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Rating Accident Models and Investigation Methodologies

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This is a report of research to identify, rate, and rank accident models and accident investigation methodologies. Models and methodologies used in 17 selected government agencies were examined. The examination disclosed 14 accident models and 17 different accident investigation methodologies in those agencies. To determine their relative merit, evaluation criteria and a rating scheme were developed from user data, statutes, applications, and work products, and each model and methodology was rated. The ratings indicated significant differences in their relative merit. The highest rated model and methodology were tested to determine if the estimated ratings were supported by observable differences in actual performance and to compare investigative results against previously reported cases. Differences found prompted further examination of the benefits and problems that would result from implementation of the preferred model and methodology. Additional exploration of comparative performance measurement techniques disclosed further differences affecting the selection decisions. The models, methodologies, criteria, .ratings, rankings, test results, and initial measurement findings are summarized in this report. Issues ranging from oversimplification to ethical questions were discovered during this work. The findings strongly suggest that significant accident investigation program changes should be considered in agencies and organizations using lower-ranked accident models or investigation methodologies and that a compelling need exists for more exhaustive research into accident model and accident investigation methodology selection decisions.

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Little guidance exists in the accident investigation field to help managers or investigators identify and choose the best available accident models and accident investigation methodology for their investigation. There was a brief surge of interest in these issues in the early 1960s (Haddon, Suchman, & Klein, 1964; Mayo, 1961), but this primarily involved discussion of behavioral and medical considerations. No comprehensive lists of choices, criteria for their evaluation and selection, or measures of performance emerged to help accident investigators or program managers choose the "best" accident model and investigative methodology. Faced with such choices, those responsible for accident investigation frequently have serious difficulties with both concepts and investigative methods — a situation the author observed and commented on while with the National Transportation Safety Board (Benner, 1977, 1981a).

Criticisms of accident investigations have been voiced by many others as well, including congressmen, members of the scientific community, and agency staff. For example, criticisms of the Occupational Safety and Health Administration's (OSHA) investigations of grain elevator explosions were extensive, and not untypical (National Materials Advisory Board [NMAB], 1980). If what is being done now is not good enough, however, what would be better? What choices are available, and how can the "best" choice be identified and selected?

OSHA, recognizing that an independent examination of its accident investigation program might indicate how to overcome such criticisms, initiated a research project to identify and explore the relative merits of alternative accident models and investigation concepts and methods. The following is a report of that research.

THE OSHA RESEARCH PROJECT

The first goal of the OSHA project was to identify the accident models and accident investigation methodologies in use in government agencies and determine the "best available" model and methodology. If OSHA was not using them, the second goal was to determine what effects their use would have on OSHA accident investigations. If the effects were significant, the next goal was to identify and analyze the main benefits and risks of their implementation by OSHA. If such implementation would offer significant benefits, the final goal was to determine the principal steps required to implement a preferred model and investigation methodology in OSHA's investigations. The results of this work were reported to OSHA in 1983 (Benner, 1983a-d).

The research was based on the hypotheses that different conceptual views or "models" of the accident phenomenon existed and that these views affected the investigation methodologies used. It was further hypothesized that after these models and methodologies were identified, a scheme for measuring their relative merit could be devised.

METHOD

Overview

The basic research method was a comparative analysis of accident investigation programs in a broad range of Federal government agencies in order to identify and define differences among them. From differences observed in the agencies' documented investigation objectives, procedures, and performance, plus comments from personnel familiar with the accident investigation program, analyses of agency investigations, and previously published works on the subject, different accident models and investigation methodologies would be isolated and defined. From these and other data, a general accident model and investigation methodology evaluation criteria would be selected or developed.

A rating scale would then be developed, and each model and methodology rated. As a "test" of the ratings, different accident cases would be reinvestigated using a high-rated accident model and investigation methodology to determine whether their use would produce different outcomes. If the results looked promising, the findings from these tests would be used to identify and define the benefits and problems that might arise if a preferred model and investigation methodology were adopted by OSHA.

Agencies Studied

The initial task was to select a sufficient number of Federal governmental organizations to ensure a broad cross-section of accident investigation programs for the study. Selection criteria included: (a) agencies known to have accident investigation programs; (b) a full range of programs, from formal, sophisticated, and well documented to simple and informal programs; (c) minimal duplication of programs; and (d) where possible, agencies' that had experienced serious accidents after which questions were raised about their programs. In addition, the NMAB panel that had reported on the investigation program for OSHA was selected because it might offer guidance for the study.

Data Acquisition

Documents detailing accident investigation programs, policies, objectives, practices, and outputs for the agencies selected were then collected and analyzed to identify and define: (a) the underlying perception of the accident phenomenon (accident model) that formed the basis for agency accident investigation programs, policy, objectives, and output requirements; and (b) the accident investigation methodology used by the agency.

The preferred sources of information were agency accident investigation orders, directives, investigation work products, and related documents. Data in organization documents were considered preferable to personal interview data. All governmental agency documents involve review processes that invariably require compromises among agency personnel's views, so that documents are more likely to reflect agency than individual views of the accident phenomenon.

Accident investigation documents from the selected agencies were searched for names of or inferences about underlying models and investigation methodologies. With two exceptions, agencies' accident models and investigation methods had to be inferred, because they were not identified by name. During this task, caution was exercised to isolate the underlying perceptions of the nature of the accident phenomenon, per se, rather than the consequences of the perceptions. The term "accident model" was used in the sense of the perceived *nature* of the accident phenomenon, which served as the working concept driving accident investigation programs and objectives. The model definitions were based on the author's interpretation of data contained in the agencies' documents and on literature sources describing accident models.

Further caution was exercised to distinguish between *method*, e.g., a systematic procedure for performing a given task, and methodology, e.g., a system of working concepts, principles, and procedures employed by a specific branch of knowledge (McDevitt, 1981). "Accident investigation methodology" is thus the system of concepts, principles, and procedures for investigating accidents.

For convenient comparison and analysis, the models, methodologies, and remarks were tabulated on a matrix as they were identified.

In addition to the document reviews, personal interviews were conducted with agency officials who were knowledgeable about their agency's accident investigation program. Questions were raised about respondents' personal views about accidents, their perceptions of their agency's views of accident investigation programs, and their experience with investigations. During the interviews, some respondents became aware of the lack of a designated accident model in their program and tried to invent some name; these spur-of-the moment names were given little weight during the analyses. In most cases, the investigation methodology was not named either, but also had to be inferred.[1]

Whenever possible, models and methodologies were named on the basis of models found in the literature. Additional names were chosen by the author during the project. Name designations were based on either: (a) similarities to published models and methodologies; (b) the author's interpretation of documented agency statements, procedures, or outputs; or (c) in the total absence of documents, the author's interpretation of interview information.

Developing Evaluation Criteria

To compare and rank the merits of these models and methodologies from OSHA's perspective, it was necessary to develop evaluation criteria, because no published criteria for this purpose existed. Evaluation criteria generally can be derived from stated program objectives. Development of these criteria was approached by analyzing: (a) accident investigation objectives found in agency documents; (b) statutory mandates in Public Law 91-596 which established OSHA; (c) agency accident investigation work products; and (d) information acquired during interviews. Previous research discussions were also considered. By comparing such data, evaluation criteria were extracted, analyzed, and defined.

Evaluation criteria for accident models. Surry (1969), Safety Sciences (1980), and Kjellen (1982) have discussed accident models in a context related to this study, but they did not develop or describe criteria for evaluating accident models. Other

[1] In related research, less than 3% of over 200 investigators could name an investigation methodology when first asked what methodology they used for accident investigation.

authors (Haddon et al., 1964; Mayo, 1961) have also addressed the conceptual and methodological issues, but from a medical and behavioral research perspective. Therefore, a set of evaluation criteria had to be developed for this study. These criteria were based on an analysis of agency programs, the reported and observed performance of and problems with those programs, analyses of available accident reports, accident investigation literature, and OSHA's statutory missions. The specific sources for each criterion are presented in the Project Task 1 Report (Benner, 1983a).

Criteria for evaluating accident investigation methodologies. Selection of accident investigation methodologies has been discussed in prior literature (Safety Sciences, 1980). There were, however, no criteria that were relevant for selecting the "best" methodology for OSHA. Such criteria must be tailored to OSHA's statutory mandates, and statutory mandates were not incorporated in previous research. Therefore, OSHA's enabling statute was reviewed to identify statements of the agency's accident investigation mission. These statements, combined with data about other agencies' programs, were then used to develop a list of criteria for judging the investigation methodologies. Previously identified considerations about investigation methods (Benner, 1981a) were also used in formulating the criteria.

Rating Scheme Development

Given the relatively unrefined rating data available at that stage of the research, a simple rating scale was sought. The rating system provided for 3 possible scores (0 to 2), depending on whether or not the model or methodology: (a) was likely to satisfy the criterion as is (2); (b) could satisfy the criterion with some modification (1); or (c) was not likely to satisfy the criterion because of some inherent shortcoming (0).

The author assigned ratings to each model and methodology for each criterion. Using data about the agencies' performance, and considering objectives, scope, procedures, and uses of work products as additional indicators, it was possible to apply this rating scale with reasonable consistency. Ratings were based on: (a) the *performance* of agency programs, as reported by interviewees or in related reports; (b) reviews of the procedures described in agency documents and their applications as shown by accident reports; and (c) the author's direct observations in investigations (Benner, 1981c). A "would" or high rating reflected a conclusion that the model would probably satisfy the criterion as normally considered. A "might" or medium rating reflected a conclusion that the model might be satisfactory if it were modified to address the demands of the criterion. A "could not" or low rating reflected a conclusion that a model simply did not accommodate the points demanded by the criterion.

All ratings were conservatively assigned, that is, if a model or methodology was satisfying or could reasonably be expected to satisfy the criterion, it was assigned a 2 rating. If with some modifications it might be adapted to satisfy the criterion, it was rated 1. If the methodology clearly could not satisfy the criterion, it was rated 0. Uncertainties were resolved by assigning the higher of the possible rating choices. This procedure has acknowledged flaws, and, undoubtedly, ratings contained some author bias. Each rating was carefully considered, however, and two sets of ratings were subsequently checked, as discussed below.

Ranking Method

A simple unweighted composite ranking scheme, using the arithmetic total of the scores for all of the rating criteria, was used to estimate a rough rank order for the candidate models and methodologies. This assumes all criteria are of equal importance, which may or may not be a valid assumption. There are, however, currently no data or logical bases for assigning an order of importance to the criteria that were developed — or any other criteria. In the case of criteria derived from statutory mandates, no justification can be advanced for assigning one criterion greater importance than another for rating purposes.

Tests of Rankings

If significant differences in the composite ratings were found, rankings were tested by reinvestigating previously investigated accidents. Twelve accidents in four categories were selected by OSHA staff as representatives of "good" or "typical" investigations. These accidents were then reinvestigated to determine if the higher ranked model and methodology would have produced better results than the original investigation.

Two tests were actually undertaken to determine if the higher ranked model and methodology were acceptable for the intended purposes. First, the accident reports were tested against the criteria for the models and methodologies to assure the relevance and applicability of the criteria. Second, the preferred model and methodology were used to reinvestigate the cases. The observations were recorded on forms designed for compatibility with the rating criteria.

Exploring Implementation Benefits and Costs

Project plans included studying the implementation of a better accident model and investigation methodology if the tests indicated appreciable benefits. Interviews with investigators who would have to make the changes were subsequently undertaken in order to identify potential problems or benefits with the new model and methodology. Further, reports of the investigators' own work were reviewed from a similar perspective. From the interviews, reviews, and analyses of problems with current investigations, a list of trade-offs involved in implementing a better model and methodology was developed.

RESULTS AND DISCUSSION

Because of the extensive scope of this undertaking and the limited funding to date, much of the research and findings are admittedly "soft." Nevertheless, they clearly indicate that the accident model and accident investigation methodology selection issues require attention.

Agencies Studied

The agency selection process resulted in selection of 17 Federal organizations and a series of relevant National Materials Advisory Board reports for study. These produced a wide range of models and methodologies, as well as experiences, that proved valuable to the study. The agencies studied are listed in alphabetical order in Table 1.

TABLE 1
AGENCY PROGRAMS EXPLORED
DURING THE STUDY

AGENCIES
Consumer Product Safety Commission
Department of Agriculture
Department of the Air Force
Department of the Army
Department of Energy
Department of Labor
Mine Safety and Health Administration Department of Labor
Occupational Safety and Health Administration
Department of Transportation
Coast Guard
Department of Transportation
Federal Highway Administration
Bureau of Motor Carrier Safety
Department of Transportation
National Highway Traffic Safety Administration
General Services Administration
Library of Congress
National Aeronautics and Space Administration
National Institute of Occupational Safety and Health
National Transportation Safety Board
Navy Department
Nuclear Regulatory Commission
National Materials Advisory Board
Panel on Grain Elevator Explosions

Data Acquisition and Model/Methodology Identification

Accident investigation program documents acquired and analyzed during the study are listed in the Appendix. In addition, examples of accident investigation reports were made available by most agency representatives, some on a confidential basis. Information acquired during interviews is documented in the Task 1 Report to OSHA (Benner, 1983a).

During the analysis, only two agencies identified the accident models or investigation methodologies by name. Therefore, any language that defined, suggested, or even hinted at a perception of "accident," "mishap," or a related term was considered to reflect an accident model. Any language that named, described, or inferred a system of methods and techniques – when distinguishable from all the other systems – was considered a discrete investigative methodology.

Fourteen accident models and seventeen accident investigation methodologies were defined from the data. Sources of the individual models and references are reported in the Task 1 Report to OSHA (Benner, 1983a). The models and methodologies identified by the study are listed in Table 2. The models and methodologies are listed in the order identified and are not related to the order in which the agencies are listed in Table 1.

Two agencies were reviewing or modifying their accident investigation program at the time they were contacted for this research. The information about the programs then in effect is reported in Table 2.

Evaluation Criteria

The data led to the development of 10 criteria for evaluating accident models. Specific sources of each criterion are described in the Task 1 Report of this project (Benner, 1983a). The model evaluation criteria are listed in Table 3.

At the beginning of the study, it was presumed that all accident investigation programs were driven by accident models, and that the methods could therefore be evaluated against common criteria. An interesting discovery during the study was that this assumption was not valid. Three relationships between the accident models and investigation methodologies were discerned:

Case 1: The accident model determines accident investigation methodology.

Case 2: The investigation methodology determines the accident model.

Case 3: An analysis method determines the accident model and investigation methodology, and neither the model nor investigation methodology particularly influences the other.

For Case 1, if the accident model satisfies the criteria, then the resultant investigative methodology should satisfy the same criteria as the model. For Case 2, if the investigation methodology determines the accident model, then the criteria for models take on a new role. Indirectly, they should provide a measure of the suitability of the accident model used for accident investigations. As for Case 3, both of the agencies involved indicated awareness of the need for a better model and investigation methodology, and at least one was examining alternatives.

In view of these findings, separate criteria were developed for evaluating the accident investigation methodologies. These criteria were derived from the statute establishing OSHA and are listed in Table 4.

Ten criteria were identified for evaluating accident investigation methodologies. There are also ten criteria for evaluating the models. This occurred by chance rather than design; no specific number of criteria was targeted at the beginning of the study.

Rating Models and Methodologies

The 3-element (0, 1, 2) rating scheme was used to assign ratings to both the models and methodologies. Arguments can be raised about the specific ratings assigned various criteria. Hopefully, in raising arguments, advocates of different ratings will be prepared to demonstrate how the criterion is, can be, or can not be served. Ratings for the criteria shown may vary slightly, but observations and analyses during the ratings process suggest it is unlikely that ratings will vary more than a point.

Review of the completed ratings suggests areas of strength and weakness for each model and methodology. Experience may indicate additional criteria are justified. They should be proposed if valid.

Rating models. Each of the 14 accident models was given a numerical rating for each criterion. The ratings were derived by comparing the model elements with the reported or observed needs that precipitated the criterion, determining how the model might address the need(s), and then deciding whether the model would, might, or couldn't satisfy the criterion. The ratings for each model for each criterion are shown in Table 5.

Rating methodologies. Each of the 17 methodologies was similarly rated on each of the 10 criteria. The needs of the criterion were contrasted with the ability of the methodology, conceptually and as practiced, to satisfy these needs. In addition, the observed results of the methodology's use in the agencies and problems indicated in the documents were also considered. These analyses led to conclusions about whether or not, and how, the methodology could meet the identified needs. The ratings for each methodology for each criterion are shown in Table 6. -

No weights were assigned to the criteria because: (a) they were derived from the governing statute; (b) they did not conflict with each other; and

TABLE 2
MODELS AND METHODOLOGIES IDENTIFIED BY STUDY

ACCIDENT MODEL	INVESTIGATION METHODOLOGY	COMMENTS AND NOTES
Epidemiologic + chain-of-events (c-o-e)	Epidemiologic + forms using c-o-e + clinical methods	Respondent said a model isn't needed; c-o-e supplements epidemiologic
Chain of events + all causes + epidemiologic	Personalized, intraorganizational boards; group + forms + extensive reviews	Need extensive review in lieu of technical truth tests; safety + legal
Chain-of-events + causal factors + epidemiologic with chemicals	Systems + intraorganizational boards; groups + forms + personalized	Accident classes used to conserve investigative resources
Single event + cause factors	Investigator's good judgment with checklists; forms; review	3 types of investigations: safety, JAG, independ7ent safety
Single event + chain-of-events	Kipling model + fault tree analysis + Gantt chart	Which model does investigation satisfy
Violation	Compliance inspection method[a]	Investigation = same as inspection
Indeterminate	Indeterminate	
Pentagon + fault tree + process	Interorganizational group with multidisciplinary members	Advocates NTSB approach + aviation (NTSB) report format[b]
Actual = events process; policy = single cause	Intraorganizational board model + events matrix modeling; each group chooses its method	Model used vs. policy model differs; actual accident investigation did not report cause(s); events analysis plays key role
Stochastic variable + event sequences[c]	Gathering data for statistical analysis + more being explored[d]	Interesting models of accident, investigation, and event
Events process + generic models + specific accident models	NTSB board/group/hearings process + events analyses[e] + forms with c-o-e	Methods can encourage cooperation; delegates some investigations and works in joint investigations
? (scaled abnormalities = incident, abnormal occurrence, accident)	Personal	Scaled abnormalities used to exercise resource control; TMI issues
Moving toward events process view	Personal; forms; multilinear events sequencing, but in transition	Widely accessible user accident investigation data; system exposed investigation problems
Haddon matrix = epidemiologic + mathematical modeling	Baker police investigation[f]; emphasizes crash engineering models; use AIS injury scale of severity	No unifying model to link crash avoidance to crashworthiness; use contract interdisciplinary teams
"We assume investigator knows what an accident is"	Baker model[f] dominates + chain of events	Investigations trigger audits and inspections of forms, records
Chain of events	Kipling + single event + forms	Includes fires
Risk-oriented events-process energy-flow model with links to work flow design and management system	MORT events & causal factors analyses; loss tree analysis criteria negotiation, energy trace; change analysis methods	Uses MORT idealized generic safety control system for both safety inspections and accident investigations
Indeterminate	NTSB for air; others statistics-driven	Technical vs. social demands on accident investigation ..

(a) Use compliance inspection procedures for accident investigation.
(b) No evidence to indicate NMAB panel used its method, format in its own investigations.
(c) Special concept of nature of an "event" includes steady state attributes.
(d) includes a blank form in a flow chart(format that reflects one proposed accident model.
(e) Events analyses include MES flow charting, fault trees, Time/Loss Analysis, time-sequenced spill maps, etc
(f) Baker model extends chain-of-events model significantly

TABLE 3
CRITERIA FOR ACCIDENT MODEL EVALUATION

CRITERIA	DESCRIPTION
Realistic	Model must represent reality, e.g., the observed nature of the accident phenomenon; model must represent both sequential and concurrent events and their *interactions with time;* model must permit representation of the risk-taking nature of work processes in which accidents occur.
Definitive	Model must define nature and sources of data required to describe the phenomenon; model must drive the investigation and analysis methods, rather than be driven by those methods; model must use definitive descriptive building blocks.
Satisfying	Model must contribute to demonstrable achievement of an agency’s statutory mission and not undermine that mission because of technical inadequacies or inability to satisfy agency performance and credibility demands.
Comprehensive	Model must encompass the development and consequences of an accident; model must define the beginning and end of the phenomenon being investigated and lead to complete description of events involved; model must help avoid ambiguity, equivocation, or gaps in understanding.
Disciplining	Model must provide a technically sound framework and building blocks with which all parties to an investigation can discipline their investigative efforts in a mutually supportive manner; model must provide concepts for testing the quality, validity, and relationships of data developed during an investigation.
Consistent	Model must be theoretically consistent with or provide consistency for agency’s safety program concepts; model must provide guidance for consistent interpretation of questions arising during an investigation and for consistent quality control of work products.
Direct	Model must provide for direct identification of safety problems in ways that provide options for their prompt correction; model must not require accumulation of a lengthy history of accidents before corrective changes can be identified and proposed.
Functional	Model must provide functional links to performance of worker tasks and work flows involved in an accident; model must make it possible to link accident descriptions to the work process in which the accident occurred; model should aid in establishing effective work process monitoring to support high-performance operation.
Noncausal	Model must be free of accident cause or causal factors concepts, addressing instead full description of accident phenomenon, showing interactions among all parties and things, rather than oversimplification; model must avoid technically unsupportable fault finding and placement of blame.
Visible	Model must enable investigators and others to sec relevance of model to any accident under investigation easily and credibly; interactions described should be readily visible, easy to comprehend, and credible to the public and victims as well as investigators

(c) the statute did not assign greater or less importance to any of the requirements, based on its legislative history.

The limitations of this relatively subjective approach and the narrow span of the rating scale are acknowledged. In assigning a rating, published descriptions of the methodologies and documented critiques were consulted, comments by interviewees were considered, and the author’s observations of investigation problems were weighted. Nevertheless, the ratings shown obviously contain some biases. Further work with more definitive and discriminating rating scales would be desirable. Any rating changes should, however, be validated by conducting real investigations using *competing methods* and comparing the outcomes. The methodologies *must* be measured and judged *by the performance results they actually produce.* A Delphi approach to these ratings0would not be acceptable. Any attempt to rate the models and methodologies statistically will encounter the same difficulties experienced by the author: No effort to obtain such data has been attempted in the past, so the literature can offer little guidance or data of value.

Ranking Models and Methodologies

The ratings on all criteria were summed for each model and methodology; the maximum score for any model or methodology was 20. The models and methodologies were then placed in rank order.

Ranking models. The composite ratings for each model are listed in descending order in Table 7, showing their relative ranking. The models with the highest ratings consider an accident as a process.

The event-based model views an accident as a transformation process by which an activity in dynamic equilibrium is transformed, with a harmful outcome, by interacting "actors" introducing rigorously timed, undesired cascading changes of state (Benner, 1978). The view is similar to that of the Department of Energy (DOE) Management Oversight and Risk Tree (MORT) energy flow process model (Johnson, 1973) and to the process model shown in the DOE investigation manual (U.S. Energy, Research and Development Administration, 1976). The process model is the model used informally at the National Transportation Safety Board (NTSB, 1978), the U.S. Nuclear Regulatory Commission (Hasselberg, 1983), and the National Aeronautics and Space Administration (NASA, 1981) at various working levels. It is also the model being taught most recently at Coast Guard courses (Hendrick, 1983), and at the Department of Interior Minerals Management

TABLE 4
CRITERIA FOR ACCIDENT INVESTIGATION METHODOLOGY EVALUATION

CRITERIA	REQUIREMENTS
Encouragement(1)	investigation methodology promote *harmony* by encouraging parties to participate in investigations and have their views heard, minimize conflict by disclosing gaps in the investigation, and efficiently but harmoniously control the presentation of individual views with appropriate technical disciplining techniques during the investigation? 2(b)(1)
Independence(2)	Methodology must produce blameless outputs: Does the investigation methodology identify the full scope of the accident, including the role of management, supervisors, and employees in a way that explains the effects and interdependence of these roles in the accident without imputing blame, fault, or guilt?
Initiatives(4)	Methodology must support personal initiatives: Does the methodology provide for positive descriptions of accidents that show convincingly what is needed to achieve adequate control of risks in a specific workplace, in a way that promotes informed and valid individual initiatives, without unnecessarily conveying blame, fault, or guilt?
Discovery(6)	Methodology must support timely discovery process: Is the investigative methodology able to discover safety and health problems when applied to these problems areas? Does methodology enable timely discovery, or must discovery be delayed until credibility of sample sizes and casualty requirements are met?
Competence(8)	Methodology must increase employee competence: Does the investigation methodology provide direct inputs that will increase the competence and safety effectiveness of personnel through training in the detection, diagnosis, control, and amelioration of risks? Are outputs resulting from the application of this investigative technology being used in training with demonstrable safety effectiveness?
Standards(9)	Methodology must show definitive corrections: Does the investigation methodology provide a timely, comprehensive, credible, and persuasive basis for establishing or reviewing efficacy of safety and health standards? Does it document accidents in a way that countermeasure options can be systematically defined, evaluated, and selected, avoiding personal opinions and judgments during multiple reviews for this purpose?
Enforcement(10)	Methodology must show expectations and behavioral norms: Does the investigation methodology support the required enforcement program by providing information about perceptions of duties under a standard, its practicality, and its effects on risk levels by (a) defining the degree of compliance or nature of compliance problems and (b) showing the role of a standard in a specific accident in a way that objective observers can trust and rely on?
States(11)	Methodology must encourage States to take responsibility: Does the investigation methodology encourage States to fulfill their occupational safety an d health mandates by providing them practical ways to produce consistent, reliable accident reports, pretested for completeness, validity, and logic before they are submitted, thus multiplying the effectiveness of their contributions?
Accuracy(12)	Methodology must help test accuracy of outputs: Does the methodology describe each accident in a way that can be technically "truth-tested" for completeness, validity, logic, and relevance during the investigation, to assure the quality of the information in each case?
Closed Loop (Sec. 26) Methodology must encourage harmonious participation: Does the	Methodology must be compatible with "pre-investigations" (or safety analyses) of potential accidents: Is investigation methodology compatible with the pre-investigation or analysis methodologies so those predictions can be used during investigations, so expected vs. actual performance of tasks and controls can be measured or validated by investigations, and so the results can be linked routinely to work flow design improvements?

Note. —Numbers in parentheses refer to PL 91-596, Section (2)(b).

TABLE 5
RATINGS OF ACCIDENT MODELS

MODEL	CRITERIA										TOTAL
	Real-istic	Defini-tive	Satis-fying	Compre hensive	Discipl-ining	Consis -tent	Direct	Func-tional	Non-causal	Visible	
Epidemiologic	1	1	0	0	0	0	0	0	1	2	4
Chain-of-events (c-o-e)	0	0	0	0	0	0	0	1	0	0	1
All cause/systems	1	1	1	1	0	0	1	1	1	0	7
Single event+ cause factors	0	0	0	0	0	0	0	0	1	0	1
Violation	0	1	0	0	0	0	1	1	0	0	3
Pentagon explo-sion model	1	0	0	0	1	0	1	0	0	1	4
Fault tree	1	1	1	1	2	1	2	1	2	2	14
Evemts process	2	2	1	2	2	2	2	2	2	2	19
Stochastic variables	0	0	0	1	0	0	0	1	1	0	3
Haddon matrix	1	1	1	1	0	0	0	1	2	1	8
Mathematical	0	1	0	0	2	1	0	0	2	1	7
Abnormality levels	1	1	0	0	1	1	1	0	1	1	7
Personal	1	0	1	0	1	0	0	1	1	0	5
Energy flow process	2	2	2	2	1	1	2	2	2	2	18

Note. — 2 = would satisfy, 1 = might satisfy, 0 = can't satisfy.

TABLE 6

RATINGS FOR ACCIDENT INVESTIGATION METHODOLOGIES

	CRITERIA										
METHODOLOGIES	Encour-agement	Depend-ence	Initia-tives	Dis-covery	Compet ence	Stand-ards	Enforce ment -	- States	Accu racy	Closed loop	**TOTAL**
Epidemiologic	1	1	1	0	1	1	0	1	1	2	9
Chain-of-events (c-o-e)	1	0	0	0	1	0	1	1	0	0	4
Individual/good judgment	1	1	1	1	1	1	1	1	1	1	10
Board/intraorgani-zational groups	1	0	1	1	1	1	1	1	1	1	9
JAG	0	0	0	0	0	1	2	1	0	0	4
Forms	0	0	0	0	0	1	0	1	0	1	3
Kipling	1	1	1	0	1	1	1	1	1	0	8
Faulttree	2	2	1	2	2	1	2	1	1	2	16
Ganntcharting	2	1	1	1	1	1	1	1	2	1	12
Compliance inspec tion -	0	1	0	0	1	1	1	1	1	0	6
Intraorganizational/ multidisciplinary group	1	1	1	1	1	1	2	1	1	1	11
Eventsanalysis	2	2	1	2	2	2	2	2	2	1	18
Statisticaldata gathering	0	0	1	0	0	1	1	2	0	1	6
Closed-end flow charts	0	0	0	0	0	1	1	1	1	1	5
NTSB Boards	2	2	1	0	1	2	2	1	1	1	13
Bakerpolice	1	1	1	0	1	1	1	2	1	0	9
MORT	2	2	1	2	2	2	2	2	1	2	18

Note. — 2 = would satisfy, 1 = might satisfy, 0 = can't satisfy.

TABLE *7*
ACCIDENT MODEL RANKINGS

RANK AND MODEL	COMPOSITE RATING
1. Events process model	19
2. Energy flow process model	18
3. Fault tree model	14
4. Haddon matrix model	8
5. All-cause model	*7*
6. Mathematical models	7
7. Abnormality levels	7
8. Personal models	5
9. Epidemiologic model	4
10. Pentagon explosion model	4
11. Stochastic variable model	3
12. Violations model'	3
13. Single event + cause factors	1
14. Chain-of-events (c-o-e) model	1

(a)Dominant within OSHA

Service (Benner & White, 1984), as well as numerous organizations in the private sector.

The MORT energy-flow event-based model also views an accident as a process, but focuses on three primary elements — energy, barriers, and targets — supplemented by contributory conditions (Johnson, 1973). It is used in the DOE, by investigators in the nuclear power field, and recently at NASA.

Not surprisingly, since OSHA is a standard setting organization, the model dominating the OSHA Field Operations Manual (U.S. Department of Labor, 1982) is the violations model, i.e., the view that a violation of a standard will cause an accident. Based on the composite ratings, this model ranks among the lowest of the models identified.

Ranking investigation methodologies. The methodologies and their composite ratings are listed in descending order in Table 8, showing their respective rankings. Based on these ratings, the investigation methodologies used in OSHA's accident investigation program manual ranked 13th and 17th of 17.

The highest ranked methodologies were found to reflect application of the events process accident model. These methodologies provide the basis for the energy trace and barrier analysis (ETBA) and the events and causal factors charting methods related to the MORT system (Johnson, 1980). Based on these rankings, event-based accident investigation methodologies should clearly be considered the preferred methodologies for agency accident investigation programs.

Based on the rankings in Tables 7 and 8, it appears that adoption of alternative models and investigative methodologies could improve OSHA's accident investigation program.

Testing the Ratings

Because of the range of the ratings and the low ranking of the OSHA model and methodologies, the reinvestigation "tests" were undertaken. The criteria could be applied in each case and provided a basis for drawing conclusions about the investigation's merits. The sample work sheets in Tables 9 and 10 demonstrate the ease of applying the criteria to individual accident cases.

The highly rated event-based accident process model was used to establish the scope of the investigation and identify factors to be investigated during the reinvestigation. Then the event-based investigative methodology was used to perform the reinvestigation and

TABLE 8
ACCIDENT INVESTIGATION
METHODOLOGY RANKINGS

RANK AND METHODOLOGY	COMPOSITE RATING
1. Events Analysis	18
2. MORT system	18
3. Fault Tree	16
4. NTSB board + Interorganizational groups	13
5. Gantt charting	12
6. Intraorganizational multidisciplinary group	11
7. Personal/good judgment	10
8. Board with intraorganizational groups	9
9. Baker police system	9
10. Epidemiologic	9
11. Kipling's 5 w's + how	8
12. Statistical data gathering	6
13. Compliance inspection[a]	6
14. Closed-end flow charts	5
15. Find chain-of-events (c-o-e)	4
16. Fact-finding/legal (JAG)	4
17. Complete the forms[b]	3

[a] One dominant method in OSHA investigations
[b] Second dominant method; used for inspections and influences OSHA investigations

analysis. The results were documented on events flow charts, which provided a direct comparison between what had been done and what was possible.

What did the tests show? A useful description of what was not known about the accident was possible with retroactive application of the preferred model and methodology. This benefit occurred despite the substantial periods of time (up to 2 years) that had elapsed since the accident. Each case was then reviewed again to determine whether the ratings resulting from individual cases would be comparable to the model and methodology ratings initially assigned. That work disclosed that the ratings were overwhelmingly supported by the reinvestigation cases. In a few instances, the case analysis showed that the ratings assigned to the lower-rated model or method were too generous. The results of the testing were reported in the Task 2 Report to OSHA (Benner, 1983b).

The test accident cases involved citations, no-mystery, and mystery accidents. Retrospective application of the preferred model and investigation methodology provided indications of the substantial impact of the current methodologies on the investigation and report.

Probably the most revealing finding was the discovery that one of the reports, which seemed plausible on first reading and which contained recommendations to cite a firm, did not describe any portion of the actual accident process when the preferred model was applied. In other words, the scope of the original report totally excluded data bout the actual accident process, which would have supported the citation!

Use of the better model specifically showed where and how the original investigations were seriously flawed with respect to scope, coverage, and other criteria. Space does not permit a complete listing of the detailed findings in each case. Table 9 shows how the models compared in a sample reinvestigation. In summary, the comparative application disclosed that if the preferred model were used, it would:

1. Assure a more realistic description of the accident process;
2. Help screen irrelevant matter from reports;
3. Help define specific gaps in the accident process understanding;
4. Discipline hypothesis development;
5. More effectively support citations;
6. Reduce the focus on employee errors as causes;
7. Guide report conclusions;
8. Show role of management decisions in accident process;
9. Help link accident process events to task design;
10. Show ways to improve corrective action efforts; and
11. Help structure narrative outputs.

Exploration of the impact of the investigative methodology on the investigations was also aided by the criteria identified earlier. The results were similar to those found with the model: Significant improvement seemed possible. The comparative abilities of the methodologies currently being used and the proposed preferred methodologies to satisfy specific criteria are shown in Table 10. It was found that, in terms of impact on investigations, the preferred methodology could:

1. Help create win/win relationships among investigating parties;
2. Show interdependence among parties;
3. Assure consideration of relative events timing;
4. Link the accident processes to training steps;
5. Provide prompt technical self-testing and validation;
6. Show the role of standards in accident processes;
7. Provide a "factual" validated basis for enforcement;
8. Provide a constructive role for States; and
9. Generate useful data for subsequent monitoring of work sites.

In summary, the test results generally supported the rankings. These analyses also helped identify some benefit and risk considerations associated with implementation of the preferred model and methodology.

Significantly, despite the elapsed time and the limits of the data available, every reinvestigation with the best model and methodology produced better understanding of the accident process

TABLE 9
COMPARISON OF ACCIDENT MODELS: CASE I EVALUATION

VIOLATIONS MODEL	EVENTS PROCESS MODEL	CRITERIA
no	yes	described accident REALISTICALLY
no	yes	DEFINED the right data needed
no	yes	SATISFIED OSHA's SAFETY mission
no	yes	covered accident COMPREHENSIVELY
no	yes	provided DISCIPLINING framework
no	yes	produced CONSISTENCY with work flow
no	yes	facilitated DIRECT corrections
no	yes	provided good FUNCTIONAL guidance
largely	yes	produced NONCAUSAL findings
no	yes	supplied VISIBLE explanation for all

Note. — The reinvestigation data show that, for this representative accident investigation in which citations were issued, the dominant OSHA violations model used by the CSHO Inspector for the accident "inspection" failed to satisfy 9 of 10 accident model methodology evaluation criteria identified during this project. The preferred model, even when applied retroactively, would have satisfied all 10.

and defined what the earlier investigation did and did not cover. Thus, data for quality control evaluations of the investigation also became available. Each reinvestigation also raised serious issues about the accident and its investigation that were not addressed during the original investigations. This prompted the next phase of the project.

Implementation Benefits and Costs

If better investigative technology is possible, as indicated by the findings thus far, should it be implemented? The preferred model and methodology would require investigators to adopt new ways of thinking about accidents and to acquire new investigative and analytical skills. Such significant changes can not be attempted in a vacuum. Therefore, implementation of the preferred model and methodology was explored in interviews with potential users of accident investigation reports and with investigators who would be required to produce them using the new model and methodology. Also, reports produced by the investigators were reviewed. From these interviews and reviews, as well as previously documented problems with current investigations, a list was developed to show benefits and potential problems if OSHA were to adopt the "best" model and investigative methodology.

TABLE 10
COMPARISON OF INVESTIGATION METHODOLOGIES: CASE 1 EVALUATION

COMPLIANCE INSPECTION	EVENTS ANALYSIS MODEL	CRITERIA
no	yes	ENCOURAGE harmonious participation
no	yes	produce BLAMELESS outputs
no	yes	support personal INITIATIVES
no	yes	help TIMELY DISCOVERY process
no	yes	Increase employee COMPETENCE
no	yes	show DEFINITIVE corrections
no(a)	yes	show EXPECTATIONS norms
partly	yes	encourage STATES to take responsibility
no	yes	help test ACCURACY
no	yes	enable CLOSED LOOP follow-up

Note. — The table shows that, for this representative accident investigation in which citations were issued, the dominant OSHA compliance inspection methodology followed by the inspector during the investigation failed to satisfy *9* out of 10 evaluation criteria identified during this project. The preferred methodology would have satisfied all 10.
(a)The citations had to be compromised.

TABLE 11
IMPLEMENTATION BENEFITS AND RISK SUMMARY

BENEFIT DESCRIPTION	IMPLEMENTATION RISKS
Will raise accident investigation performance expectations	Claims that changes not needed
Gives own implementation direction	Claims that changes stifle initiatives
Broadens investigator perspectives	Allegations of wrong model
Supports CSHO's initiatives	Concur but no action
Increases standards options	Demands for quick success
Improves standards evaluations	
Sets better standards priorities	
Satisfies mission needs	
Improves OSHA's external climate	
Redefines accident investigation purposes	Draws "hardliner" statisticians' fire
Shifts focus to safety	
Supports safety goal setting	
Provides measures of achievement	Goals can be misused
Identifies best available methods	Creates a me-too problem
Controls accident investigation methods used	
Supports initiatives awards	
Managers accept concepts readily	Managers too busy to learn
Cuts risk with proven method	
Methods demonstrate success quickly	
Structures industry role in accident investigation	
Channels existing energies	Weak skills could discredit methods Accident investigation
Supports accident investigation incentives awards	leaders must be managers
Investigators don't focus on violations	
Facilitates better accident investigation training	Some people can't use methods
Resolves past accident investigation problems	
Provides skill screening criteria	Need new skills for accident investigation
Makes timely quality checks feasible	Need penalty assessment factors
Provides for new kinds of actions	May interrupt statistical series
Produces condensed accident descriptions	Workload trade-offs uncertain
Permits easy recall of descriptions	
Allows informed reviews	Review group can bias evaluations
Results would permit publicity	
Program could eclipse NIOSH efforts	

These trade-offs are listed in Table 11. The trade-offs are detailed in the Task 3 Report of the project (Benner, 1983c). The substantive benefits seem to outweigh the risks by a very wide margin, suggesting that the present OSHA program should be upgraded without delay.

Implementation Plans

On the basis of these findings, an implementation plan for the agency was explored .and developed. That work addresses different kinds of issues and will not be detailed here. The work is reported in the Task 4 Report of this project (Benner, 1983d).

FOLLOW-ON RESEARCH

During the course of this project, the author experienced a growing awareness of several broader accident investigation issues. Several have major consequences and are currently being explored.[2] In the interest of brevity, only the more significant issues are highlighted.

Accident Investigation Roles

One of these issues emerged from the realization that three widely differing views o

f(2)Current work is being sponsored by Events Analysis, Inc.

the role of accident investigations exist. These views of accident investigation roles are:

1. A data-gathering effort to support hypothesis validation;
2. A form of applied research project; and
3. A predictive pre-accident analytical effort.

Accident investigation program documents indicated that many persons thought of an accident investigation as a data-gathering effort to acquire information for later statistical analysis and determination of causal factors and trends. A good example of this view is found in the National Institute for Occupational Safety and Health's (NIOSH) background reports leading to the NIOSH Accident Investigation Manual (Safety Sciences, 1980). A second group, including NASA, the NTSB, and others, seems to view each accident investigation as an applied research effort, on which action is expected to be taken. Both of these views focus on post-accident investigations, while a third group looks at accident investigations as a predictive, pre-accident, analytical effort. This view is expressed in the DOE MORT program and has been advocated in a System Safety Society presentation to OSHA (Moriarty, 1981). Each view has significant consequences (Benner, 1984).

The major consequence is the timeliness of corrective safety action. A secondary consequence is the source and nature of such safety action. Retrospective action tends to be more "experience-oriented" than action based on a predictive analysis. The relationship between accident investigations and safety action is undergoing substantial changes in a growing number of fields, as shown in Figure 1. The traditional pathways for information influencing safety actions, shown as a dotted line in Figure 1, are yielding to new pathways to safety actions (solid lines) at a steady but apparently accelerating rate as the methodological tools to support this change become available. Observed reactions to serious accidents suggest, however, that *both* predictive and retrospective efforts are demanded by our society today.

Accident Investigation Objectives

A second issue emerged from the realization that the acquisition of new knowledge and understanding is a common accident investigative objective. This suggests that the capability of alternative methodologies to discover, define, and present new knowledge is

FIGURE 1
INFORMATION SOURCES FOR SAFETY ACTIONS

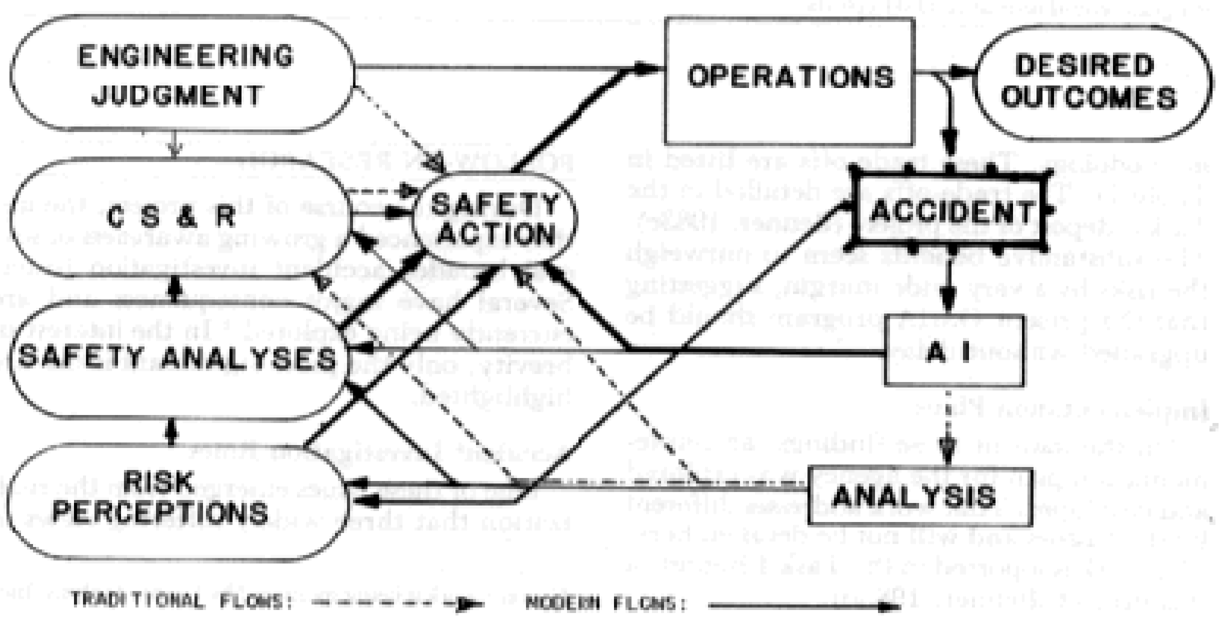
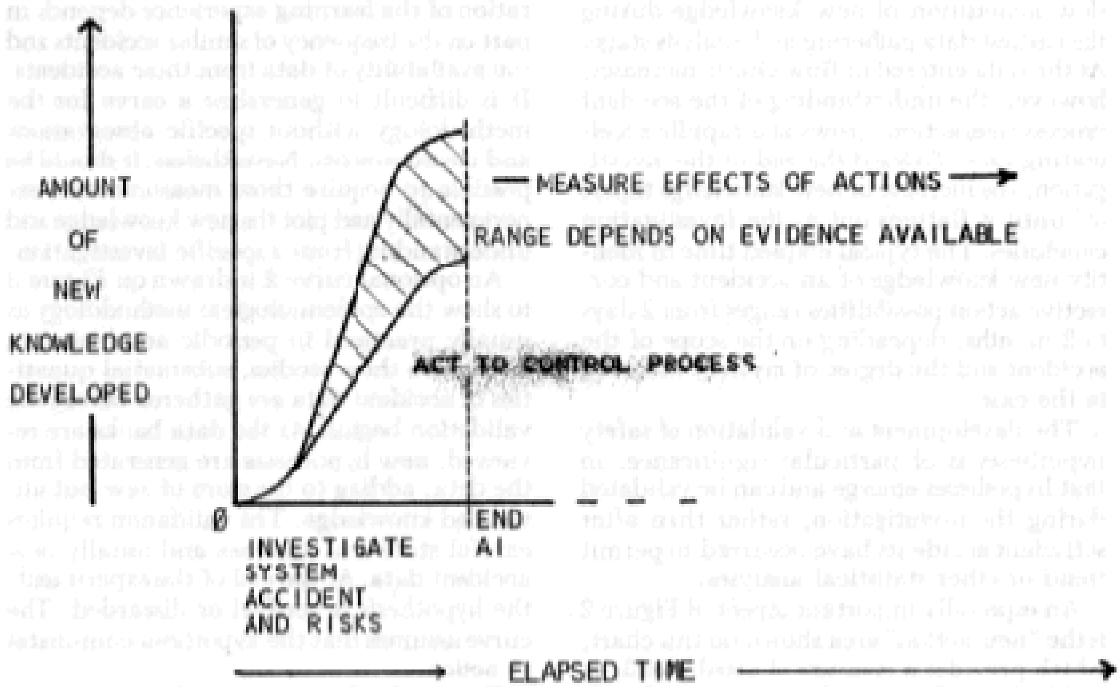


FIGURE 2
DEVELOPMENT OF NEW KNOWLEDGE FROM ACCIDENT INVESTIGATION
CASE 1: EVENT-BASED INVESTIGATIVE TECHNOLOGY



an important consideration in selecting an investigative methodology. Further inquiry into differences among methodologies studied in the project has revealed wide variations in the:

1. Capability to discover new knowledge during investigations;
2. Efficiency of the search for new knowledge;
3. Level of detail of the new knowledge discovered;
4. Validation rate for the new knowledge;
5. Availability of the new knowledge for implementation; and
6. Applicability of the new knowledge to ongoing routine activities.

Current research is directed toward providing comparative measures of each of these attributes. Although numerous obstacles remain, a few attributes seem to be amenable to measurement.

One of the first tasks is to define the new knowledge to be measured. In accident investigation, new knowledge is a new understanding of an accident process step that did not exist before the investigation began. With event-based analysis procedures, this can be defined in terms of relationships among events sets in a process. This approach permits a distinction between knowledge of *system* processes and their operation and knowledge of the *accident* process. It also has an impact on accident investigation objectives: Read again the rating criteria in Tables 3 and 4, which suggest several “new knowledge” objectives.

One approach to measuring several attributes among methodologies is shown in Figure 2. The coordinates of the matrix are the items of new knowledge gained after an accident occurs (at time zero) and the elapsed time after the accident. Figure 2 shows a general shape of the cumulative New Knowledge vs. Time curve for the event-based investigation methodology, drawn from the author’s experience with the investigation of about 60 major accidents in which the methodology was used.

The eventual height of the curve reflects the capability to discover new knowledge items and provides a crude measure of that capability. (See 1 above.) Note the relatively slow acquisition of new knowledge during the earliest data gathering and analysis stage. As the data entered in flow charts increases, however, the understanding of the accident process interactions grows at a rapidly accelerating rate. Toward the end of the investigation, the increase in new knowledge tapers off until it flattens out as the investigation concludes. The typical elapsed time to identify new knowledge of an accident and corrective action possibilities ranges from 2 days to 2 months, depending on the scope of the accident and the degree of mystery involved in the case.

The development and validation of safety hypotheses is of particular significance, in that hypotheses emerge and can be validated during the investigation, rather than after sufficient accidents have occurred to permit trend or other statistical analyses.

An especially important aspect of Figure 2 is the "new action" area shown on this chart, which provides a measure of attributes 3, 4, and 5 above. Because of the concrete detail, real-time validation methods, and minimal abstraction used with the event-based investigative methodology, action on new knowledge developed during the investigation can be defined from very early in the investigation until the investigation ends. This enables action to be taken during the investigation if desirable.

The efficiency (attribute 2 above) is indicated by the height of the curve divided by the length of time required to reach a point along the curve. The greater the ratio, the higher the investigative efficiency.

Figure 3 shows comparable curves for a program using traditional epidemiological methodology for accident investigation. Curve 1 is based on the author's observations of experiences with the acquisition and analysis of data for over 100,000 accidents covering a 10-year period (Materials Transportation Bureau [MTB], DOT, 1971—1981). Note that the methodology is considered here in the context of a single accident and the growth of knowledge related to that accident. Clinical observations are credited with some new insights, but they must be validated with further experiments. The data gathered are usually
extensively influenced by pre-existing hypotheses, so they serve the primary function of validating hypotheses. In either case, the duration of the learning experience depends in part on the frequency of similar accidents and the availability of data from those accidents. It is difficult to generalize a curve for the methodology without specific observations and measurements. Nevertheless, it should be possible to acquire those measurements experimentally and plot the new knowledge and understanding from a specific investigation.

An optional curve 2 is drawn on Figure 3 to show the epidemiological methodology as usually practiced in periodic accident data studies. In those studies, substantial quantities of accident data are gathered before the validation begins. As the data banks are reviewed, new hypotheses are generated from the data, adding to the store of new but unverified knowledge. The validation requires careful statistical analyses and usually new accident data. At the end of the experiment, the hypothesis is verified or discarded. The curve assumes that the hypothesis culminates in action.

During the development of this curve, attempts have been made to track the reduction in losses in some manner. Although unsuccessful thus far, the effort has raised the issue of the ethics involved in selecting an investigative method that requires additional losses to validate hypotheses. This seems to place people at unnecessary risk to confirm or repudiate a researcher's hypotheses. It further suggests that the generation of hypotheses in this area requires attention.

In Figure 4, the curves are overlaid on the same coordinate scales, permitting an estimate of the comparative merits of several attributes of two methodologies. Figure 4, for example suggests that the event-based analysis methodology should be favored because of (a)the amount of new knowledge discovered, (b) the relative efficiency of the search, and (c) the timely availability of corrective action guidance. As additional accidents are investigated, new data could be acquired to provide more valid indications of comparative performance. Nevertheless, the author's experience and observations support the generalized curves shown. It is interesting to note that accident preinvestigations can be shown on this curve too.

FIGURE 3
DEVELOPMENT OF NEW KNOWLEDGE FROM ACCIDENT INVESTIGATION
CASE 2: EPIDEMIOLOGIC INVESTIGATIVE TECHNOLOGY

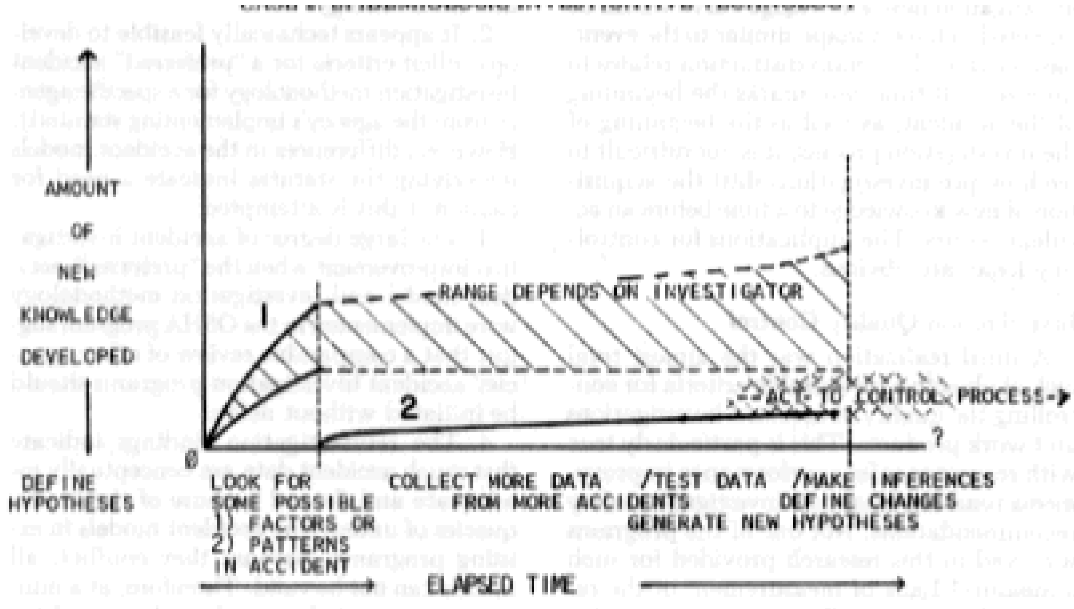
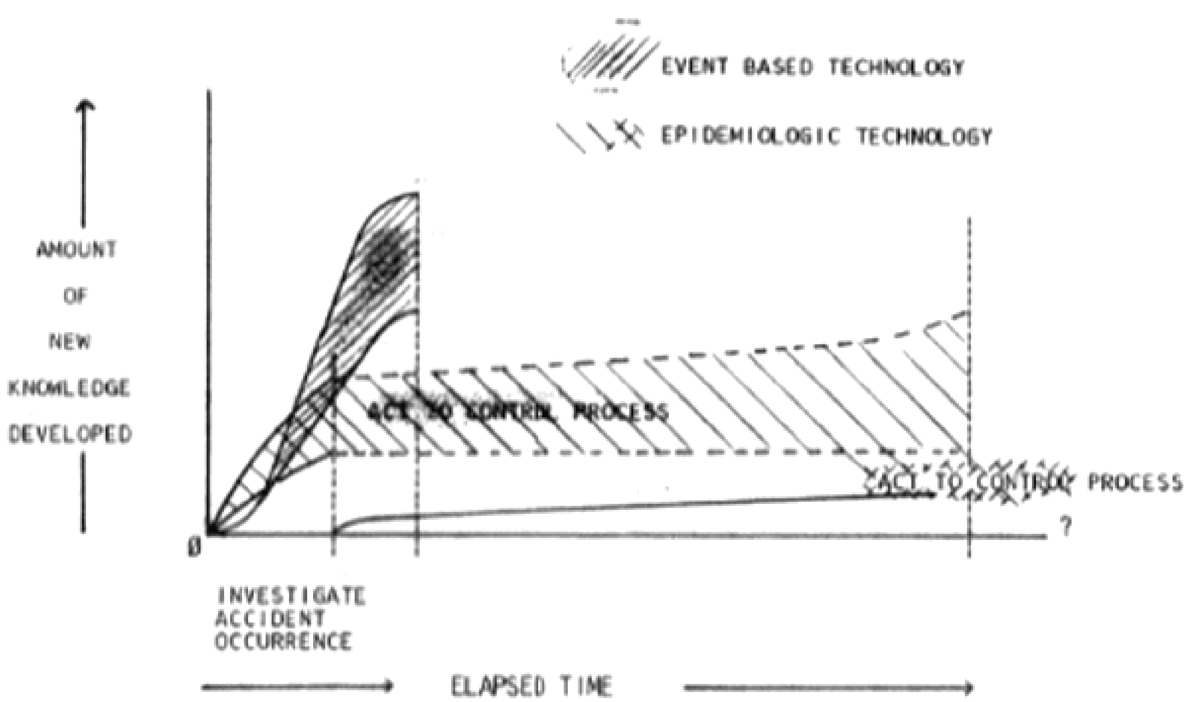


FIGURE 4
DEVELOPMENT OF NEW KNOWLEDGE FROM ACCIDENT INVESTIGATION
COMPARISON OF EVENT-BASED AND EPIDEMIOLOGIC INVESTIGATIVE TECHNOLOGY



Because the pre-investigation technology is similar to the event-based technology, the preinvestigation new-knowledge curve would be expected to have a shape similar to the event-based curve. The main distinction relates to time zero. If time zero marks the beginning of the accident, as well as the beginning of the investigation process, it is not difficult to see how pre-investigations shift the acquisition of new knowledge to a time before an accident occurs. The implications for controlling losses are obvious.

Investigation Quality Control

A third realization was the almost total lack of objective measurable criteria for controlling the quality of accident investigations and work products. This is particularly true with respect to safety performance improvements resulting from post-investigation safety recommendations. Not one of the programs surveyed in this research provided for such a measure! Lack of measurement of the research-defining attributes of investigative methodologies also has been reported (King, 1977).

Accident Concepts Underlying Statutes

Finally, in deriving rating criteria for models and methodologies from the safety statutes for the agencies involved, the author observed differences in the accident concepts underlying the statutory mandates. These differences have not yet been fully defined, categorized, and assessed, but they do exist and their existence should be recognized by the safety research and accident investigation community.

CONCLUSIONS

The work thus far suggests several conclusions:

1. The number of conceptual accident models that drive governmental accident investigation programs seems unnecessarily diverse. Since they conflict, all models can not be valid. The continued use of many models appears objectionable, given their potential shortcomings as indicated by their ratings against performance criteria and the consequences of those shortcomings on the accident data they produce. Lower rated models in governmental safety and accident investigation programs should be critically reviewed and probably supplanted with a better model and methodology.

2. It appears technically feasible to develop explicit criteria for a “preferred” accident investigation methodology for a specific agency from the agency’s implementing statute(s). However, differences in the accident models underlying the statutes indicate a need for caution if this is attempted.

3. The large degree of accident investigation improvement when the “preferred” accident model and investigation methodology were implemented in the OSHA program suggest that a comparable review of other agencies’ accident investigation programs should be initiated without delay.

4. The reinvestigation findings indicate that much accident data are conceptually inadequate and flawed because of the inadequacies of underlying accident models in existing programs. Because they conflict, all models can not be valid. Therefore, at a minimum, some of the accident data used for analysis and action in agencies’ safety programs are unacceptably incomplete and otherwise seriously flawed and are leading to incomplete, misdirected, or delayed remedial action.

5. Based on these findings, more exhaustive research into the measurement and rating of accident models and accident investigative methodologies is recommended. Such information can offer substantial benefits to program managers in and out of government.

REFERENCES

Benner, L. (1977). Accident theory and accident investigators. *Hazard Prevention, 13,* 18—21.
Benner, L. (1978). Four accident investigation games. Oakton, VA: Lufred Industries, Inc.
Benner, L. (1979). Crash theories and their implications for accident research. *American Association for Automotive Medicine Quarterly Journal, 1,* 24—27.
Benner, L. (1981a). *Accident investigation —A case for new perceptions and methodologies* (Publication No. 800387). Warrendale, PA: Society of Automotive Engineers.
Benner, L. (1981b). Accident perceptions: Their implications for investigators. *International Society of Air Safety Investigators Forum, 14,* 13—17.
Benner, L. (1981c). Methodological biases which undermine accident investigations. *Proceedings of International Society of Air Safety Investigators International Symposium,* 1—5.
Benner, L. (1983a). *Task report no. 1: Accident models*

and investigation methodologies employed by U.S. government agencies in accident investigation programs (Contract No. 41USC252G3). Washington, DC: OSHA.

Benner, L. (1983b). *Task report no. 2: Potential impacts of preferred accident model and investigation methodology on OSHA accident investigations* (Contract No. 41USC252C3). Washington, DC: OSHA.

Benner, L. (1983c). *Task report No. 3: Summary report of projected benefits and risk associated with OSHA'S adoption of preferred accident models and investigation methodology* (Contract No. 41USC252C3). Washington, DC: OSHA.

Benner, L. (1983d). *Task report No. 4: Upgrading OSHA accident investigations with best available accident model and investigation methodology: Recommended implementation steps* (Contract No. 41U5C252C3). Washington, DC: OSHA.

Benner, L. (1984). *Safety's future shock II.* Paper presented at the Department of Energy Environmental, Safety and Health Seminar Series for 1984, Germantown, MD.

Benner, L., & White, L. (1984). *Accident investigators handbook for category I and II investigations* (Final Report to Minerals Management Service, Contract No. 14-12-0001-30038). Oakton, VA: Events Analysis, Inc.

Haddon, W., Suchman, E. A., & Klein, D. (1964). *Accident research.* New York: Harper and Row.

Hasselberg, R. (1983). Personal communication. U.S. Nuclear Regulatory Commission, Chattanooga, TN.

Henderick, K. (1983). Personal communication. U.S. Coast Guard.

Johnson, W. (1973). *The management oversight and risk tree-MORT (SAN 821-2).* Germantown, MD: U.S. Atomic Energy Commission.

Johnson, W. (1980). *MORT safety assurance system.* New York: Marcel Dekker.

King, K. (1977). *Feasibility of securing research-defining accident statistics.* (Publication 78-180). Cincinnati, OH: NIOSH.

Kjellen, U. (1982). *The deviation concept in occupational accident research — Theory and method* (draft version). Stockholm, Sweden: Occupational Accident Research Unit, Royal Institute of Technology.

Mayo, L. W. (Ed.) (1961). *Behavioral approaches to accident research.* New York: Association for the Aid of Crippled Children.

McDevitt, J., & Benner, L. (1981). White paper no. 1: System safety methodology for conference on the state of the art of system safety. *Hazard Prevention, 18,* 26—31.

Moriarty, B. (1981, April). Statement of the system safety society before the U.S. Department of Labor, Occupational Safety and Health Administration on regulation of hazardous materials. Subpart H, 2 CFR 1910.

National Aeronautics and Space Administration. (1981). *L39A mishap investigation board report.* Cape Kennedy, FL: Author.

National Materials Advisory Board, National Research Council. (1980). *The investigation of grain elevator explosions* (NMAB-367-1). Washington, DC: Author.

National Transportation Safety Board. (1978). *An overview of a bulk gasoline delivery fire and explosion* (Report HZM 78-1). Washington, DC: Author.

Safety Sciences. (1980). *Briefing on procedures manual for use of the NIOSH accident investigation methodology "AIM"* (Contract No. 210-78-0126). Morgan-town, WV: Author.

Surry, J. (1969). *industrial accident research,* A human engineering appraisal. Toronto: University of Toronto Dept. of Industrial Engineering.

U.S. Congress. (1970, December). Public Law 91-596. U.S. Department of Labor. (1982). *OSHA Instruction CPL 2.45, Field operations manual with revisions through 1982.* Washington, DC: Author.

U.S. Department of Transportation. (1982). DOT form 5800 report data base. Washington, DC: Materials Transportation Bureau.

U.S. Energy Research and Development Administration (now U.S. Dept. of Energy). *Accident incident investigation manual* (ERDA 76-20). Washington, DC: U.S. Government Printing Office.

APPENDIX: AGENCY DOCUMENTS REVIEWED

Baker, J. 5. (1975). *Traffic accident investigation manual.* Evanston, IL: The Traffic Institute, Northwestern University. (Cited by U.S. DOT/FHWA as basis for investigations)

Consumer Product Safety Commission. (1980, October). *In-depth accident investigations* (Order 9010.24). Washington, DC: Author.

International Civil Aviation Organization. (1979, March). Aircraft accident investigation (Annex 13). (The United States is a signatory to the ICAO treaty). Montreal, Canada: Author.

Library of Congress. Library of congress regulations LCR1817-1 and LCRL8L7-4. Washington, DC: Author.

National Aeronautics and Space Administration. (undated). *Basic safety requirements* (Vol. I) (NASA SHB 1700.1). Washington, DC: Author.

National Institute for Occupational Safety and Health. (1978). *Feasibility of securing researching-defining statistics* (Technical Report No. 78-180). Cincinnati, OH: Author.

National Institute for Occupational Safety and Health. (1980). *Procedures manual for use of the NIOSH accident investigation methodology (AIM).* Morgantown, WV: Author.

National Materials Advisory Board, National Academy of Sciences, Panel on Causes and Prevention of Grain Elevator Explosions. (1981a). *Investigation of grain elevator explosions* (NMAB 367-1). Washington, DC: Author.

National Materials Advisory Board, National Academy of Sciences, Panel on Causes and Prevention of Grain Elevator Explosions. (1981b). *Prevention of grain elevator and mill explosions* (NMAB 367-2). Washington, DC: Author.

National Materials Advisory Board, National Academy of Sciences, Panel on Causes and Prevention of Grain Elevator Explosions. (1981c). *Pneumatic dust control in grain elevators* (NMAB 367-3). Washington, DC: Author.

National Transportation Safety Board. (1975). *Inquiry manual, aircraft accidents and incidents* (Order 6200.1). Washington, DC: Author.

Navy Department. (1978). *Aircraft safety engineering accident investigation guide* (NAVAIR 00-80T-67-1). Washington, DC: Author.

Navy Department. (1981). *Handbook for the conduct of forces afloat safety investigations* (NAVSAFCEN 5102/29). Washington, DC: Author.

Navy Department. (1982, April). *Mishap investigation and reporting* (OPNAVINST 5102. lA). Washington, DC: Author.

U.S. Coast Guard. (1982). *Mishap investigating and reporting* (COMDTINST 5100.29). Washington, DC: Author.

U.S. Code of Federal Regulations, Titles 10, 14, 16, 29, 30, 32, 33, 41, 42, 49 in 1982 issues of *CFT.* Washington, DC: U.S. Government Printing Office.

U.S. Code of Federal Regulations, Title 49, chapter 800—831, Regulations of the National Transportation Safety Board, 1982. Washington, DC: U.S. Government Printing Office.

U.S. Department of the Air Force. (1972, March). *Investigation of USAF aircraft accidents* (AFR 127-1). Washington, DC: Author.

U.S. Department of the Air Force. (1979, May). *The U.S. Air Force mishap prevention program* (AFR 127-2). Washington, DC: Author.

U.S. Department of the Air Force. (1980, January). *Investigating and reporting USAF mishaps* (AFR 127-4). Washington, DC: Author.

U.S. Department of the Army. (undated). *Procedures for investigating officers and boards of officers* (Army Regulation 15-6). Washington, DC: Author.

U.S. Department of the Army. (1980, September). *Accident reporting and records* (Army Regulation 385-40). Washington, DC: Author.

U.S. Department of Defense. (1977, June). *Military standard 882a, System safety program requirements.* Washington, DC: Author.

U.S. Department of Energy. (1976a). *Accident/incident investigation manual* (ERDA 76.20). Germantown, MD: Author.

U.S. Department of Energy. (1976b). *MORT Users manual* (ERDA-76-45/4 1976, Rev. 1). Germantown, MD: Author.

U.S. Department of Energy. (1978). *Events and causal factors charting* (DOE 76-45/14, Rev. 1). Germantown, MD: Author.

U.S. Department of Energy. (1982a). *Environmental protection, safety and health protection information reporting requirements* (Order DOE 5484.1). Germantown, MD: Author.

U.S. Department of Energy. (1982b). *Environmental protection, safety and health protection program for DOE operations* (Order DOE 5480.1). Germantown, MD: Author.

U.S. Department of Labor. (1977). *OSHA 2288 investigating accidents in the workplace (A manual for compliance, safety and health officers).* Washington, DC: Author.

U.S. Department of Labor. (1982). *OSHA instruction CPL 2.45 Field Operations Manual* (Chapter XVI and Chapter V). Washington, DC: Author.

U.S. Department of Labor, Mine Safety and Health Administration, National Mine Health and Safety Academy. (undated). *Special investigations field operations manual.* Arlington, VA: Author.

U.S. Department of Labor, National Mine Health and Safety Academy. (1978). *Safety manuals Nos. 1—10.* Beckley, WV: Author.