countermeasures, the effectiveness of which has been evaluated in relatively few cases.

Almost entirely nonexistent has been either epidemiologic or sociologic research into the "process" by which injury control priorities are either established and implemented, or sought but blocked. Why, for example, despite years of documentation about their value is it so difficult to obtain adequate regulations and legislation for use of seatbelts and other passenger restraints or to keep such legislation for motorcycle helmets? Why at the same time is there such concern, effectively translated into congressional action, about the safety of school busses, when a bus program may save the lives of only 30-40 persons per year, and then only at great cost?

Why has the National Transportation Safety Board had such a poor batting record in convincing others to adopt its countermeasure proposals despite extensive and thoughtful system modeling? Recent studies from the National Bureau of Standards show that sodium chloride mordant in upholstery fabrics may add to the toxicity of fumes when such fabrics burn. Why is there resistance within the Department of Commerce to applying the results of this work toward reduction of deaths from fire? Research is no more useful than the applications to which it is put. And much more research about the whys and why nots of this application process is needed.

I noted earlier that in looking for causal factors that might affect frequency and severity the epidemiologist seeks out clues about the host, agent, and environment. Through work by Gibson[2] and by Haddon[3] the agent in injury events has been identified as physical energy (chemical, thermal, kinetic, electrical, or radiation) transferred to the body in sufficient quantity and at rapid enough rate to damage tissues. The following are two epidemiologic models based on the interaction with this agent. The first model is concerned more with identifying causes while the second deals with identifying the range of countermeasure options.

III. A Model for Injury Occurrence and Outcome

The safe use of energy that has been massed by man, or the safe exposure of humans to forms of energy massed by nature, depends on two generic factors--the level of functioning of the person and the demands of the task inherent in making the energy serve the functions we wish.

Each person has certain capabilities which vary from moment to moment and from one person to another. One of these capabilities is one's knowledge about one's self in relation to different aspects of the environment. Such knowledge depends upon basic intelligence, experience, education, short and long term memory, and attitudes and belief systems which one may bring as cultural heritage. Another capability is the ability to receive information about the environment through inherent senses such as sight, hearing, touch, smell, taste, vibratory sense, and vestibular function.

Yet a third attribute is the ability to make rapid judgements about one's self in relation to the environment as a result of the combination of information received through the senses and knowledge applied in interpreting such information. Finally, there must be the capability to act in response to judgements that suggest danger may exist. In order to act effectively to the variety of tasks that we must perform daily, a person usually must have range of motion, strength, stamina, speed, and balance.

In summary, therefore, each person must have the capability to receive information correctly, process it in timely fashion, and react appropriately.

What are some common task demands? Some tasks are extremely complex, requiring extensive learning, judgement, intelligence, or all three. Other tasks require use of several senses simultaneously, or the ability to pay attention to multiple stimuli or signals at one time. In other cases, there is a requirement for quick action, dexterity, strength, balance, or stamina. Tasks may vary in demand not only from one task to another, but also for a single type of task over time. In general, the more automated the task the easier it is to perform and the more consistent is it likely to be.

The Pre-Injury Phase

Let us now put the person with his or her capabilities and limitations together with the task and its unique set of demands. As long as the actual performance of the person exceeds the demands of the task at all times there is no likelihood that an event potentially capable of producing injury will result from the interaction. If for any reason, however, the task exceeds the performance level the energy being managed or controlled by the task is no longer in control and may be available to cause injury.

This moment at which task demand exceeds the performance is commonly referred to as an "accident" by the public.

Three types of situations exist in which the demands of a task may momentarily at least exceed the performance of the individual. First, a person may suddenly or chronically function at a level of performance below the average for most people. This can happen because of an acute or chronic medical condition such as epilepsy, diabetes, heart disease, mental illness, or senility, or because a person is temporarily under the effects of a drug like alcohol or carbon monoxide or is extremely young.

There is also some documentation that lower performance may occur during the premenstrual and menstrual parts of the normal menstrual cycle, and conceivably during some hours of circadian cycles. Inexperience with the particular task, or certain social or societal conditions and pressures may also lead a person to function at less than usual performance level, an example being the driving behavior of a teenager in the presence of peers.

Another way in which demand may exceed performance is because the task either is continuously difficult or has suddenly and temporarily become substantially more demanding. This may happen for various reasons, some common and some unique. As the task increases in demand the performance level of the person also increases somewhat, but often not enough to prevent demands from exceeding performance at least on occasion. The change on the part of the person represents utilization of some of his or her spare capacity until maximum performance level is reached in order to attempt to avoid what has been perceived by the person to be an impending disaster as the task gets increasingly out of control. Spare capacity refers to the level of performance a person is potentially able to produce at any given moment in order to prevent task demand from exceeding performance level.

We are now ready to examine the third type of failure situation, one that is commonly overlooked because people tend to think only of human failure <u>or</u> task overload. In this case both the person and the task contribute to the event. The person may be temporarily or consistently functioning at <u>somewhat</u> less than average level at the same time that the task is temporarily or consistently <u>somewhat</u> more than usually demanding. Thus, because of joint contribution the two lines are close together and have significantly greater than average likelihood of crossing.

Why is this sort of relationship so often overlooked when it may in fact be the most frequent mechanism in the initiation of injury events? There are probably two reasonable explanations. First, most of us are taught from grade school on to oversimplify explanations of causation. Thus, we are more likely to be trained for and attuned to seeking single causal factors than to identify and tease out more complex etiologies, perhaps involving several conditions acting simultaneously.

Probably equally important, many of the relative increases in task demand are so common and so subtle that most of us respond to them subconsciously, and we do not realize that it is only because we usually have sufficient capability to maintain a fair degree of spare capacity that we are able to effectively deal with sudden and sometimes unnecessary increases in task load without disaster.

Given the information about the interactions of humans and tasks in the pre-injury phase, it should be possible to combine the examples of varying human capabilities and different task demands, and spare capacity into a single diagram. This has been done in the figure which shows that as the task gets more demanding, it (a) reaches a point at which it is beyond the capability of the least competent (with respect to that task) members of society, and (b) reduces the amount of spare capacity that more competent members may have remaining at any given moment so that they can avert disaster if there is a sudden further increase in task demand, a sudden decrease in their own performance, or both.

Let us assume, as shown in this figure, that a point has been reached at which task demand exceeds performance level and the real or potential energy that is being managed is now no longer under control. At that moment the pre-injury phase has been ended and the injury phase of the event begins.

<u>The Injury Phase</u>

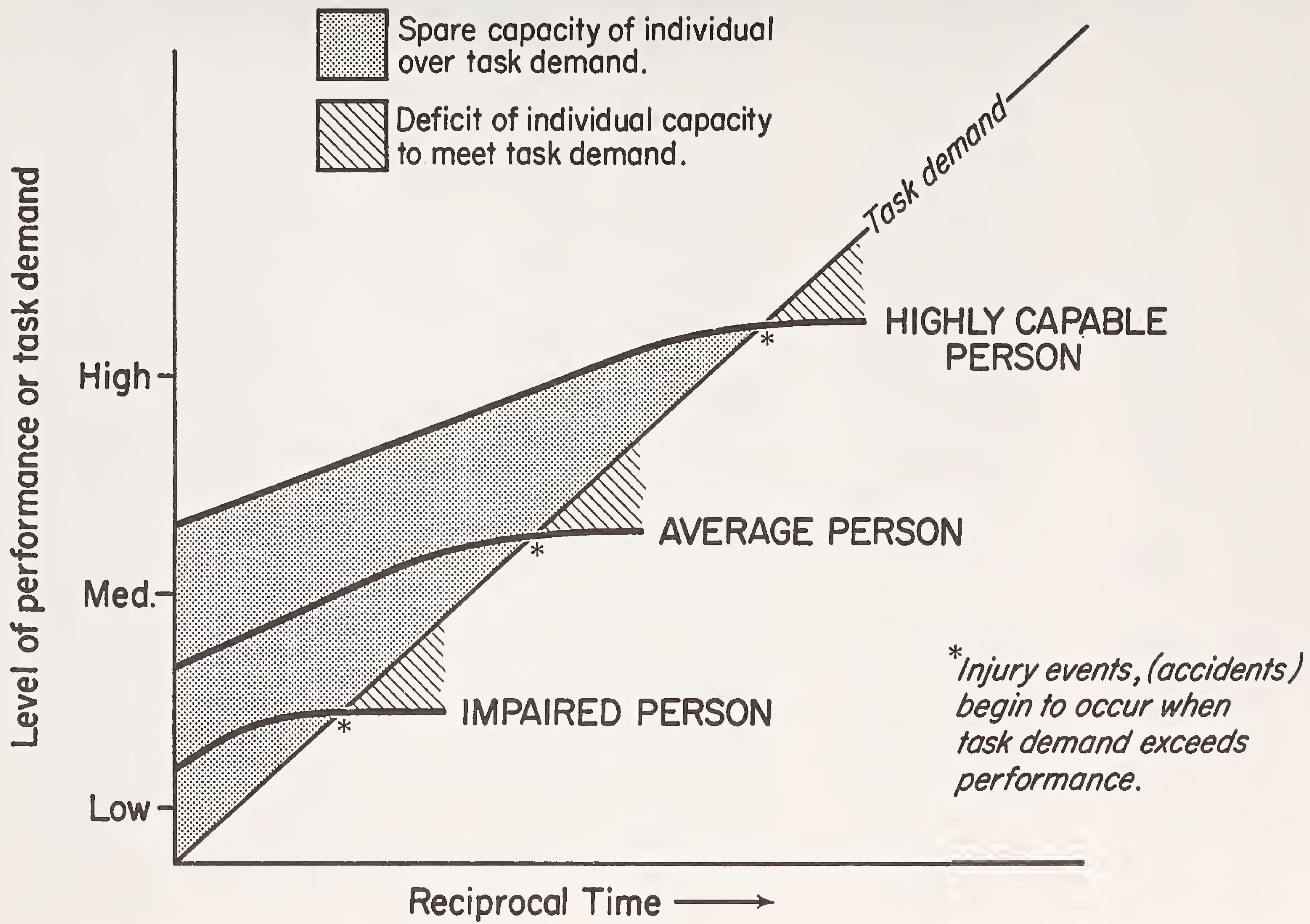
The fact that energy is out of control does not in and of itself mean that an injury must necessarily occur. Several intervening conditions determine <u>whether</u> injury will occur and <u>how severe</u> it will be. The basic principles are the following:

1. The greater the mass of energy that exists and is released, and the more rapid the release, the greater the likelihood that injury will occur and that it will be severe.

2. If the energy reaches tissue, the rate of the transfer (ideally described in units of energy per unit of body tissue per unit of time) determines the severity of injury.

3. Severity is also determined by inherent characteristics of the tissue itself and of the organism.

RELATIONSHIP BETWEEN HUMAN PERFORMANCE AND TASK DEMAND



An Alternative Pathway

Although all unintentional injury involves damage by misapplication of physical energy some such events occur through a mechanism other than the unintentional transfer of energy from an external source to the person. The body carries out its own internal mechanisms for energy management that permits us to maintain a balance or homeostasis with the environment. An event that interferes with this homeostasis can also cause harm through energy misapplication. Examples include drowning, some types of poisoning, and exposure to extreme cold.

Post Injury Phase

One further generic factor determines the ultimate outcome of injury. This is the entire series of actions that occur after the injury and which may result at one extreme in early rehabilitation without permanent harm, or at the other extreme in either death or continuing disability. Data suggest for example that somewhere between 15-25% of persons who die from highway crashes might still be alive if emergency care were more readily available and of better quality.

Innocent - and not so innocent - Bystanders

One of the questions that is sometimes raised by people who consider the energy management model just described is whether it takes into account the apparently common occurrence in which an innocent bystander is injured. The answer is yes. We need to consider two types of situations, that in which the individual who is injured clearly is an inadvertent victim, and that in which he or she only appears to be so.

The model presented indicates that if an energy management task is greater than the individual's capability of dealing with it the energy may go out of control. From that point on the errant energy may be available to injure the person who was originally handling it, or it may create damage to any other people or structures that happen to be in the immediate vicinity. Thus, the driver of a bus or pilot of a plane who loses control of the vehicle may take with him not only his passengers but, especially in urban areas, many others who are only circumstantially associated.

Can this be described as a random event? It can only in a very narrow sense. One may not be able to predict which particular innocent bystander is likely to be injured. But it may be possible to prognosticate fairly accurately how many such persons, of what types, and under what conditions. Socioeconomic, cultural, and legal circumstances, for example, determine the degree of crowding that may exist in an apartment house, or on a bus, and the likelihood that the particular bus or building meets specific safety codes. Federal, state, or local standards may dictate whether a plane, or a truck with high energy explosives, is permitted to travel through areas that are heavily populated or whether precautions have been taken so that even if the energy is out of control it will damage relatively few unsuspecting persons.

Let us now look at the not so innocent bystanders. Surprisingly, there are more of these than is commonly thought. One group of not so innocent bystanders is easily identified--people who stand around and observe arguments, fights, fires, and other disasters and who consciously run the risk of being drawn into a potential chain of damaging events.

Another group is individuals who are seriously or fatally injured as passengers of drivers impaired by alcohol. There is now strong evidence that such persons as a rule also have been drinking and usually are as impaired as is the driver of the vehicle.[4]

What about people who are lost in ravages of floods, tornadoes, earthquakes, or volcanoes? Surely they must be innocent victims. Information suggests that in fact this may not be the case. One is the long history, going back into antiquity, of rebuilding homes and even entire cities at the same location where previous ones were just destroyed by "natural events" with high probability of reoccurring. Furthermore, such redevelopment may use precisely the same methods of construction that were shown to be noneffective in the past. Finally, in contrast to this ignoring of long-term warnings, there is the deaf ear turned to notices of immediate danger.

Thus, in the presence of natural massings of potentially destructive energy, people through all of the methods described above do not function in a manner most conducive to keeping the energy within some modicum of control, i.e, in a way that will limit its harmful effects on them. Such individuals cannot be called innocent bystanders. (It must be emphasized that this statement is not as pejorative as it appears on first reading. Although persons who ignore warnings about imminent disasters may be acting foolishly, those who build or rebuild in known hazardous locations or ways may be doing so because they personally have no other options because of shortages of land, money, etc. The "blame" for such persons being at greater risk may rest with the community or society rather than with the individuals.

IV. A Model for Countermeasures Against Injury

Before describing the range of options for reduction of injury and its outcomes, we need to examine first some important questions concerning relationships between what is known about the mechanisms of injury events, and what actions may be appropriate to reduce the frequency and severity of injury. Appropriate countermeasures to a specific type of problem--whether it be injury or illness--can be derived logically from what is known about the natural history of the event and its circumstances. But, contrary to common opinion, they do not necessarily flow obviously from such knowledge.

The difference between obvious and logical is that an obvious solution is one suggested primarily by examining relative frequencies of different factors in injury events and by attacking first the factors with highest frequency. A logical solution on the other hand is one that may include information about frequency as one of its considerations but that is suggested primarily by examining the relative feasibility of countermeasures for affecting ultimate outcome of death, disability, and discomfort and for having limited unwanted side effects such as excessive economic or social costs. Occasionally, an obvious solution is also a logical solution.

The ideal logical solution to a health problem is one that can be applied universally and that works with a very high degree of effectiveness once applied. Such ideal solutions often do not exist, however, and one may have to be content with logical solutions that are applicable to helping all people only under more limited circumstances or to fewer people over a wider range of events. The appropriate approach in this case to dealing with a particular type of injury or other health problem would be to put together a network of somewhat overlapping logical solutions that have high effectiveness for limited situations or limited but acceptable degrees of effectiveness for wider situations so that in combination these partial solutions can bring about substantial reduction in injury frequency and severity.

The model for injury control[5] developed by Dr. William Haddon starts with the concept of physical energy as the agent in injury events and asks in progressive order with relation to the previous model what methods exist for limiting the harmful effects of that energy on people and property. Here is his list of logical solutions.

1. Prevent the initial marshalling of the form of energy.

2. Reduce the amount of energy marshalled.

3. Prevent the release of energy.

4. Modify the rate or spacial distribution of release of energy from its source.

5. Separate in space or time the energy being released from the susceptible structure.

6. Separate the energy being released from the susceptible structures by interposition of a material barrier.

7. Modify the contact surface, subsurface, or basic structure which can be impacted.

8. Strengthen the living or nonliving structure which might be damaged by the energy transfer.

9. Move rapidly in detection and evaluation of damage and counter its continuation and extension.

10. Carry out all those measures which fall between the emergency period following damaging energy exchange and the final stabilization of the process (including intermediate and long-term reparative and rehabilitative measures).

This series of options is both unique and interesting because it places the emphasis on dealing with the energy at all stages that lead to and can affect ultimate outcome instead of emphasing primarily how humans can be modified, and particularly doing so in the pre-injury phase, as has been the most common approach for many years. Changing people is not excluded per se in this series; it is one of the possible methods available to prevent the release of energy. Reducing task demand is another method appropriate here.

My only problem--and it is a minor one--with the Haddon model is my belief that especially within the third option alone there exist many potential countermeasures whose details could be spelled out more explicitly. Human performance, for example, can be maintained at satisfactory level for specific tasks at least theoretically by the following means:

a) Limit exposure to certain tasks either voluntarily or legally only to individuals who are capable of performing them.

b) Educate people so that they have requisite knowledge about the nature of task demands and knowledge and skills so they are able to deal with these demands.

c) Manipulate those attitudes and behaviors of people that may be amenable to conscious control through a combination of education about reasons for appropriate attitudes and behavior, peer pressure, and laws and regulations.

Turning to task demands, these can be altered in the following manners:

a) Simplify the task so it puts less of a burden on single senses and permits one to assess the same information with equal effectiveness using other sensory routes.

b) Simplify the task so it requires less intelligence, learning or memory.

c) Simplify the task by making cues more easily visible, legible, and less subject to visual confusion.

d) Simplify the task by not requiring simultaneous attention to two or more cues.

e) Simplify the task by neither providing stimuli so quickly that the individual cannot respond to all within the time available (as may occur in rush hour traffic) nor so slowly that the individual becomes bored and is unable to concentrate on that task.

f) Simplify the task by not putting controls of similar design so close together that they may be confused.

g) Simplify the task so it is not possible to turn on a piece of equipment inadvertently while part of the body is near a portion of the equipment that can create harm.

h) Reduce task demand by not leaving out important information that the individual needs in order to assess the environment. This concept includes a sufficient repetition of information so that it is not lost entirely if, for whatever reason, it is overlooked the first time it is available.

i) Reduce physical demands of the task by decreasing the amount of strength, speed, stamina, balance, or range of motion required.

j) Finally, make the task so demanding that persons not competent to perform it well will be unable even to start the activity and thus by physical means will be protected from having any exposure to the hazard.

These ideas I'm sure are quite familiar to those who specialize in human factors engineering.

V. Comments About Past and Current Research

Several important limitations exist concerning injury research as it has been and is now being carried out. First, as already noted, research about the process by which ideas and data are converted to action programs is almost entirely absent.

Second, regarding another issue already alluded to, very few studies have sought to examine a range of potential contributory factors simultaneously in a manner that would permit observation and assessment of interactions. Even where such examination has occurred, as in the multidisciplinary accident investigation program of the National Highway Traffic Safety Administration, the emphasis has been on more obvious types of failures or problems, whether involving humans or the product/environmental complex. Studies to explore more subtle interactions, such as shown in the figure, just don't exist in the multidisciplinary endeavors. I do not know if this absence is because few people are aware of the concept or because the technology for teasing out the subtle is felt as yet to be too much in its infancy.

This absence of such studies is especially surprising since several laboratory type efforts for the Department of Transportation suggest that there is potential pay dirt in combining human factors and epidemiology. Such combined methods could determine to what extent and under what circumstances theoretical problems identified through laboratory studies actually result in real world problems.

In illustration, studies for DOT indicate that drivers in several late model American made automobiles have only about 40-70% of possible maximum visibility available to them[6], and that in most automobiles manufactured in the early 1970's drivers in the top and bottom 20% of size have difficulty in seeing or reaching all control devices when wearing seatbelt and shoulder harness.[7] Consumer Advisory Booklets just issued by NHTSA show that the braking performance to get a car from 60 to 0 mph for 1976 car models ranges from 159 to 250 feet.[8] For 1976 tires placed on a fully loaded car the reserve capacity ranges from 0% to 25%.[9] So what?! It's about time we knew what this means in real world crash experience. One report about crashes of large trucks suggests that as many as 900,000 such events annually may be attributable at least in part to limitations inherent in the design of current rear view mirrors and other problems of limited vision on these vehicles.[10]

Turning to product safety, ceramic top stoves are now made with burners that do not change color when they get hot. Theoretically, this subtle increase in task demand represents a problem for, among others, the person who has reduced vision and heat sensation because of aging, or the person who is distracted. But what does it mean in terms of real events? I ask that question only academically as a epidemiologist. As an administrator concerned with injury control I have very strong feelings that, given the information that already exists about the behavior of children and of housewives under pressure, and the physiology of aging, manufacturers should have had more sense and more sense of responsibility than to market such a potential hazard in the first place.

Third, attention should be directed to cultural contributors to injury events. I refer here to two different phenomena. One of these is the fact that when a new product or pattern of functioning is introduced into a culture it often appears to be associated initially with a very high injury rate during a learning period. Some of this may be because the product itself commonly is still in prototype state with important hazardous bugs to be worked out. This seems to be the case, for instance, with the snowmobile.[11]

But an important part of the problem also appears to be absolute or relative ignorance by users and others exposed about rules of use and potential hazards. A good example is the pattern of problems associated with the introduction of the automobile to the United States 75 years ago and to many of the so-called developing nations now. A paper about traffic problems in Sudan[12] presented in 1975 documented that even such simple rules as on which side of a traffic island one should drive may be nonexistent in some places where there are still very few cars. Education probably is useful during this early phase. But, because it is useful early we tend to think it is still just as useful after the passage of years; and this assumption may not be correct.

The other cultural phenomenon is that different populations vary in what is expected or permissable regarding acting out, relating to each other and relating to the surrounding environment. This means that there may be important cultural variations in the frequency and causation of injury events, in seeking of care once such events occur, and in the potential success of specific countermeasures. By and large, this aspect of injury and injury control has not been explored because few sociologists have been interested in injury as an area for research, although recent conference proceedings edited by Dr. Alphonse Chapanis represent an important entree of human factors specialists intc this field.[13]

Fourth, some very rare but exceedingly catastrophic forms of injury events now are on the verge of becoming predictable, and research about responses to such predictions is warranted. I refer to the fact that it is now possible to warn people about imminent tornadoes and tidal waves, and that similar capability almost exists for avalanches and earthquakes. One study suggested that observable differences in death rates from tornadoes in northern and southern United States may be largely attributable to differences in resident responses to warnings.[14] Since the capability to predict and to warn is likely to precede the capability to prevent by several years at least, we had better have some rather good information about what available countermeasures are likely to produce.

Finally, one of the important problems of dealing with real world phenomena, usually after the fact, is that the quality of data, especially those collected through official sources, can only be described as generally execrable whether one refers to information about the extent or nature of populations at risk, frequency of injury events, severity, causation, or countermeasures. In illustration, one research group reported that 61% of the motorcycle crashes resulting in treated injuries or death that they found were not listed in the official police statistics.[15] Another study identified 668 contributory factors among 104 randomly selected motor vehicle crashes in Iowa.[16] Fifty percent of these factors were reported to be vehicle related, 31% involved the environment, and 19% the driver.

According to the author of the study, "the results of this investigation appear to contradict the prevalent concept that 85% of all motor vehicle accidents are due to driver malfunction. This concept results from a rather consistent reporting on the part of the National Safety Council. If the sources of information are examined, the apparent contradiction is understandable. Individual states report their yearly traffic accident experience to the National Safety Council on a standard form. This form allows for 12 contributing circumstances to motor vehicle accidents. Two relate to the vehicle, and the other 10 relate to the driver. There are no roadway circumstances allowed.

If the results of this investigation were to be reported within the confines of the standard summary form, the total number of contributory factors in the 104 accidents would have been reduced from 668 to 140, and 125 would be driver related. Within the context of the source material available to the National Safety Council, this sampling of accidents would be analyzed to indicate 89% of the contributing circumstances were driver related. The majority of the contributory factors could not be tabulated."

Lack of awareness of this problem is especially important because it shapes everything from the initial hypotheses to the end results of the many researchers who only incidentally do research about injury instead of engaging in such activity seriously over several years. Such persons commonly do not stay long enough to learn about and avoid the pitfalls of the data. To paraphrase Dante, "all hope of valid data abandon, ye who enter here". But drawing also from a recent short story by Isaac Bashevis Singer,[18] even in hell one can continue to strive for improvement.

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NEEDED HUMAN RESEARCH AND NEW METHODOLOGICAL CONSIDERATIONS BEING FORCED BY THE LAW

George A. Peters, Esq.

GEORGE A. PETERS is both a lawyer and an engineer who has long been active in human factors. As a lawyer, he has limited his practice to product liability litigation, retaining an active interest in engineering as it relates to the law. Mr. Peters is the author of the book Product Liability and Safety (Coiner Publications, 1971) and many articles in law journals.

Peters' presentation to the workshop is based on the premise that it is the common law which provides the major forcing function in safety endeavors today. It is in the courts that "... the vital safety issues and concepts are framed, final factual decisions are rendered..." Peters contends that it is time, past time really "... for the professionals to get more involved in these safety issues, so that valid information will be available to the courts, and to those whose efforts could prevent the injuries that give rise to law suits."

Most human behavioral research has been narrowed by experimental hypotheses and procedure shaped by our academic training, peer review systems, images of laboratory controls and physical science models, and conceptual theories evolved from age old philosophical issues. The scope of such research has been limited, not only by the nature of self-generated hypotheses in truly independent research situations, but also by restrictions implicit in contract research and industrial research organizations. Now, nothing is wrong with this, except that the narrowing process may have so narrowed our field of view that we've failed to perceive many excellent research opportunities. This is particularly true in the field of safety where opportunities abound for the talents of the research scientist, and the results could serve to reduce the human carnage from an undisciplined modern technology.

Because personal safety is a primary societal concern and preventable injuries still occur with staggering regularity, our system of law has gradually changed and has created forces that might tend to correct this socially intolerable situation. The cost of the human life or limb has been rapidly escalated, under the law, so that there is greater incentive to perform, subsidize, or apply human research. The courts are becoming increasingly specific in delineating safety responsibilities and safety requirements for those having some control for unsafe conditions or unsafe acts. Thus, the increasingly important areas of safety research are those being formulated by the courts, rather than the more traditional kinds of hypotheses that might be generated by independent research scientists or those performing under contract obligations.

The laws that should be of vital concern are not those legislative statutes that create governmental agencies empowered to issue rules and regulations relating to safety. This may be a highly visible enterprise but it has little to do with the vast bulk of safety law or the concerns of the professional safety specialist. It is the common law, or judge created law, that is being applied each day to tens of thousands of individual lawsuits in the local county, parish, or district courtroom that is the major shape force today. This is where the vital safety issues and concepts are framed, final factual decisions are rendered, and millions of dollars are awarded on the basis of safety related conclusions. It is where the answers are sought to a wide variety of safety issues that could have been the subject of legitimate human safety research, or human behavioral research, but where such answers are frequently given only by those who can speculate or extrapolate from information that has not been founded on any experimentally verified data. It is time for the professionals to get more involved in these safety issues, so that valid information will be available to the courts, and to those whose efforts could prevent the injuries that give rise to lawsuits.

Rare Events

As to liability for rare events, let us consider the design of a toilet paper dispenser. What type of human behavior with a toilet roll might cause injury for which the household or premises owner might be legally at fault and financially liable? What would be the range of foreseeable or predictable human error? One example, part of our common law for nearly two decades, involved a case where a woman who became locked in a lavatory, saw an opening above the door through which she might escape, put her left foot on the lavatory seat, grasped with her left hand a fixture on the wall, grabbed the top of the door with her right hand, then placed her right foot on the toilet roll and its dispenser. She then decided that it would be too acrobatic to climb over the door, so she started to return to her original position, but somehow shifted her weight on the toilet roll and it rotated causing her to lose her balance and fall to the floor where she sustained moderate injuries. The Judge stated that "She must be taken as having acted entirely rationally," and damages against the householder were allowed. (Sayers V. Harlow Union District Council, 2 All E. E. 342, England, 1958).

Similarly, when a landlord failed to repair the water pipes to an unflushing toilet, after a fire, damages were awarded to a woman who injured her back pailing water from the bathtub to the toilet (Mitchell V. Friedman, 11 N. J. S. 344, 78 A2d 417, 1951). Thus, pailing water to an unflushing toilet or standing on a toilet paper roll are, legally, not such rare events or remote causes as to deny liability. Therefore, they are the classes of human behavior that are predictable, about which data should be gathered by someone, because liability or fault is attached to the omission of such considerations. Now, who would perform such research? I don't think that the manufacturer of toilet paper rolls would think it within his province and the manufacturer of dispensers or fixtures might be too small or believe that this is a systems, a general contractor, or an architect's problem. So, we have an example of rare event research and application information that's just not rolling along.

The design and layout of bathroom products is, indeed, medieval and primitive, rather than functional and adapted to the range of anthropometric and behavioral variations clearly foreseeable. That the bathroom is a major source of home injuries is rather obvious. But, I know of few human factors scientists who are vocationally preoccupied with this particular area of research. I have seen bathrooms expanded in scope with more space, objects, compartments, utensils, and ornamentation as builders react to perceived buyers' tastes....but this merely means that there is an expanding variety of new accident conditions being built into home.... perhaps, because there is a comparative absence of research findings relative to this essential area of our life space. This situation may not be remedied until we have a Piaget of the bathroom who has a Jacques Cousteau flair for dissemination of empirical findings.

Failure to Provide Safety Devices Where Human Error Foreseeable

A young boy put his arm inside a launderette washing machine after it had stopped its spin cycle, it then started spinning and injured the boy's arm. An expert testified that if a door interlock had been installed, the machine could not have started spinning with the door open, and the injury would not have occurred. In this case, the appeals court stated that there was evidence sufficient for a jury to find a design defect under strict liability against the launderette owner in much the same way it could against the manufacturer, retailer, or leasor (Garcia v. Halsett, 3 Cal. App. 3d 319, 82 Cal, Rptr. 420, 1970). This case extended the manufacturer's liability for negligence in failing to adopt and provide reasonable safety devices (Varas v. Barco Mfg. Co., 205 Cal. App. 2d 245, 22 Cal. Rptr. 737, 1962) to strict liability for failure to provide safety devices such as interlocks. Obviously, such interlocks must not themselves be unreasonably susceptable to a fail unsafe mode, a malfunction associated with a foreseeable misuse, or an intentional suppression of function.

Failure to Compensate for Human Clumsiness

A coffeepot shattered and flying glass struck and injured the consumer. It was alleged that the user had accidentally bumped it against a faucet while filling it with water, that this may have cracked it and ultimately caused it to shatter upon heating. The court decided it was a jury question whether the coffeepot was defective, given an insubstantial bumping during an intended and foreseeable use.

Failure to Provide Auditory Warning

A construction worker was killed when a front end loader backed over him because the driver could not see the worker, who stood about 30 feet away, due to a blind spot. An expert testified that the blind zone could have been reduced by mirrors and the danger also reduced by an audible backup warning (Pike v. Frank C. Hough Company, 2 Cal. 3d 465, 85 Cal. Rptr. 629, 467 p. 2d 229, 1970).

Failure to Provide Adequate Vision

A young child, standing in front of a bakery truck, could not be seen by the truck driver who started forward and injured the child.

The bakery truck attracted children who purchased the bakery products being sold from the truck and, therefore, the truck was equipped with a mirror so that the driver could see in front of the bumper. However, there was still a blind spot, and an expert testified that additional mirrors would have prevented the accident (Menchaea v. Helms Bakeries, Inc., 68 Cal. 2d 535, 67 Cal. Rptr. 775, 439 p. 2d 903, 1968).

Label Warnings

In 1965 (in Hubbard-Hall Chemical Co. v. Silverman 340 F. 2nd 402, 1st Cir.), a Federal court held that a printed warning of danger was insufficient on an insecticide label, that skull and bones or similar pictoral symbols were also necessary and, for the failure to include the pictoral symbol, the manufacturer could be held liable for any injuries, such as insecticide poisoning, proximately caused by the omission. Why, because it was foreseeable or predictable that farm laborers may have limited education and reading ability. Those injured were Mexican-Americans who could not read the insecticide label because it was printed in English. Incidently, this liability attached despite the fact that under the Federal Insecticide Act and despite the fact that the United States Department of Agriculture had approved the label.

This underlines the well known fact that compliance with government standards or approval by government agencies is no more assurance of safety than compliance with voluntary concensus trade standards or approval by industry supported organizations that certify or endorse a product's safety. Safety standards and safety certification must achieve quantum jumps in validity. However, they may continue to be accepted as bare minimums for safety and some evidence of due care, but only in negligence actions. In some jurisdictions, there is still some life to one of their original purposes in aiding attorneys in the defense of lawsuits. While still a viable insurance loss control measure, safety standards today are relatively poor and very costly end-products of safety research. Open publication of original research findings, as required by most accepted codes of ethics for scientists, remains the most effective means of disseminating scientific information. Open publication best serves the ultimate public beneficiary, who (in the final analysis) actually underwrites the cost of research. Contrast this with the restricted transmission of scientific research to a standards formulation process that is intrinsically biased by its concensus compromise procedures and the self-interest of those who are typically active in such activities. This poses a moral and ethical obligation that far too many scientists have overlooked to the detriment of the vitality of safety research and the public interest. Research performed in support of a standards development program, if separately published, might prove of greater ultimate value than the standard itself.

Obviousness

In Luque v. McLean (8 C. 3d 136, 104 Ca. Rptr. 443, 501 P. 2d 1163, 1972), a young man was injured when he slipped on wet grass and his hand entered the discharge chute of a rotary power motor. The jury was instructed that there could be no liability for the injuries, if the young man had been aware of the defect at the time of the accident; that is, a distinction was drawn between obvious as contrasted with hidden defects. The California Supreme Court repudiated this distinction, so the safety engineer must pay as much attention to obvious hazards as he does to hidden hazards. Safety research should not depreciate obvious hazards.

How safe is safe?

Back in 1963 (in Roberts v. United States, 316 F. 2d 489, 3d Cir.), where a manufacturer failed to place any warning labels on containers of ethylene glycol, a Federal court held "one who supplies a product... for another to use is subject to liability for bodily harm...if...from the facts known to him should realize the product...is likely to be dangerous for use... and fails to exercise reasonable care to inform...of facts and conditions which make the product likely to be dangerous." This is known as "negligent failure to warn" and employs the risk criterion of "dangerous."

Now, even in strict liability, the same criterion had been used, as employed in the Restatement of Torts, second, section 402 A, in the following context: "One who sells any product in a defective condition unreasonably dangerous to the user or consumer or to this property is subject to liability for physical harm thereby caused." Now, this means that a product could be reasonably dangerous and no legal fault would attach. Thus, product safety engineer were using this criterion as to whether a particular risk was acceptable, tolerable, or safe. In other words, to be unsafe, it had to be unreasonably dangerous.

To put this into proper context, a safety engineer searches to identify all hazards. Then he determines the risk associated with each hazard. The risk analysis is but a prelude to a determination as to whether the risk is acceptable or unacceptable; this decision-making involves a personal value judgement as to whether the magnitude of the risk is a tolerable risk or of such a magnitude as to require some risk reduction action. It is that value judgement that is the essence of the professional practice of safety engineering, since each decision accepts or rejects a predictable amount of human injury and property damage.

Certainly, this kind of decision-making requires some understanding of what the law regards as a safe or unsafe product, process, act, condition, or system. Guidance is not found in the cookbook application of design requirements, the code compliance mentality of technicians, nor from jailhouse lawyers attempting to apply the letter of the law while failing to understand its spirit, intent, trend, or worse case implications.

Ultimately, it could be a jury that second-guesses the safety engineer's original decision as to whether a hazard constitutes such a risk that is unsafe. The jury does this as a first step, before deciding the damages to be awarded to the injured, based upon the words contained in the Judge's Instructions to the Jury. As I have previously mentioned, the words used the phrase "unreasonably dangerous," that is, that risks created should not be unreasonably dangerous.

This level of acceptable risk was reduced when the California Supreme Court, in 1972, in Cronin v. J. B. E. Olson Corp., 8 Cal. 2d 121, 104 Cal. Rptr. 433, 501 P. 2d 1153 eliminated the term "unreasonably dangerous" and substituted the term "defect." Thus, the jury instruction and the criterion used by the product safety engineer were that a defective design is a design that subjects a user or bystander to a "unreasonable risk of harm" from the reasonable and foreseeable use of a product. However, on March 23rd 1976, a California Appeals Court, in Foglio v. Western Auto Supply, 56 C. A. 3d 470, another lawn mower case, ruled that the unreasonable risk of harm instruction was erroneous, prejudicial, and in contravention of the common law of California. Only the term "defect" was to be used. Thus, the level of risk that can be tolerated has and is being lowered. So the safety engineer must have a better understanding of low risk and rare event hazards, a broader understanding of design alternatives, less reliance on customary practices of the industry, and better insight into what those sitting on juries would believe to constitute a defect and unacceptable risk. Thus, the law is changing the rules of the game for safety engineers, and those safety engineers who understand this fact of life have a new blatant thirst for a broad range of safety research data, analyses, and conclusions.

Since any safety engineer must expect, sometime during his professional career, to testify in court proceedings, he should also have some understanding of what is meant by such terms as assumption of the risk, contributory negligence, and comparative negligence. But, for assumption of the risk, do we have very much research that will help us really define what it is when a person "voluntarily" and "unreasonably" subjects himself to a "known" danger, with an "appreciation" of the "amount of danger?" For contributory negligence, exactly what constitutes a failure to use "ordinary care" for the protection of one's own safety? Do we understand why some people continue to operate or use a product after "discovery" of its "defective condition?" Do we have a rationale basis for allocating, in percentages, the degree of "human fault" under comparative negligence determinations now being made by juries? The behavioral sciences could contribute a great deal if they could rigorously explore, carefully define, and illuminate risk-taking behavior in terms and circumstances useful to lawyers, judges, juries, industrial managers, and safety engineers in connection with the "recognition" and "appreciation" of "danger," failure to exercise "proper care" for personal safety, and the assumption of risk in varying situations and by groups varying in age, intelligence, education, etc.

This is a worthy field of endeavor and one that could greatly influence the field of safety. Worthwhile results would command the attention of a widespread group of people, since the forcing function may be the very economic survival of otherwise viable industrial and commercial enterprises. The imperative lies in our future generations, who should not be needlessly maimed and crippled in the fashion of our current generations who are forced to work, travel, and live in an unconscionably unsafe environment.

METHODS FOR STUDYING COMPLEX HOMEMAKING TASKS

Rose E. Steidl, Ph.D
Cornell University

ROSE E. STEIDL, is professor and chairman, Department of Design and Environmental Analysis in the College of Human Ecology at Cornell University. Dr. Steidl has long been involved with research on household tasks and the design of home work environments. Her work is reflected in numerous technical and consumer oriented publications. Among these is the book Work in the Home (John Wiley and Sons, 1968, co-authored by Ester Crew Bratton).

Although Steidl's work has not been directly concerned with accident or safety research, the methods she has employed and discusses in the present paper, do have immediate application to such research. Of particular interest is the use of memo motion film techniques in observational studies.

Introduction

Task complexity is a comparatively unstudied area in home management in relation to safety, yet information about complex tasks may contribute to accident prevention. In this paper, I include some information about complex tasks and present two methodological approaches which have been used and may serve as a bench mark for further work.

Homemaking work is an ever present and changing problem. Some changes come from within the home--from the homemaker herself, the family, the tasks. Other changes come from outside the home--the goods and services available, technological developments and shortages, the community, and the weather, for instance.

Even though homemaking work has many changing aspects, there is often a certain amount of sameness that leads to many routines and almost surface attention while doing the different tasks. The worker's mind is not completely occupied, but not free enough to let the homemaking task become the secondary task for very long.

Homemaking includes many tasks with contrasts in characteristics. Some tasks are physically demanding, others more thought demanding; some are judged large, others small; some discontinuous, others continuous; some liked, others disliked; some are simple, others complex. We do not know enough about task complexity. For example, does complexity come from within each task, from the coordination of tasks within the home, from the coordination of tasks between the home and outside it, or from the context within which the tasks are done?

Some of our data suggest that one source of complexity is from combining and fitting tasks together (Steidl, 1975a). Managing a home requires coordinating both a variety of activities and the parts of each activity. Many tasks encompass time and location variables; the worker controls some of the discontinuity of action, and events external to the situation may affect further the stops and starts. However, some of the intermittency of action is inherent in the nature of the task. The processing may continue without the worker being present, thus permitting the worker to change to another activity (Steidl, 1963a; Steidl and Bratton, 1968).

Machine washing of laundry can be used as an example of intermittency of action that is inherent in the nature of the task. A natural division of action occurs after the machine is loaded and the washer started. Washing time must elapse before the next part of the task can be done, and the worker need not be present during that time interval. In meal preparation, much of the work may also be intermittent. For example, baked potatoes cannot be produced by one continuous action; work is necessarily interrupted while the potatoes bake. the worker, therefore, has active and inactive work periods for the job of baking potatoes.

This characteristic of intermittent action on a task is not unique to homemaking tasks, and it is not a particularly difficult concept to comprehend. What is probably difficult is to identify all of the implications, and at this workshop, to consider the importance for safety. Both the amount of shifting from one activity to another and the number of activities being carried on concurrently may be closely related to fatigue, to attention demands. Other considerations are the number of changes of location, the duration of action in the various work periods, the tasks done together, and the order of doing them.

We have used memomotion film records of meal preparation and cleanup to study the continuity of action on each menu item or "job" and the following graphs* provide timing and changes of location data from one set of case studies in which the working conditions were varied but the menu remained constant (Steidl, 1957).

Memomotion film analysis

A memomotion film is a motion picture film exposed at less frequent intervals than the common rate of 16 frames per second in micromotion films. Usually, memomotion films are made at the rate of one frame per second, but occasionally at 10 frames per second. Each frame is a picture exposed for a fraction of a second. This technique was developed almost

*Ed. note: Graphs and other figures referenced in the text are presented at the end of this paper.

30 years ago, in 1947, by Dr. Marvin E. Mundel, an industrial engineer at Purdue University. Mrs. Mary Koll Heiner at Cornell University recognized the potential for studying work in kitchens and we adapted the technique to our purpose. I brought several films with me and will use them to demonstrate some of the methods of analysis and characteristics of tasks. The memomotion films, of course, do not provide a complete record since 15 out of every 16 frames of the film are missing. The action is jerky, like the old Charlie Chaplin films, rather than continuous and smooth. For the most part, the missing detail has not been a problem. Analysis is easier, however, when a brief written record is made concurrently with the film record; the analyst then has a faster and less tedious job of recording data. Whether the same thing is true with the more sophisticated recording systems available now may be a question you would discuss later.

We have analyzed memomotion films for various kinds of information:

"to determine what activity was being done, how it was done, what was used, who was doing it, who else was present, and exactly where it took place. The duration of the activity and the sequence of events can also be determined.

"Time can be determined most directly by obtaining a count of the number of frames on the film for the unit of activity being studied. When one frame of film is briefly exposed every second during the observation period, the number of frames counted can be equated to the number of seconds. Reference to a clock in the camera field may also provide information about the passage of time," (Steidl, 1963b, page 14).

A film record has a number of advantages over a paper and pencil record of an observation: it provides a fairly permanent record; it can be analyzed for various types of information; observations and analyses can be verified; and it permits reviews of activity which may suggest additional information that will contribute to the solution of the problem or help identify other problems.

A memomotion film also has these advantages:

. The analyst has less film to review, since it is a more condensed record than a micromotion film.

. Undesirable conditions may be emphasized, since motions are jerky and accentuated.

. It is not necessary for an observer to be present during a trial to record what a subject does.

. An hour's activity can be reviewed at normal speed of 16 frames per second in four minutes, thus permitting a quick overview of a trial.

. It is well suited to problems that do not require as detailed analysis as permitted by a micromotion rate of 16 or more frames each second," (Steidl, 1963b, page 14).

Of the disadvantages of any film record, the one that is unique to memomotion films stems from the intermittent record, i.e., action is missing during the unrecorded periods. Of course, some information may be missing in any film because the worker's back is to the camera, thus concealing the activity. However, when data are recorded also by an observer concurrent with the filming, the problem may be eased.

Next, I want to present several examples of the kinds of data from memomotion film records of a complex task--meal preparation--and films from two of our studies.

Since the data from the films and observations are objective, some means of obtaining the person's evaluation and perception of the activity and situation should be used to help interpret the objective data. For instance, effort ratings have been correlated with total number of center-uses (or trips), time at each center (or work station), and the over all assessment of different arrangements (Steidl, 1960).

Interview method and continuity of action

Data from personal interviews have also been used to study continuity of action in household work. As you would expect, the information is ordinarily at a much grosser level than that from films. For instance, interviews asking for recall of the preceding day's activities and the estimated time for each activity gave us knowledge of the number of blocks or units of activity, the duration of each, the sequence of activities, and the variety (Steidl, 1963; see also Steidl and Bratton, 1968). From these data we obtained descriptive information pertaining to continuity of action. The number of blocks of activity averaged 20 per homemaker and two-fifths of the blocks of activity continued for less than 30 minutes; one-third of the homemakers reported activities in three activity areas (such as food, clothing, family) and another one-third reported activities in four activity areas.

Our experience indicates that respondents can reconstruct their time-use, and especially when the query concerns the last 24 hours rather than a part of the last 24 hours. The sequential listing of activities and associated time periods lends itself to several kinds of analyses, including those indicated.

Complex homemaking tasks - interview method

Another approach to studying complex homemaking tasks besides the filmed observations is the personal interview, using questions about the cognitive factors of attention, judgment, and planning. Explanatory information can be obtained about the functioning of each cognitive factor, difficulty factors, and task preferences, as well as ratings for complexity, difficulty and preference. Three journal articles provide details of the methodology and the results from intensive interviews with a selected population of young wives (Steidl, 1972; Steidl, 1975a; Steidl, 1975b). The information that follows is based on those articles.

Open-ended questions were used and many could be used or adapted in further studies. Two questions about homemaking tasks in general elicited a range of information and provided rich insights into the concept: "What makes homemaking tasks complicated?" "What makes homemaking tasks uncomplicated?" Following this, the respondent nominated tasks high in attention and others low in attention and answered open questions including these:

-"Why do you think (name of task) requires a great deal of attention (or judgement, or planning)?" or, "Why do you think ________ requires very little attention (or judgement, or planning)?"

"Are there any things about your work situation or where you do this task that make the work more difficult?" and "Are there any things about your work situation or where you do this task that make the work less difficult?"

-"What do you like about this task?" "What do you dislike about this task?"

The coding of the responses was, of course, time consuming. The diversity of responses was impressive. Some of the diversity came from the variety of tasks nominated. One advantage of the open-ended questions was the richness of the information. With this as background, a more structured interview schedule could be developed; broad categories might be used, followed by a request for more specific information if appropriate. For instance, the wives' explanatory information about the high cognitive factors emphasized the content of the work, and especially quality and quantity considerations, timing requirements, and process or procedure activities. Some wives also noted aspects of the environmental context--the house, community, and family.

More specifically, the quality and quantity considerations often concerned quality, especially aesthetically pleasing results such as color, flavor, things going together; also variety of products, interesting products; growth, health, diet, and nutrition factors; attending to temperature settings to obtain a quality product; and judging the sturdiness and durability of items. The quantity considerations often involved judgments about how much to do or use.

The timing considerations concerned careful timing required; decisions about when to do the task; judging the amount of time needed; and the time squeeze. Some noted also timing tasks to prevent accidents or provide safety for their children.

The high cognitive tasks also required thought about the process or procedural activities such as how to proceed with the task: attending, judging, or planning how much, when, what to use or substitute; and the preparatory work and organizing work required.

The family and human relations involved also were among their concerns: pleasing self and others; taking care of the preferences and needs of others. The age of the child, the schedules of the child, wife, and husband for work and other activities were other considerations..

The preceding examples are some of the more frequent kind of responses in the wives' explanations of high cognitive tasks. Our data provide information about the dimensions of complexity of tasks and of tasks that are not complex. The wives' responses also point up the impact of their situation when they are tight on time and of the social and physical setting in which tasks are done.

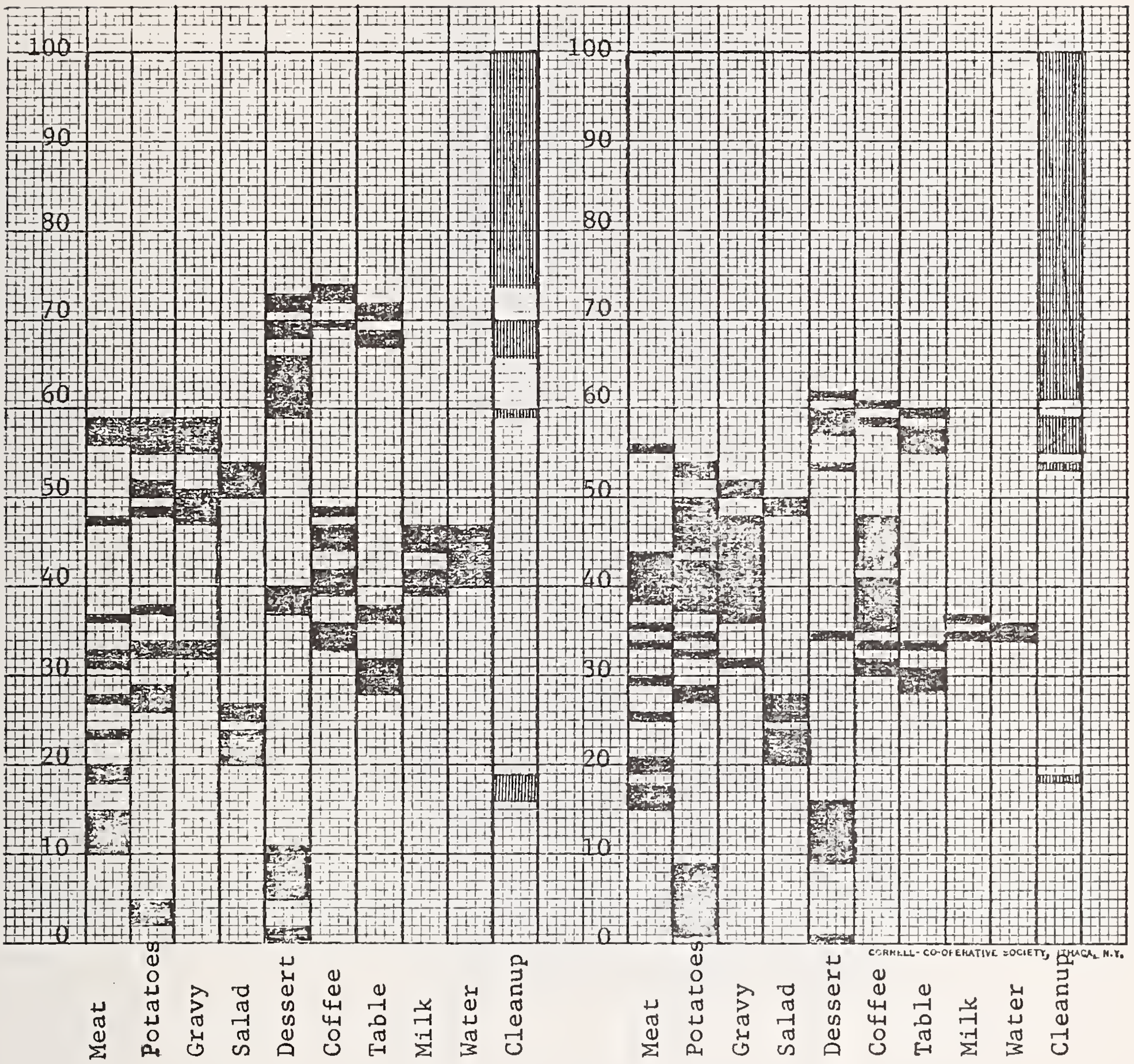
The relationship between difficulty factors and complexity should not be overlooked. The high cognitive tasks were rated almost equally as easy and difficult. The homemakers identified factors making tasks both more difficult and easier to do. Since about half of each set of reasons concerned the quality of the physical environment, it should be included in further studies of task complexity.

Conclusion

Two methods of studying complex homemaking tasks--the interview and memomotion film analysis--provide different kinds of information about tasks and the situations in which tasks are done. Many homemaking tasks encompass time and location variables; the worker controls some of the discontinuity of action, the process determines some, and events external to the situation may affect further the discontinuity of action. Since action is intermittent, coordination of tasks is needed. Social interaction makes additional demands on the worker's attention. The context within which tasks are done, such as inadequate time, multiple task performance, equipment breakdown, and poor quality of supplies, may contribute to difficulty or complexity of task. The nature of the work and the setting in which it is done are both important in studying task complexity.

Percent of center-uses
N = 113

Percent of time at centers
N = 4904 seconds at centers



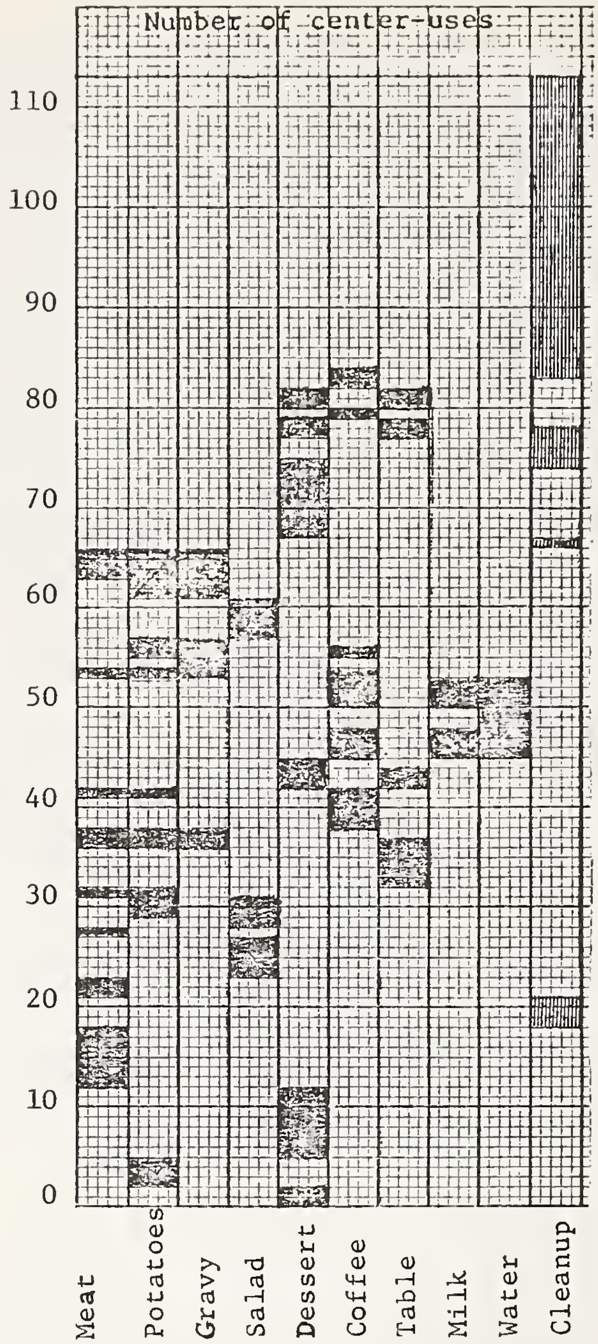
FLOW OF WORK FOR PREPARATION AND CLEANUP OF ONE DINNER

The solid portions in each column represent action on a given job for the meal, the blank portions no action. Study of the graphs shows:

- the number of different times a job received attention (meat--8 times);
- proportion of center-uses during each attention period;
- proportion of time during each active and inactive period;
- action on several jobs during some attention periods (meat, potatoes, gravy);
- sequence of work (first job--dessert; next--potatoes; dessert; meat; cleanup; etc.).

Discontinuity of action during preparation and comparatively short work periods on each job were common for this menu (ground beef patties; mashed potatoes; pan gravy; tossed vegetable salad; milk, water, coffee; brownies).

Source: Steidl, Rose E. (1957) "Effects of Multiple Water and Drainage Facilities on Work Involved in Family Meal Preparation and Cleanup," Ph.D. thesis, Cornell University, Ithaca, New York.



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Number of trips into the kitchen

(From memomotion films of four meals in two homes, before and after adding functional storage devices, 1959)

	Family C		Family J	
	Before	After	Before	After
	Number of trips into kitchen			
Homemaker	14	22	4	12
Helpers				
Work only	13		20	20
Visit only		1	10	11
Work and visit	1	1	13	7
Visitors	8	18	3	
Total	36	42	50	50

Steidl, 1961b

Duration of periods in and out of the kitchen

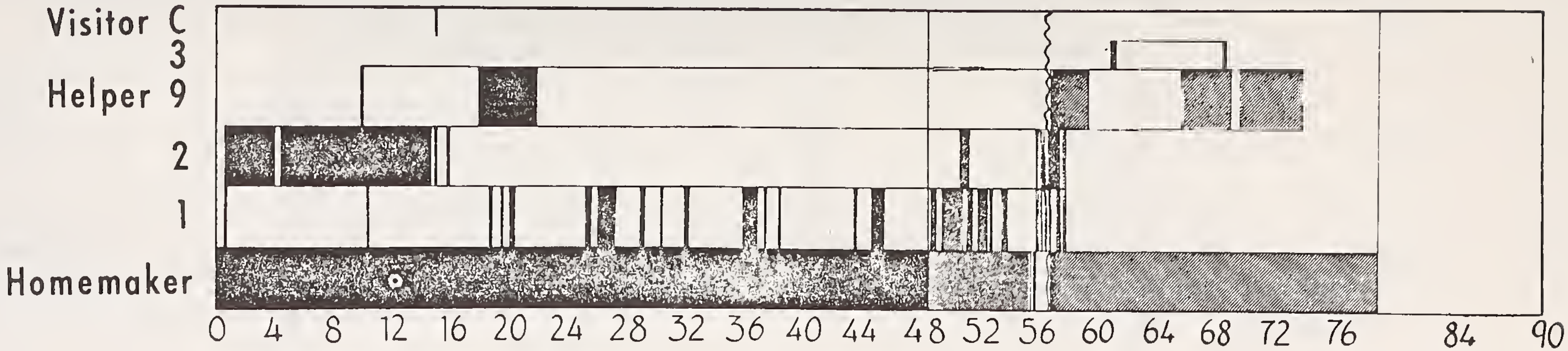
(From memomotion films of four meals in two homes, before and after adding functional storage devices, 1959)

Duration of period	Homemaker				Helpers				Total			
	Before		After		Before		After		Before		After	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Seconds	Family C: number of periods											
1-29	8	11	10	16	11	4	1		19	15	11	16
30-59	1	1	6	3	1	2	1		2	3	7	3
60 and over	5		6		2	5		1	7	5	6	1
No data		2		3		3		1		5		4
Total	14	14	22	22	14	14	2	2	28	28	24	24
	Family J: number of periods											
1-29	1	1	1	4	31	18	27	16	32	9	28	20
30-59			3	3	5	7	5	6	5	7	8	9
60 and over	3		8	1	7	12	6	9	10	12	14	10
No data		3		4		6		7		9		11
Total	4	4	12	12	43	43	38	38	47	47	50	50

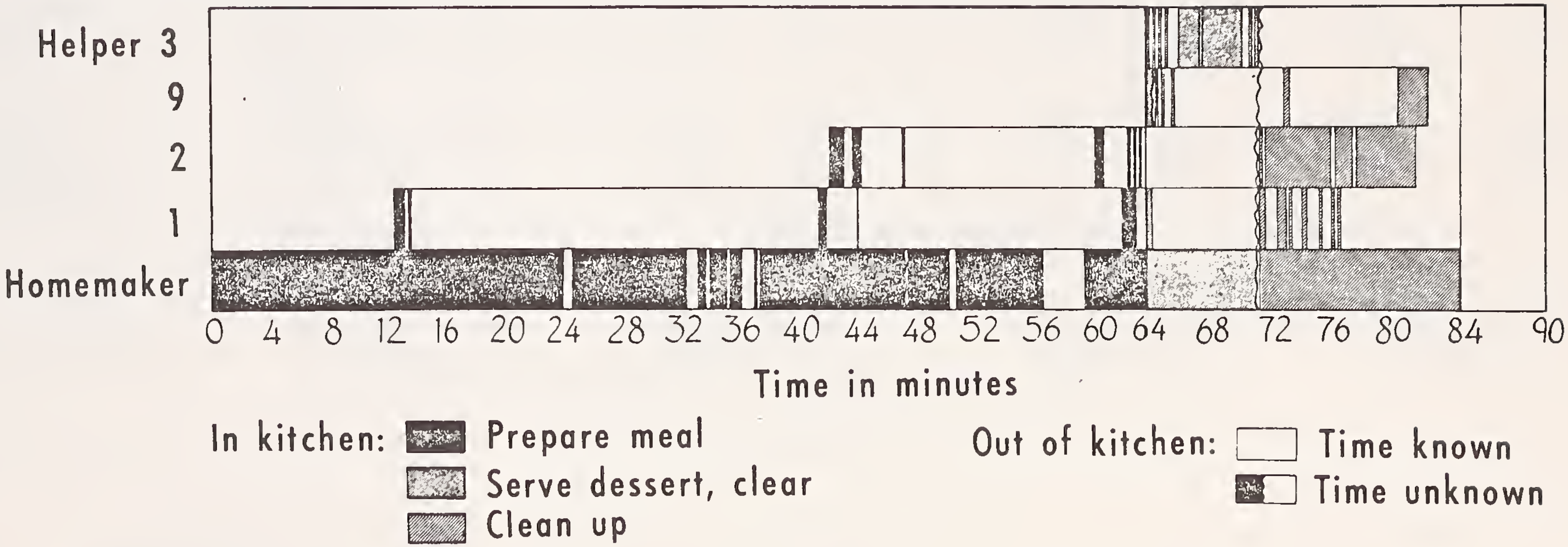
Steidl, 1961b

Time for everyone's periods in and out of the kitchen

Graph 3b: Family J, first meal preparation and cleanup



Graph 4b: Family J, second meal preparation and cleanup



Steidl, 1961b

Type of areas and time used for work

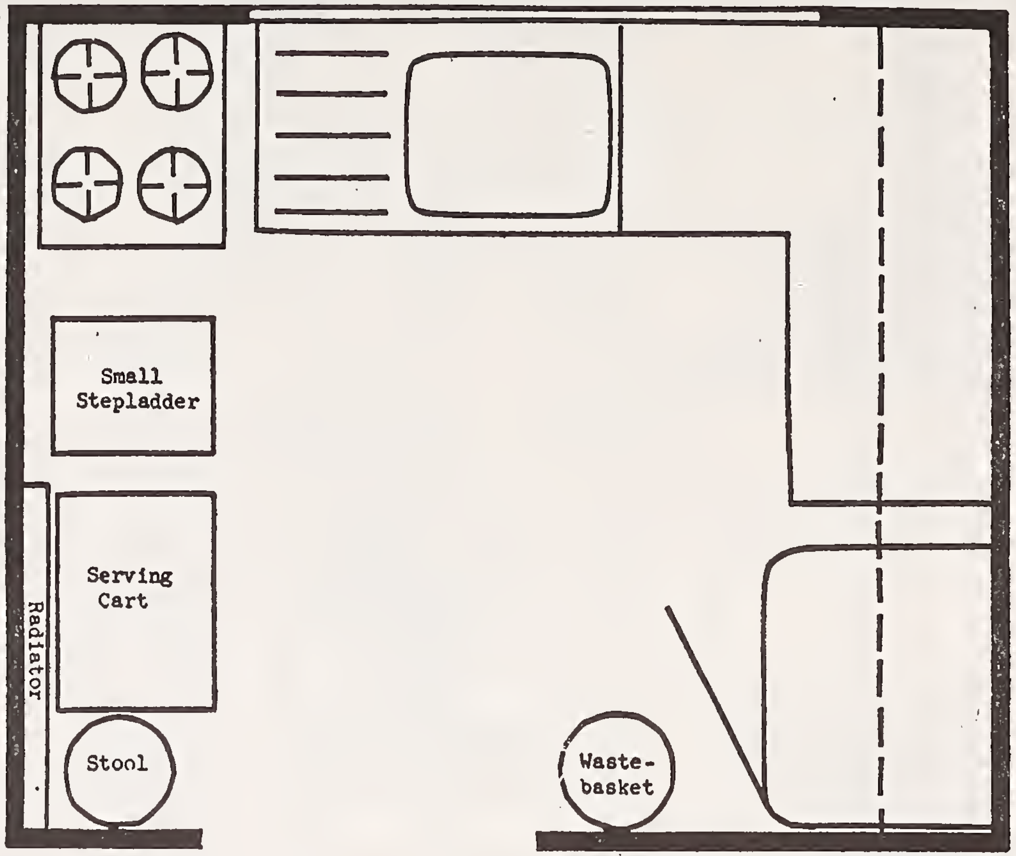
(From memomotion films of four meals in two homes, before and after adding functional storage devices, 1959)

Type of Area	Uses of Areas							
	Family C		Family J		Family C		Family J	
	Before	After	Before	After	Before	After	Before	After
	Number				Seconds			
Appliances	252	178	201	204	2253	1659	3535	2658
Counter	164	109	158	184	1484	1149	1357	1453
Storage	162	123	174	193	649	486	644	779
Dining	22	21	28	21	814	376	1610	351
Other*	9	1	2	8	220	9	84	86
No data	3	4	2		13	11	14	
Total	612	436	565	610	5433	3690	7244	5327
	Percent				Percent			
Appliances	41	41	36	33	42	45	49	50
Counter	27	25	28	30	27	32	19	27
Storage	26	28	31	32	12	13	9	15
Dining	4	5	5	3	15	10	22	6
Other*	1	+	+	2	4	+	1	2
No data	1	1	+		+	+	+	
Total	100	100	100	100	100	100	100	100

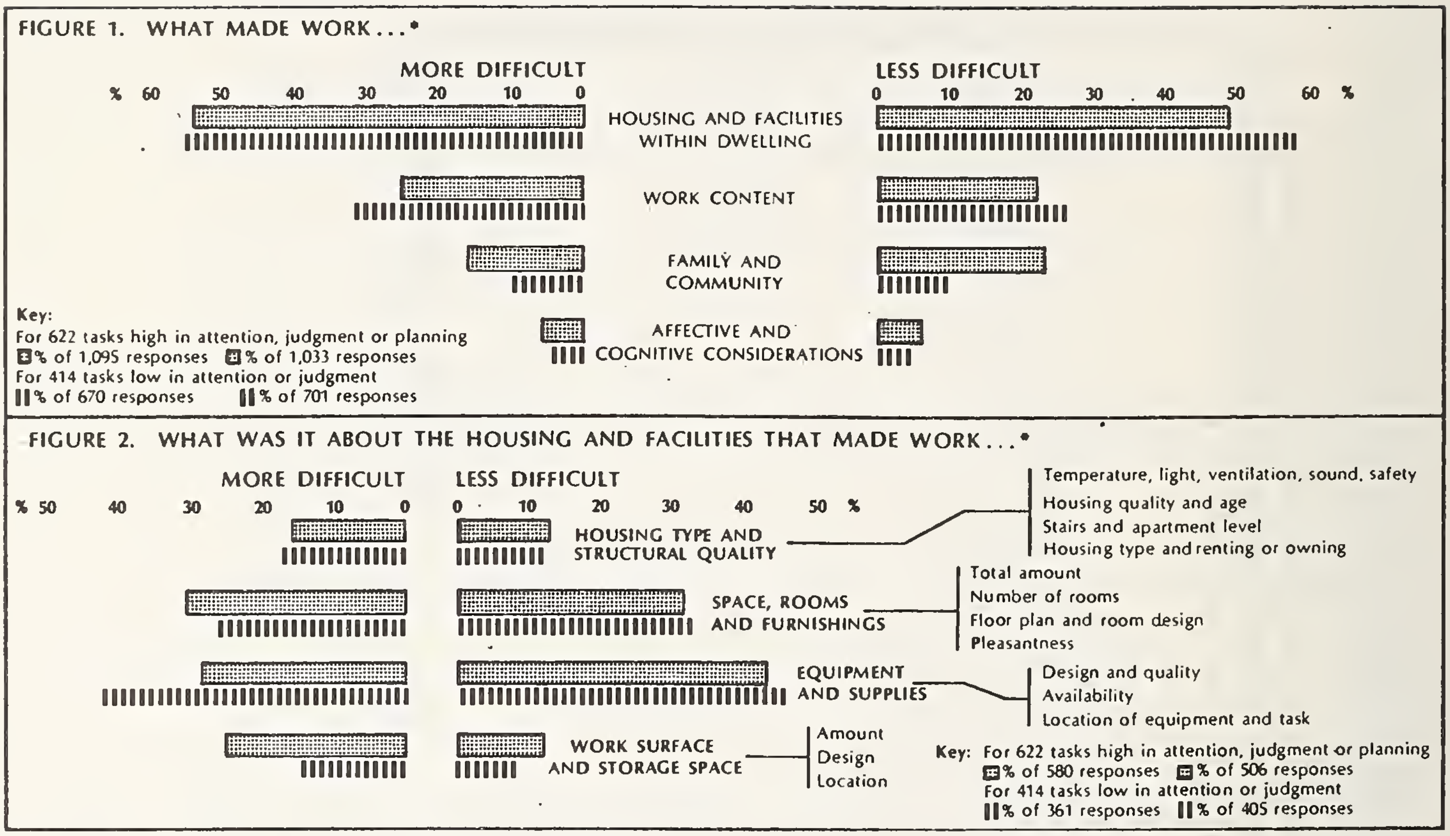
*Work done occasionally while walking between areas such as reading the cookbook.
+ = some, but less than 0.500 percent.

Steidl, 1961a, Table 10

Figure 1. Kitchen floor plan in apartments of family C and family J.



Steidl, 1961a



* According to the responses of 208 homemakers in Ithaca, N.Y., and vicinity, 1967

Steidl, 1972 (Based on Tables 2 and 3)

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DATA COLLECTION FOR HAND TOOL INJURY: AN APPROACH

M.M. Ayoub, Ph.D., P.E.
Texas Tech University

Jerry Purswell, Ph.D.
University of Oklahoma

John Hicks
Cities Service Oil Company

M. M. Ayoub, is professor of Industrial Engineering and Biomechanical Engineering as well as Director, Institute of Biotechnology at Texas Tech University. His research interests center around ergonomics, with particular interest in biomechanics and work physiology.

The paper presented here, co-authored by Jerry Purswell, University of Oklahoma, and John Hicks, Cities Service Oil Company, presents an ergonomic approach to data collection for the study of hand tool injuries. Ayoub et al consider the worker, the tool, the task, and work practices in their determination of required information and the development of a reporting procedure for hand tool injury.

INTRODUCTION

The term hand tool used in this paper refers to any of the wide range of hand held instruments used to perform a given task. These hand tools can be powered either by muscular exertion or by outside source, but all are held and manipulated by the human hands in a man-task-environment system consisting of the worker himself, the tool used, and the environment in which the work is performed.

A hand tool should be and is designed to extend the human physical capabilities in performing an activity, but at the same time these tools have caused injuries to the user as well as to other individuals in a variety of ways. As a rule these accidents are often attributed to negligence or bad luck, but rarely, if ever, have they been examined to identify the real mechanism of injury to eliminate or at least expose it in order to prevent repeated occurrences. Only in recent years has an effort been made in this country to examine accidents with more interest than just score keeping. This is partially the result of the Occupational Safety and Health Act of 1970.

Data published by the National Safety Council (1972, 1973) indicate the severity of hand tool injury problems. Hand tool injury data accounts for 6% of all compensible injuries in 1971 and 1972. Due to the high incidence and high cost of tool injuries, it is imperative that efforts be initiated to investigate and attempt to eliminate the causes of these hand tool injuries. Such action would certainly decrease the frequency and severity of the hand tool injuries.

Purpose

The purpose of this paper is to show an Ergonomic approach for the collection, and analysis of information on hand tool injuries and illnesses and to test such a system of injury collection and analysis on a group of accident cases at Tenker Air Force Base. This system is presented in detail in a later section.

Summary and Evaluation of Injury Statistics

Based on the literature search compiled by Ayoub, Purswell and Hoag (1975), it was clear that the injury data available are related primarily to incidents of a fatality or disabling injury which results from hand tool use. Additional data are available from some states which relate the incidence of injury to a particular type of hand tool. However, data are not generally available to relate the incidence of injury to a particular hand tool and mechanism of injury. Of course, the mechanism of injury can, in some cases, be inferred from the statistics available for the type of hand tools such as knives, but more data are needed to relate the incidence to the mechanism of injury.

For the data available there are differences in criteria used to pay compensation for hand tool injuries, for instance, an injury may be classified as a disabling injury in California if it results in absences from work one full day, or shift, beyond the day of injury, while the comparable period in New York is seven days. These differences in criteria make it difficult to make comparisons between the available injury data. The following sections contain a summary of the data available on injuries resulting from hand tool use.

A. Hand Tool Injuries as a Proportion of All Compensable Injuries

The National Safety Council (1973, 1972) published the data shown in Table 1 on the source and cost of compensable work injuries as reported by state labor departments in the U.S. for the calendar years of 1971 and 1972.

It can be seen that hand tool injuries accounted for six percent of all injuries and the average cost of compensation only for each accident was $740 in 1971 and $850 in 1972. The relative position of the various injury sources as a percentage of all injuries did not change from 1971 to 1972, but the average compensation costs did increase approximately 15 percent for each injury source. Comparable data for a calendar year 1973 was not published in the 1974 edition of *Accident Facts*.

TABLE 1

SOURCE AND COST OF COMPENSABLE WORK INJURIES[1]

Source of Injury	Percent of All Cases 1971	1972	Average Compensation Costs per Case 1971	1972
Handling objects, manual	23	23	$ 990	$1,140
Falls	20	20	1,470	1,690
Struck by falling, moving objects	14	14	750	860
Machinery	10	10	1,110	1,280
Vehicles	7	7	1,570	1,800
Stepping on, striking against objects	7	7	480	550
Hand tools	6	6	740	850
Other	13	13	1,182	1,350

[1] Accident Facts, 1972 and 1973 editions.

Data published by the State of New York for the period 1966 through 1970 (1972) show that injuries resulting from hand tool use account for 7.0 percent of all injuries and 4.9 percent of the compensation awarded accident victims. The average cost of compensation per hand tool injury was $1,305. The data available from New York were summarized for the five-year period but no annual information was available to determine any time trends.

The State of California published information annually on work injuries, so it is possible to infer the time trend of injuries resulting from hand tool use as shown in Table 2.

The data in Table 2 indicate that hand tools were involved in approximately 9.0 percent of all disabling injuries and 1.9 percent of fatalities over the six-year period of 1967-1972. There is also an indication that the trend of hand tool injuries is upward over the last three years of data (1970-1972).

Data were not available from California on the average compensation cost of a hand tool injury.

Table 3 presents data for the State of Ohio, showing the percentage of fatalities and injuries produced by hand tools for all compensable injuries.

A comparison of these various data sources indicates differences from state to state, but in general, it can be concluded that injuries resulting from hand tool use account for 5-10 percent of all compensable injuries.

B. Injuries Resulting from Powered Versus Nonpowered Hand Tools

The data available from New York, California, and Ohio for hand tool injuries include a number of subclasses, permitting an analysis of powered versus nonpowered hand tool injuries. Table 4 presents data for California showing powered hand tool injuries as a percentage of all hand tool injuries.

Table 5 presents data from the State of Ohio for powered hand tool injuries as a percentage of all hand tool injuries.

Data from the State of New York for 1966-1970 indicate that 21.1 percent of hand tool accidents were produced by powered hand tools, and that the average compensation cost per case was $1,610 compared to $1,221 per case for nonpowered hand tool accidents. Considering the data from these three states as typical, it can be stated that powered hand tools account for 21-29 percent of all hand tool injuries. It may also be inferred from the New York data that compensation for a powered hand tool accident will be an average of approximately $400 more than for a non-powered hand tool accident.

Referring to Table 1 presented earlier, it may also be observed that the cost of a hand tool compensation claim in New York was almost twice the national average.

TABLE 2

FATALITIES AND DISABLING INJURIES RESULTING FROM HAND TOOLS
TOTAL USE IN CALIFORNIA FOR THE PERIOD 1967-1972
AS PERCENTAGE OF ALL INJURIES

Year	Hand Tool Fatalities as Percent of All Fatalities	Hand Tool Injuries as Percent of All Injuries
1967	1.5	8.7
1968	1.4	9.0
1969	2.0	8.8
1970	2.1	8.7
1971	1.5	9.0
1972	2.8	9.4

TABLE 3

FATALITIES AND DISABLING INJURIES PRODUCED BY HAND TOOLS
AS A PERCENTAGE OF ALL COMPENSABLE INJURIES
FOR THE STATE OF OHIO

Year	Hand Tool Fatalities as Percent of All Fatalities	Hand Tool Injuries as Percent of All Injuries
1969	Not Available	4.7
1970	1.0	4.8
1971	2.1	5.0
1972	1.2	5.1
1973	Not Available	5.5

TABLE 4

INJURIES RESULTING FROM POWERED HAND TOOL USE AS A PERCENTAGE OF HAND TOOL INJURIES FOR STATE OF CALIFORNIA

Year	Percentage
1967	26.6
1968	27.4
1969	28.5
1970	28.2
1971	25.1
1972	29.1

TABLE 5

INJURIES RESULTING FROM POWERED HAND TOOL USE AS A PERCENTAGE OF ALL HAND TOOL INJURIES FOR STATE OF OHIO

Year	Percentage
1969	22.8
1970	20.6
1971	24.2
1972	23.1
1973	21.6

C. Injuries Related to Specific Type of Hand Tool Use

The data from New York, Ohio, and California were analyzed to obtain the percentage of total hand tool injuries contributed by each type of hand tool. Some problems exist in obtaining comparable classifications of injuries by type of hand tool in each state, but these were generally overcome by rearrangements of the detailed accident data where necessary. Table 6 presents the data for hand tool type versus percentage of total hand tool injuries for New York, Ohio, and California.

It can be seen from Table 6 that there is very good agreement among the three states over several years of data on the 1, 2, and 3 relative ranking of hand tool injuries produced by knives, wrenches, and hand hammers. There is also good general agreement on the relative ranking of the frequency of injury for the other hand tools within the list. Exceptions to this general agreement in ranking are where the basic data do not permit data tabulation on a comparable basis for a particular tool type such as a bar or pneumatic tool. The data in Table 6 can be considered to represent one type of priority listing for defining research requirements to improve the safety of hand tool use. Of course, it would be very desirable to have some estimate of the relative exposure of a worker in using each type of tool in order to more effectively plan a research program, but such data are unavailable.

Another consideration in establishing research program priorities is the cost of a given type of hand tool injury as compared to the frequency of injury. As stated earlier, the only data available which relate compensation costs to a specific hand tool injury type is New York state. Table 7 presents these data.

It can be seen from Table 7 that injuries resulting from the use of shovels and spades result in the highest compensation costs of all hand tools, while only ranking fifth in number of injuries among all hand tools. Similarly, injuries resulting from the use of knives rank fourth highest in compensation costs while ranking number one in frequency of injury. Such differences in incidence of injury versus compensation cost of the injury must be taken into account in the establishment of research priorities.

In order to consider the development of control measures to prevent hand tool injuries, it is necessary to have an understanding of the mechanism of injury as noted earlier in this paper. The most complete data available in this case is from the State of Ohio. Table 8 presents a compilation of data for various hand tool categories where the type of accident, nature of injury and part of body injured are shown. The following comments for knife and wrench injuries illustrate how the data in Table 8 may be used to better understand the mechanism of injury:

(1) Knife - lacerations account for 89 percent of all injuries, as would be expected. Most of these lacerations occur on the fingers and hands.

TABLE 6

PERCENTAGE AND RELATIVE RANK OF SPECIFIC HAND TOOL INJURIES AMONG ALL TYPES OF HAND TOOL INJURIES FOR NEW YORK, OHIO, AND CALIFORNIA

Type of Hand Tool	Percentage and Rank of Hand Tool Injuries					
	New York 1966-1970		Ohio 1969-1973		California 1967-1972	
	%	Rank	%	Rank	%	Rank
Knife	17.0	1	17.7	1	17.7	1
Wrench	10.8	2	11.3	2	7.7	2
Hand hammer	9.2	3	7.1	3	7.1	3
Nozzle/hose	3.9	7	3.5	6	5.0	4
Shovel/spade	4.2	6	5.0	4	4.2	5
Bar	6.2	4	1.4	10	3.5	8
Scissor/shear	1.8	11	0.8	12	3.3	9
Power drill	3.2	10	3.7	5	2.8	10
Power saw	3.4	8	3.3	7	3.8	7
Grinder	1.0	12	1.9	9	2.5	11
Sledge	3.3	9	3.3	7	2.1	12
Pneumatic tools	5.1	5	0.9[1]	11	4.0	6

[1]Some pneumatic tool injuries classified in non-hand tool categories.

TABLE 7

TOTAL COST AND COST PER CASE FOR SPECIFIC TYPES OF HAND TOOL INJURIES FROM STATE OF NEW YORK FOR PERIOD 1966-1970

Type of Hand Tool	Total Cost of Compensation	Cost per Case
Shovel/Spade	$4,199,400	$3409
Wrenches	4,037,100	1260
Hammer	3,217,300	1178
Knife	2,991,500	595
Bars	2,732,400	1483
Pneumatic	2,423,600	1606
Sledge	1,943,700	1967
Hoses/Nozzle	1,925,100	1655
Power Saw	1,676,400	1647
Power Drill	1,351,000	1434
Scissors/Shears	660,100	1211
Hook	592,900	1808
Power Grinder	324,300	1150

(2) Wrench - the most frequent type of accident is slipping (without falling, which is another category of accident) or overexertion. Injuries where a person is struck by a moving object are also important. The most common type of injury is a sprain or strain, with contusions being the second most frequent type of injury. Injuries to the low back occur most often, with the arms, hands and fingers also becoming involved in a significant number of wrench accidents.

These two examples illustrate the type of information contained in Table 8 for each type of hand tool. Such information is not detailed as could be desired to fully understand the circumstances of each type of hand tool accident, but it does provide the best basis available for understanding hand tool accidents sufficiently to outline a program of research in the area. The objectives of this program of research will be the collection of additional data which can be used to design safer hand tools and workplaces.

The following section provides an analysis of the requirements for injury-relating data, given the type of information which is currently available for hand tool injuries and taking into account the needs for additional data before safer hand tools, workplaces and work practices can be designed.

Requirements of Injury-Relating Data

The statistics available today on injuries and illnesses caused by the use of hand tools are inadequate for an evaluation of the characteristics of the tool design, user practices, task design, and the worker which contributed to an accident or illnesses. Available information can be divided into three classes: (1) statistical information on the number of injuries by industry, age, severity, cost, etc., (2) anecdotal accounts published in safety or trade journals whose intent is to promote safety, and (3) medical articles concerned with the treatment or description of the injury or illness.

The type of statistical information available has been presented in the previous sections. It was noted that the data can only be used to generally indicate the agency of injury for a specific hand tool, leaving unanswered many questions about the mechanism of injury. Both anecdotal and medical reports have purposes which are not necessarily consistent with resolving tool design problems. Anecdotal accounts of injuries typically emphasize the need for better work practices, maintenance of tools, and using the correct tool for the job. Seldom is any information given on the number of workers exposed to the hazard, the number of accidents which occurred or factors which may have indirectly contributed to the situation. Medical accounts of injuries are primarily concerned with treatment of the injury with only a brief description of how the injuries occurred. Medical accounts of illness are more informative of variables which influence the condition and frequency of occurrence in the population, but frequently lack quantitative information on the tools and workplace in which the illness or injury developed.

TABLE 8

TYPES OF HAND TOOL ACCIDENTS ANALYZED IN TERMS OF PERCENTAGE OF EACH TYPE OF ACCIDENT, NATURE OF INJURY AND PART OF BODY INJURED FOR STATE OF OHIO. (1971 $ 1972)

Type of Hand Tool	Percentage of Accidents within Each Category														
	Type of Accident			Nature of Injury					Part of Body						
	Slip (Not fall) or overexertion	Striking against objects or material	Struck by moving objects	Contusion	Fracture	Laceration	Puncture	Sprain - strain	Low back	Trunk	Arms	Hands	Thumb & fingers	Legs	Feet & toes
Knife	2.0	42.1	55.6	0.3	0.4	89.3	5.9	1.0	0.4	1.8	8.7	18.1	59.6	5.3	1.5
Wrench	48.9	14.2	31.9	21.1	12.8	16.3	1.2	47.5	23.2	4.7	14.5	8.8	18.0	5.1	3.6
Hand Hammer	10.1	5.4	83.3	43.6	26.6	13.8	3.5	16.5	6.3	3.2	9.3	14.5	46.0	8.1	6.9
Nozzle/Hose	46.8	9.1	34.8	25.9	10.4	6.7	0.7	52.4	23.3	8.6	8.6	2.1	4.5	16.8	4.0
Shovel/Spade	85.8	6.8	5.8	6.8	2.4	4.2	0.0	88.4	56.6	5.4	7.8	3.2	2.2	4.4	1.4
Bar	52.9	4.7	36.0	14.0	22.7	12.2	0.0	30.8	20.3	1.2	7.0	1.7	10.5	4.1	7.0
Scissors/Shear	19.2	28.8	47.9	2.7	4.1	47.9	17.3	25.0	4.1	1.4	23.3	13.7	45.2	1.4	5.5
Power Drill	29.1	17.0	43.5	8.2	24.3	13.0	16.4	21.0	4.8	5.7	23.0	23.9	27.0	4.3	2.6
Power Saw	3.1	19.4	49.6	0.8	1.6	69.1	0.0	2.5	1.6	1.6	3.9	9.3	65.1	13.2	1.6
Grinder	10.9	15.5	63.6	8.2	4.5	70.1	9.0	11.9	7.3	1.8	22.7	19.5	19.1	24.5	2.7
Sledge	37.6	3.8	57.7	33.4	19.0	4.8	1.2	39.2	21.4	4.5	7.9	7.2	17.2	13.1	13.1
Pneumatic Tools	30.8	7.7	36.3	19.8	17.6	11.0	13.6	29.6	8.8	5.5	19.8	8.8	29.7	9.9	8.8

This section of the paper discusses the general requirements of data collected to provide the information basis for assessing the importance of characteristics of the worker, the tool, the task and the work practices in the occurrence of injuries and the development of occupational illnesses.

A. Description of Data Requirements

An outline of the requirement of injury-related data is shown in Figure 1. Notice that the injuries and illnesses are categorized by several factors. For each accident or illness a complete description of the conditions relevant to the situation are described. The system characteristics of the worker, tool, task and work practices are all considered in terms of the injuries and illnesses associated with these factors. The system characteristics such as the worker, tool, etc. are further subdivided into the individual factors associated with each major characteristic.

Through a planned, coordinated set of studies, the importance of these system characteristics to the design of the various types of tools can be evaluated. Basically two types of information are required: (1) Detailed information on actual injuries and illness to assess the causes, and (2) studies of the impact of specific attributes of the work, tool, task, or work practices on the occurrence of accidents and illnesses. The first category of information has to be collected in industry, while the second category of information can be developed in a laboratory or a combination of laboratory-field studies. The sections which follow describe the information required in each of the categories.

B. Information about the Worker

The information required in this section is descriptive information about the worker which may permit an evaluation of which characteristics of the worker directly or indirectly contributed to the injury or illness. These data are required based on the assumption that all the relevant antecedents may not be recognized by the safety or medical personnel writing the report, and it is possible that the relationship between the antecedents and the accident or illness may not be understood by the researcher in the area. Briefly the areas of information required are:

(1) Anthropometry--A complete description of the size of the members of the body which are used to control the tool and the angles between the links of the body when the tool is operated. Special attention must be given to describing the position of the hand.

(2) Motor Skills--A profile of motor skills of the workers to obtain any relationships between these skills and accidents. For example, Welford (1958) made the observation that accident prone workers have better than average motor skills, but in young workers a combination of too much confidence in their motor skills and inexperience reduced their ability to recognize a dangerous situation and led to the more frequent occurrence of accidents. This observation requires verification on a U.S. population of workers.

		SYSTEM CHARACTERISTICS																
		WORKER					TOOL					TASK				WORK PRACTICES		
		ANTHROPOMETRY	MOTOR SKILLS	SENSORY	TRAINING	PSYCHOMOTOR	SIZE, SHAPE AND POWER	MATERIAL AND TEXTURE	WEIGHT AND BALANCE	PROTECTION (Heat, Shock, Toxin, etc.)	HOLDERS	ENVIRONMENT	WORK PLACE	ENVIRONMENT	WORK PIECE	JOB REQUIREMENT	INDIVIDUAL	COMPANY
INJURY INDICES	FREQUENCY																	
	SEVERITY																	
ENERGY FORMS CAUSING INJURIES	KINETIC																	
	CHEMICAL																	
	THERMAL																	
	ELECTRICAL																	

FIGURE 1 - Hazard Indices and System Characteristics Taxonomy.

(3) Sensory Skills and Sensory Feedback--A profile is needed of the acuities of the visual, aural, tactal and proprioceptive senses and the ability of the worker to use this information.

(4) Psychomotor Skills--Measures of the ability of the individual to combine mental processes with motor processes will provide the opportunity to assess the importance of skills such as hand-eye coordination on the occurrence of injuries.

(5) Training and Experience--Training and experience will be an indicator of the knowledge the individual has of the tool, the correct methods of using the tool and the potential dangers associated with its use. One basic assumption has to be made in using experience as a measure of knowledge. This assumption is that the opportunities for learning are directly proportional to the years of experience, i.e., that with an increased number of years of experience more learning experiences will be encountered instead of repeating the same learning experiences. A measure of the value of training and experience on the rate of occurrence of injuries and illnesses will then result.

Some of the information in these five categories can and should be collected on the job at which the injury occurred or the illness developed while other information will have to be collected in research projects. For example, the cost of periodical surveys of the motor skills, sensory skills and psychomotor skills of a large segment of a company's work force cannot economically be justified as a routine procedure. Information on the anthropometry, training and experience of a worker who is injured or becomes ill would not be prohibitively expensive to obtain. Therefore, research studies on selected populations of workers should be conducted to evaluate the role of motor skills, sensory skills and psychomotor skills on injuries and illnesses. Information on the anthropometry, training and experience should be collected as routine investigative information whenever a work related injury or illness occurs.

The measure of the attributes also determines the approach to collecting the information. Measurement of the motor, perceptual and psychomotor skills requires special training and equipment which is expensive. By comparison, the cost of collecting anthropometric data and assessing the training and experience level is considerably less expensive.

C. Information about the Tool

The information about the tool is subdivided into descriptive information about the tool, its construction and how it operates and information describing the physical coupling between the tool and its operator and between the tool and workers in the immediate area surrounding the operator. In the literature, the following reasons are frequently given for injuries involving hand tools: (1) using the wrong tools for the job, (2) insufficient or incorrect maintenance of tools, (3) using the tools improperly, (4) improper storage of tools, (5) defective tools and (6) failure to use protective gear. But these causes are not discussed in terms of the frequency of these factors being involved in accidents, e.g., no information is presented on the percentage of hand tool accidents which are caused by use of the wrong tool for the job.

In 1970, there were 1472 disabling injuries reported in California which involved wrenches, but descriptive information was not provided which will help reduce future injuries through avoidance of the hazardous condition which contributed to the accidents. In 1972, 381 cases of accidents involving wrenches were reported in Ohio. Of these 381 cases, 199 (52%) involved a slip or overexertion, 52 (14%) involved striking an object or material and 116 (30%) involved being struck by a moving object. It is possible to speculate on the causes of these accidents, but no information is provided which could be used to test the hypotheses. Only by isolating the specific causes of accidents can progress be made in reducing accidents and illnesses.

The information which is required includes the attributes of the tool, how it is used or misused and the contribution of the various aspects of the job. Using information from anecdotal reports, knowledge of the design of tools, statistical reports such as the Ohio data and experience with the use of a tool, data collection studies need to be designed to obtain information from accidents and illness cases which will lead to an improved understanding of the role of tool design in injuries and illnesses.

D. Information about the Task

This category of information provides a description of the task and its attributes which might contribute to the occurrence of accidents or illnesses. Specifically included in this category are: (1) a description of the workplace, (2) a description of the workpiece, (3) a description of the environment and (4) a description of job requirements. The information included in the description of the work piece will depend on the task, but in general should include information to describe the position of the worker while performing the task, facilities for proper storage of tools and material, housekeeping practices and the relationship (spatial) with other workplaces and/or machines. To describe the workpiece, information on the operation performed on the workpiece and the material from which the workpiece is constructed is required. Environmental information includes the noise, illumination, radiation, vibration, heat (or cold) and air quality at the workplace. Finally, the job requirements include information on the forces, pressures, and job duration.

E. Work Practices

Included under this category is a description of the work practices (i.e., methods and procedures) used to accomplish the job. These practices might be a function of the individual worker, the company's policies or equipment, or industry-wide methods. They might also be influenced by government regulations, e.g., an OSHA regulation might determine a work practice which influences the health or safety of the workers by altering the method used in performing the job.

It can be seen from the foregoing descriptions of requirements for injury-related data that a high priority must be given to developing a more useful data base of hand tool injury and illness information. This data base must contain sufficiently detailed information for the major hand tool types to permit an analysis of the mechanism of injury. Control measures can be successfully developed for hand tool injuries only after the required data have been collected. The most appropriate methods for collecting these data, taking into account the costs and benefits involved, must be developed in a research program.

The Proposed Approach

In order to develop an appropriate procedure for the collection of hand tool injury data, the following steps were chosen:

1. Determination of the information required to describe the accident and possibly to later estimate the contribution of less obvious psychological and physiological factors.

2. Construction of a suitable form and reporting procedure.

3. Evaluation of several injury cases to establish the usefulness and effectiveness of the information collected.

4. An iterative process of steps 1, 2, and 3; continued until the procedure is proven to be suitable.

To determine the information required to identify the cause of an accident, it is useful to consider an example. Consider a case involving an electrician who cut the palm of his left hand while replacing some wiring on a large aircraft. Many factors may be directly or indirectly involved including workplace limitations, a faulty tool, inexperience in a skill required by the task, and others.

To collect the needed information, the system characteristics approach of Ayoub, Purswell and Hoag (1975) was employed. It covered all aspects of the worker, the tool, the task. These are summarized in Figure 1.

Information collected about the worker is generally on anthropometry, training, and experience. Measurements of motor skill, psychomotor skill and sensory feedback ability are considerably more complex than collecting the survey type information and would require a large segment of the worker's costly time. For this reason, collection of this type of information should be confined to selected populations of workers. Results could then be related statistically to the large study population to assess their role in causes of hand tool accidents. In this case, however, an effort was made to test motor and psychomotor skills through administration of the One-Hole test. (Salvendy, 1975) Designed to test the ability of an individual to acquire a manipulative skill rapidly, it was used here to investigate the effectiveness and practicality of such a test in this context. In collecting injury data, a safety representative should, collect information including name, age, sex, measurements of the hand and arm and their positions during the task, and training and experience in this and similar jobs, as well as conduct the administration of a motor skill and psychomotor skill test in this instance. Data collected concerning the tool should include all of the subheadings listed under tool in Figure 1.

To describe the task it is necessary to include a workplace description, a workpiece description, a summary of task requirements; meaning a description of necessary forces, torques, pressures and their duration. For the example, the information required may be:

workplace - on left side of aircraft, 15 feet above ground on a metal scaffold. Working at face level.

workpiece - 2 ft. x 3 ft. panel of several hundred wires.

task requirements - very light grip pressure and shoulder torque.

environment - 70 degrees, loud constant noise, clean area, adequate lighting.

All of the relevant information concerning work practices should be collected immediately from the individual involved, where possible, and the supervisor. All practices (i.e., methods and procedures) used in the performance of the task; whether individual, company policy or government regulation must be included. The aircraft worker in the example might state only that he used a square knot off center method of splicing and that no other practices are applicable. For this study all of the work practice categories were included in data collection efforts.

In addition to the system characteristics associated with an accident it is also possible that non-obvious stress factors contributed to the accident. Stress profile questionnaires may be useful. A sample used is attached (attachment 1).

Another factor, job dissatisfaction, may also contribute to the occurrence of an accident. Any relationship between job dissatisfaction and accidents is, however, unclear at this time. (Scott, 1972) Therefore, no attempt to measure this factor was made.

The information collected in each case was evaluated to determine if any characteristics of the worker, the tool, the task or work practices contributed to the occurrence of each accident. Since the purpose of this study was to develop a reporting system and involves a small data base; no specific recommendations for reducing hand tool injuries were made.

With the previously discussed information requirements in mind, a report form and procedure were developed incorporating the most advantageous combination and sequence of activities. The form (attachment 2) is standardized and includes a list of instructions. Further breakdown and standardization may be needed to collect more. The form was used in a pilot study at Tinker Air Force Base.

In this Pilot study the procedure followed was:

1. Location of subject
2. Completion of forms
3. Administration of the One Hole Test

Data were collected in cooperation with the Tinker Air Force Base Safety Office. All workers involved were employed by the Air Force Logistics Command which in 1974 reported 13.5 percent of its work related accidents to be associated with hand tools.

The initial data were collected over a period of two days. First, all accidents which occurred in June 1975 were surveyed and thirteen cases involving handtools were extracted from the files. After consulting with supervisors a week in advance, it was found that ten of the thirteen would be available for consultation.

The information collected in each case was evaluated to determine that characteristics of the worker, the tool, the task or work practices contributed to the occurrence of each accident. With the previously discussed information requirements in mind, the complete processing of each subject required approximately ninety minutes; thirty minutes for information collection and the rest for travel and subject location time.

Results and Discussion

Information collected from the initial ten subjects revealed the following:

Sex	9 males, 1 female
Average age	36 years
Training	2 subjects were trained to use the tool involved
Average experience	10.9 years
Average time missed due to injury	85.5 minutes

More specifically, Table 9 shows the predominance of manual tools and finger injuries in the group of accidents surveyed.

This is, of course, too little information to identify any trends but is sufficient to demonstrate that such details, descriptive of the injury population, may easily be collected incidental to investigation for cause. It is felt that the body of information collected did in fact prove adequate to describe all of the accidents in terms of the system characteristics. Table 10 summarized the system characteristics which were identified as contributing factors in the causes of the initial ten accidents.

A validation of the effectiveness of the collected information was accomplished by selecting five additional accident cases and investigating them. Again all of the cases were easily described in terms of the system characteristics involved. The data allowed an independent expert to judge that he had a good understanding of each accident after reading the reports.

TABLE 9

SOURCE OF INJURY AND BODY PART INJURED FOR TEN CASES
AT TINKER AIR FORCE BASE

Body Part

Tool	Head	Hand	Finger	Arm
elec. drill	1	1	1	
elec. saw	1			
wrench		1	1	
saw			1	
pliers			1	
file			1	
razor blade			1	

The information collected for the five additional accident cases showed significant similarity to the results in the initial effort. Table 11 summarized the data in terms of the system characteristics. Tables 10 and 11 suggest several interesting trends and conclusions which will be discussed later in the Discussion and Conclusion section. While the amount of data are too small to be conclusive and no scores for the whole worker population are available, it appears that the One Hole Test may be useful in pinpointing a deficiency in motor skill level. Certainly it will be important to investigate motor skill as a system characteristic.

The results of the life stress profile were difficult to interpret. Although there are no population norms to compare to, the finding suggests a tendency toward risk taking behavior. How much this would account for the common disregard of safe work practices is uncertain since many additional factors must be considered such as simple overconfidence, supervisor pressure to increase productivity, and ignorance of safety rules......etc.

Having established information requirements and shown the system characteristics approach to be a reasonable method to describe an accident for the purpose of analysis; it remains to be decided how control measures can be developed. After a major data collection effort, the data will likely point to some obvious controls such as use of gloves with certain tools or wider use of safety glasses, but in many cases only the problems will be identified leaving the necessity of further research to eliminate the hazard.

Discussion and Conclusions

Discussion

Tables 10 and 11 summarized the results of the accident investigations in terms of the system characteristics which were principally involved in each incident. Referring to these tables again, it is apparent that certain of the characteristics are more common in occurrence than others. While this sample is too small to be conclusive; individual work practices clearly dominates while training and tool design and function show only slightly less involvement and all three are highly related. Motor skill, because of the One Hole Test score indications, is also a very important characteristic.

On the basis of the information available from this study it is suggested that the following be slated for primary emphasis in the initial stages of any research which will follow:

1. Individual Work Practices
2. Motor Skills
3. Training
4. Tool Design and Function

Other system characteristics should be added to this list as progress is made and additional funds and opportunities become available.

TABLE 10

PRINCIPAL ACCIDENT CAUSES FOR TEN CASES
IN TERMS OF SYSTEM CHARACTERISTICS

	WORKER						TOOL										TASK				WORK PRACTICES			
CASE	Anthropometry	Motor Skill	Training	Experience	Age	Health	Function	Power Class	Prot. Equipment	Holders	Size	Shape	Material	Texture	Weight	Balance	Workplace	Workpiece	Environment	Task request	Individual	Company	Industry	Government
1	●		●											●		●					●			
2																					●			
3			●			●								●							●			
4																					●			
5																●					●			
6							●												●		●			
7						●	●																	
8			●				●																	
9													●											
10			●				●			●											●			

PRINCIPAL ACCIDENT CAUSES FOR
ADDITIONAL FIVE CASES

	INDIVIDUAL						TOOL										TASK				WORK PRACTICES			
CASE	Anthropometry	Motor Skill	Training	Experience	Age	Health	Function	Power Class	Protective	Holders	Size	Shape	Material	Texture	Weight	Balance	Workplace	Workpiece	Environment	Task request	Individual	Company	Industry	Government
1			●						●												●			
2																					●			
3			●			●											●	●						
4							●															●		
5			●										●								●	●		

This relatively small priority list matches the top two priorities arrived at by Ayoub, Purswell and Hoag (1975) and includes training which developed as the fifth priority in that study. Of course, the sample here is too small to be conclusive but this does indicate that a degree of confidence may be placed in the expert opinion method of priority assignment developed by Ayoub et. al. (1975).

Conclusion

Handtools are a serious threat to the worker who uses them when a characteristic of himself, the tool, the task, work practices and/or their interactions interferes with a safe application. The data available support this statement since it shows that handtools account for between five and 10 percent of all work injuries. However, little can be done to improve the safety of handtool use until more is known about what causes the accidents which occur. A typical accident data collection form assigns causes of accidents to categories. One form in particular uses the categories listed below.

1. Unsafe Condition
2. Unsafe Act
3. Unsafe Personal Factor
4. Material Failure
5. No Fault of Personnel or Material

If carefully completed, these categories might reveal areas where emphasis is needed to reduce injuries but the action taken could not be directed to the cause because no specific cause is defined. There is, then, a void between what causes accidents and what can be done to prevent them. To fill this void a wide range of information is required; identifying the principal causes of handtool accidents.

By incorporating the system characteristics of Purswell, Ayoub, and Hoag into a data collection form it was shown that actual causes of accidents can be identified. Once the system characteristics identified most frequently as principal causes are located, specific research can be needed or preventive measures can be started in these areas. The research will ultimately reveal the steps necessary to devise effective control measures for handtool injuries.

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ATTACHMENT 1

LIFE STRESS PROFILE

Attachment 1 - Life Stress Profile

(all responses are confidential)

(1) Do you generally eat at the same times each day? ________

Did you do so on the day of the accident? ________

(2) Were you planning special recreational activity for after work the day of the accident? ________

(3) Were you concerned about a personal problem on the day of the accident? ________

(4) Had you been off work for a full day or more prior to the day of the accident, (including weekends)? ________

(5) On the day of the accident were you concerned about an important financial or business arrangement?

(e.g., buying land, a car, insurance, etc.) ________

(6) Do you occasionally bet on football or play poker? ________

(7) On the average, how many alcoholic drinks do you drink in a week? _____ a day? _____ (one can or glass equals one drink)

(8) On the day of the accident, did you have a disagreement with your supervisor or a fellow worker? ________

(9) Was there a change in your working conditions within three days prior to the accident? ________

(10) How many work related accidents have you had in the last 12 months including lost time, first aid and unreported accidents? _______

(11) Prior to the accident were you engaged in any unusual off-the-job activity? (e.g., overhauling a car, building a swimming pool, etc.) _______

ATTACHMENT 2

CODING INSTRUCTIONS

A. Where a question mark appears, Code 1-yes, 2-no

B. Question No. 4

Injury Type		Body Part		Severity	
NAME	CODE	NAME	CODE	NAME	CODE
Amputation	1	Eye	1	First aid	1
Bruise	2	Head, neck	2	Missed 1 day	2
Cut	3	Back	3	Missed more than 1 day	3
Burn	4	Internal	4		
Dislocation or Fracture	5	Trunk	5		
Concussion	6	Arm	6		
Strain	7	Hand, wrist	7		
Hernia	8	Finger	8		
Electric	9	Leg	9		
Multiple	10	Toe	10		
Other	11	Multiple	11		

C. Question No. 14
Hand used: Code 1-right, 2-left

D. Question No. 17
Power Class

NAME	CODE
Manual	1
Electric	2
Pneumatic	3

E. Question No. 32 Possible Cause

NAME	CODE	NAME	CODE	NAME	CODE
Unsafe condition	1	Fatigue	5	Poor maintenance	9
Unsafe act	2	Wrong tool	6	Improper storage	10
Unsafe personal factor	3	Improper use of tool	7		
Material failure	4	Poor tool design	8	Defective tool	11

1	Name		Code		
2	Case number			9	Age
3	Experience in this and similar jobs (mo)			10	Sex
4	Training for this tool?			11	Grade
5	Description of injury	Injury type		12	Time of injury
		Body part		13	Minutes since break
		Severity		14	Minutes to break
6	Work time missed (minutes)			15	Hand used
7	Health ; Is it related to acc?				Draw stick figures showing position at the time of the accident and describe the position of the hands
8	Below, trace the hand used				
16	Was anthropometry a causative factor?				

		Code
17	Tool used	
18	Function	
19	Power class	
20	List any protective equipment used	
21	Were any holders, retainers, pouches, etc., used?	
22	If 21 is yes, describe:	
23	Size, shape and balance	
24	Texture: Causative?	
25	Material: Causative?	
26	Weight: Causative?	
27	Workplace: Causative?	
28	Workpiece: Causative?	
29	Environment: Causative?	
30	Task Requirements: Causative?	
31	Individual work practices: Causative?	
32	Company work practices: Causative?	
33	Government work practices: Causative?	
34	Possible causes: Causative?	
35	Comments: Causative?	

SIMULATION IN ACCIDENT RESEARCH

Stanley Rubinsky, Ph.D., P.E.
University of Rhode Island

STANLEY RUBINSKY is professor of industrial engineering at the University of Rhode Island. His research includes small power tool accident research, study of hazards aboard commercial fishing vessels, and the design of a state plan for implementation of OSHA in Rhode Island.

Rubinsky's paper describes the use of two types of simulators: (1) the "process simulator" which is designed to perform like a normal machine except that "an accident involving the simulator cannot result in injury..."; and (2) the "accident simulator" with which noninjurious "accidents" can be caused to occur. The major difference between these two types of simulators appears to lie in the purposes of the experimental situations in which they are employed. The process simulator was used in studies to determine the variables affecting the occurrence of accidents. The accident simulator was employed to subject participants to "accidents" in a training situation.

A classification of accidents by cause should be of help in developing preventative measures. Such a classification scheme could include accidents due to design deficiencies, accidents caused by negligent misuse, and those caused by misuse or improper use because of lack of knowledge. Obviously, accidents caused by design deficiencies would be eliminated by improving the design. An example of this is a household electric meat grinder in which an operator lost the tips of two fingers in the feed screw section. Increasing the length of the entrance tube so that the fingers would no longer reach the feed screw would eliminate the possibility of an accident from this source. Accidents caused by deliberate negligence or misuse are much more difficult to cope with. An investigation of the reasons for the negligence would seem to be in order. Was the negligence the result of fatique, drugs, mental stress, or a lack of appreciation for the possible injury? Knowledge of these factors could suggest some program of remedial action. If the accident were the result of the lack of knowledge or training, the remedial steps are immediately apparent. But, what is the most effective educational or training method? It was the attempt to answer some of these questions which led to the investigation of simulation as a possible research tool.

Incidentally, I am referring only to accidents and not to injuries because, to my mind, they are essentially equivalent. It is usually pure chance which separates the accident from which no damage occurs from that in which substantial injury or even death could result.

Our investigation into the causes of accidents led to the development of two types of simulators. The first type, which we call the process simulator, is designed to perform like a regular process, machine, or hand tool except that an accident involving the simulator cannot result in injury to the operator. For instance, the meat grinder could have been fitted with a soft plastic or rubber feed screw and a soft substance such as gelatine cubes substituted for the meat. Thus all possible methods of misusing the grinder could be investigated and fingers caught in the feed screw as a result of this misuse would not be injured. It was on this basis that a punch press process simulator was designed and tested.

The Process Simulator

A Powermaster Benchmaster No. 142E 2-ton power driven bench press was purchased and modified for use as a simulator. This press could be operated in three ways: by foot pedal, by a hand lever, or by a pair of interlocked handlevers, thus providing the option of operation in any one of three modes, varying from no protection of the operator's hand to protection of one or both hands.

A typical accident with this machine occurs during a press cycle when the operator fails to remove his hand from between the closing dies. The result can vary from laceration of a finger tip to the complete loss of several fingers. In order to eliminate the possibility of real injury to the operator, a modification of the blanking or stamping die normally mounted in the machine was made. The lower, or female, half of the die pair was made in the usual form, except that it was fabricated of wood and painted to resemble metal. The male, or upper half of the pair, however, was made of Porlon, a plastic material containing micropores filled with ink. The modified die is, in effect, a self-inking rubber stamp. This die substitutes an inked impression from a soft die for the stamped impression made by a steel die. The Porlon "die" was fastened to a spring-mounted dieholder so that when an operator's finger was caught between the pair of dies no injury, pain, or discomfort would result. The operator did suffer an inked mark on the "injured" finger. Heavy card stock was substituted for the metal blanks normally used as workpieces.

The press was also equipped with a counter to register the number of strokes of the press, and with a second counter actuated by a microswitch mounted on the spring dieholder to accumulate a count of "accidents." A light and a buzzer were connected to the circuit that was counting the accidents. Suitable switches made it possible for the buzzer to be disconnected. The counting circuit thus could be used selectively to signal the operator when an error or accident occurred.

The simulator was tested, first to determine whether accidents could be forced to a reasonably high and countable frequency and, second, to ascertain whether those variables which were thought to influence real accidents would similarly influence the frequency of simulated accidents.

The punch press was set up to stamp cards using the foot pedal control mode. Thus, since there were no guards on the press either or both hands could be caught between the dies. Twenty college students, 10 male and 10 female, volunteered to serve as subjects. The males were divided randomly into two groups, as were the females. One group of males and one of females were paid a flat hourly rate. The second set of groups were paid the same hourly rate as a minimum, but could earn more money by increasing their output. Both groups were instructed in the designated method of operation and each subject was allowed an eight-minute practice period and a two-minute rest before the production run. The subjects were told that the experiment was designed to study the effect of workplace layout and design on production output.

The test results revealed that six of the twenty subjects were accident free and that two of the subjects incurred six accidents each during a one-hour run. An analysis of the results led to the conclusion that accidents could be made to occur with sufficient frequency to allow a meaningful study in a reasonable length of time and, further, that the frequency of accidents could be manipulated by changing experimental conditions.

Following this work, the simulator was refined by replacing the lower die block by an aluminum block in which were embedded four sensors, one in each corner, which enabled the experimenter to determine that a workpiece was in place at each stroke of the press and also that the workpiece was properly positioned so as to produce a good part. Further, a delay circuit was introduced so that an accident shut off power to the press for a predetermined time in order to introduce a money penalty. In addition, the press has been equipped with a vigilance task. At the appearance of a red light, the operator is required to push a button to extinguish the light before operating the next press cycle. Failure to activate the button results in a press shut down of a shorter duration than that of the accident shut down. Also, all the counters and control equipment are now located at a remote location so that the observer is not in the same room as the subject and can, therefore, have no effect on the subject's performance. Additional research using this simulator is now going on.

The Accident Simulator

The second type of simulator is that which simulates the accident, again, with no danger to the operator. In the design of this device, several criteria were set up. First, the "injury" resulting from the accident should be aversive to the subject; second, the "injury" must be directly related to the accident; third, the unsafe act causing the accident should not be trivial; fourth, the total environment should be realistic; and fifth, the injury must be certifiable by an objective and competent jury as being physically and psychologically harmless to the subject.

A bench grinder was modified and equipped with water jets that could be used to spray the operator (an aversive stimulus) in such a way as to simulate an exploding grinding wheel or a flying spark. Originally, the jet was activated by a hidden remote switch controlled by the experimenter.

Since the unsafe act consisted of standing in front of the grinder during the start up period, the manual switch was replaced by a hidden mat switch located in front of the grinder. If the operator started the machine while standing on the mat, the spray was activated. If the operator stepped in front of the grinder after it reached operating speed, the spray was not activated.

The accident simulator was used to investigate its effectiveness as an aid in safety training and education. Basically, two questions were explored. First, did the demonstration of an accident aid in the training for the safe use of a machine and, second, was there any additional value in having the trainee actually experience the simulated accident?

Briefly, thirty-two subjects were randomly divided into four groups. Each group received written instructions and a demonstration of the correct method of operating the grinder. In addition, one group received a demonstration of the simulated accident, another group was subjected to the accident while operating the grinder, and the last group received both a demonstration and an experience of the accident. In all cases, the simulated accident was used only during the orientation session and never used during the test sessions. All subjects were told that the object of the experiment was to test their ability to separate 10 samples of steel by observing the pattern of grinding sparks. Each subject, therefore, started the machine ten times. An analysis of the results of this first experiment showed that all three groups exposed to the simulated accident either by demonstration, by experience, or both, had statistically significantly fewer accidents than the members of the one group that had no experience with the simulated accident. There were no significant differences among the other groups.

A second test involving 72 college students was arranged to duplicate the first experiment except that each subject was tested three times with a one week interval between tests one and two, followed by a three week interval between tests two and three. The result of this experiment showed that while the mean number of accidents of all groups seemed to be reduced somewhat with the passage of time, the differences were not significant except that the group for which the accident was both demonstrated and experienced had significantly fewer accidents than did the other groups.

A third test involving 120 volunteer students was conducted. In this test the control group of 30 students received written instructions and a demonstration of the correct procedures, as had been done in the two previous experiments. The remaining three groups were each shown and subjected to training accidents, one group to two, a second to five, and the remaining group to ten accidents. In addition, each group was subdivided and one subgroup was given a consecutive schedule of accident exposure and the other an intermittent randomly selected schedule of exposures. Finally, the groups were all tested for retention of training at one month, three month, and six month intervals.

By the end of six months, 80 subjects remained so the groups were equalized by randomly eliminating subjects from the larger groups. The analysis of the results surprised us. Briefly, the difference of all groups from the control group exceeded expectations, but there was no significant difference among any of the other groups nor was there a difference between subgroups attributable to differing schedules of accident exposure. Finally, it was clearly shown that the improvement in the accident rate which was attributed to use of the simulator was retained for at least six months after training.

Thus, we believe that accident simulation offers a powerful means for training in safety procedures. However, this is not necessarily an easy undertaking since the simulation should meet the criteria already stated. One may conceive, for instance, of arranging for accidents in a driving simulator but it is doubtful that such accidents would have much effect on subsequent driving habits unless and until a suitable aversive result of the accident can be devised.

Process simulation requires only that it be realistic in its operation and completely harmless to the operator. The present punch press simulator is now being used to study effects of secondary tasks. It may be used to study machine guarding; the effect of fatigue, drugs, visual and aural distraction, noise; and other such factors and their effect on a machine operator.

To sum up, we believe that both types of simulators will prove to be valuable learning and research tools in our efforts to gain a better insight into the causes and prevention of accidents.

Participants

Jonathan Adler
National Bureau of Standards
Washington, D.C.

* M. M. Ayoub
Texas Tech University
Lubbock, Texas

* Ludwig Benner, Jr.
National Transportation Safety Board
Washington, D.C.

** Philippe V. Cardon
National Institutes of Health
Bethesda, Maryland

Robert Cunitz
National Bureau of Standards
Washington, D.C.

* Robert Eicher
Energy Research and Development Administration
Washington, D.C.

John V. Fechter
National Bureau of Standards
Washington, D.C.

Charles Fried
National Bureau of Standards
Washington, D.C.

* Willie Hammer
Hughes Aircraft Company
Culver City, California

Clarke E. Jones
National Bureau of Standards
Washington, D.C.

Joel Kramer
National Bureau of Standards
Washington, D.C.

* Invited Presentation
** Dinner Speaker

Pat Meguire
National Bureau of Standards
Washington, D.C.

J. J. Persensky
National Bureau of Standards
Washington, D.C.

* George A. Peters
Los Angeles, California

Val Pezoldt
National Bureau of Standards
Washington, D.C.

** R. David Pittle
Consumer Product Safety Commission
Washington, D.C.

Louis G. Porter
National Bureau of Standards
Washington, D.C.

Jerry Purswell
University of Oklahoma
Norman, Oklahoma

Jerry Ramsey
Consumer Product Safety Commission
Washington, D.C.

Stuart Robinson
National Bureau of Standards
Washington, D.C.

* Stanley Rubinsky
University of Rhode Island
Kingston, Rhode Island

* Rose E. Steidl
Cornell University
Ithaca, New York

Harold P. Van Cott
National Bureau of Standards
Washington, D.C.

* Julian A. Waller
University of Vermont
Burlington, Vermont

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