MODELS FOR ACCIDENT INVESTIGATION

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FOREWORD

This report represents the second half of a two part literature review project commissioned by the Alberta Occupational Health and Safety Division under the direction of a project team consisting of Judith Evans, Lynn Hewitt and John McDermott. The project was initiated by Dr. Herbert Buchwald, Managing Director, who recognized the need for critically examining the various approaches to understanding accidents. Such an analysis represents an important prerequisite to refining the division's strategies for collecting, interpreting and using accident data in the service of effective accident prevention programs.

Dr. Harvey's first literature review (Theories of Accident Causation December. 1984) traced the historical progression of ***accident causation theories and models*** from the original single factor theories to the more recent systems theory approach.

In this report, Dr. Harvey discusses a cross-section of ***accident investigation models*** in terms of their ability to satisfy five evaluative criteria. These criteria, derived from the occupational health and safety literature, represent major purposes of accident investigation. On the basis of his analysis, Dr. Harvey recommends the "best' current approach. In addition, he discusses factors which limit the usefulness of data from accident investigations

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EXECUTIVE SUMMARY

Four general models for accident investigation are reviewed and evaluated with respect to five purposes which comprise the goals of accident investigation. The investigation models chosen for review are: The Heinrich model, with its focus on unsafe acts and unsafe conditions; the epidemiological model, which considers the three broad factors of host, agent, and environment; fault tree models (specifically, the MORT system); and the multilinear events sequencing model recently proposed by Benner.

The evaluative criteria developed for this review consist of five purposes served by accident investigations. These purposes are legal (does the model consider safety code violations?), descriptive (can use of the model provide a detailed description of the accident?), causal (can accident causes be determined by the model?), prevention (does use of the model lead to recommendations for improved safety?), and research (will use of the model provide reliable and comprehensive data useful for accident research?).

The Heinrich Model. This model seems to be most clearly associated with the legal purpose of investigation, with its emphasis upon unsafe acts and conditions. The major criticism of. the model is its potential for introducing bias into the investigation procedure, since the investigator's attention is focussed not upon the facts per se, but upon the unsafe aspects of the accident event only. The identification of unsafe aspects after the accident has occurred is deceptively easy (the hindsight bias), and can lead to conclusions that

are unfair, incomplete, and/or false.

Epidemiology. Epidemiology is a methodology applied to accident events that seeks to identify the factors associated with the host, agent, and environment that are correlated with various categories of accidents. This model avoids the potential for bias noted above, and can potentially lead to an investigation report that describes the accident event completely. However, epidemiology is deficient in two respects; first, it needs guidance from a theory of accidents, and second, it needs an efficient and theoretically based scheme for the classification of accidents.

Fault Tree Models. The general fault tree approach to accident investigation is attractive because it advocates a description of all the necessary and sufficient conditions for an accident within the work system in question. However, a specific adaptation of the model (MORT) has failed to attend closely to the accident event itself, and instead focuses the investigation largely toward management oversights. The model is also criticized for facilitating bias and because it could easily lead to broad recommendations for prevention (eg., more training; more supervision) rather than specific ones.

Multilinear Events Sequencing. This model, proposed by Benner, is similar in many respects to a general fault tree model, but unlike MORT, it does limit its focus to the accident event itself. Benner advocates close attention to the sequence of events leading up to the accident, with special status given to the temporal relations between events. This investigative model is very compatible with the systems theory approach to accident causation. The model encourages a complete description of the accident event and successfully avoids introducing investigator bias. The multilinear events sequencing model is judged to be the best investigative model currently available.

Issues and Conclusions. Many issues related to accident investigation in general are raised. Among them are the following.

(1) It is important to consider what the content of an on—site investigation should be. An investigation report could consist of facts alone, or could include inferences, conclusions, and recommendations as well. (2) It is important that the potential for the biased gathering of facts be recognized and minimized so far as possible. (3) There is a need, especially if research purposes are to he achieved, for a relatively simple yet theoretically guided system for the classification of accidents.

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MODELS FOR ACCIDENT INVESTIGATION

The purpose of this review is to identify the major models for the investigation of accidents, to describe the essential features of these models, and to evaluate them in terms of generally accepted criteria. Four models are reviewed. These four were chosen because (a) they were applicable to accidents in general, rather than being designed for accidents of a particular type, and (b) either the models, or some variant of them, were widely used, or the models are recent developments having features that hold promise for improvement.

It was decided to develop evaluation criteria rather than rely on the criteria of others because the only explicit criteria reported in the literature were developed by an individual whose investigation model is included in this review. (Of course, his model would do well by his own criteria!) The evaluation criteria were developed from a consideration of the generally acknowledged purposes for investigating accidents. It was decided that the model which best satisfies the needs of these purposes would receive the most favourable evaluation.

An important distinction should be made at this point. This paper consists of a review and evaluation of accident investigation _models_, the general frameworks from which investigation practices are developed. Thus, comments on and evaluations of investigation models are not evaluations of how these models are actually put into practice, and this review is not intended as an evaluation of any particular investigation procedure.

A. Introduction.

The purposes of an accident investigation system are generally agreed to consist of one or more of the following:

1. To satisfy legal requirements, and to document any violations of the safety code.
2. To describe the events and circumstances surrounding the accident.
3. To identify the probable cause or causes of the accident; often to include both immediate causes and remote causes (the latter are sometimes referred to as enabling conditions).
4. To recommend what changes could be made to the safety code or to the work site that would decrease the probability of a similar accident in the future.
5. To gather accident information for use in accident research programs and safety programs.

Similar statements of these purposes can be gleaned from many authors representing a variety of perspectives on the investigation of accidents; for example, Benner (1980, 1983) on the evaluation of investigation models, Ferry (1980) on management safety methods, Heinrich, Petersen, and Roos (1980) on analysis and prevention, Lilienfield and Lilienfield (1980) on epidemiology, and the “Field Instructions IP 106” issued by Work Site Services, Occupational Health and Safety Division, Workers’ Health Safety and Compensation, Government of Alberta (1979). While not all sources list all five as important reasons for investigating accidents, the present author believes that each purpose is mentioned often enough in the literature to warrant inclusion in a review of accident investigation models.

In this review four general models for accident investigation, two of which are widely used in some form and two of which have been proposed recently, will be considered primarily with respect to their ability to satisfy these five investigative purposes, and secondarily with respect to theoretical adequacy and in relation to Benner's (1983) evaluation of investigation models (which used a different set of evaluative criteria). This review and evaluation of the models is followed by a brief discussion of several issues relevant to the investigation of accidents regardless of which model one uses. These issues include (a) how to gather facts, (b) judgment biases, and (c) the problem of classification. These issues form a common thread running through the discussion and evaluation of the four investigation models. However, before describing the models, I will discuss the five purposes in more detail, indicating the possible implications of each for an accident investigation model.

B. Purpose of Accident Investigation.

This discussion of the purpose of accident investigation is meant to accomplish two things. First, it will clarify the basis upon which the investigation models are to be evaluated, and second, it will raise some issues regarding accident investigation in general, and focus attention on some of the questions that should be considered when developing policy and procedure regarding investigations. My purpose, however, is not to resolve these issues, but merely to identify them. The five purposes are discussed in the order in which they are listed above, and are named legal, descriptive, causal, prevention and research.

1. Legal. There are two senses in which investigation serves a legal purpose. The first is to satisfy the requirement that certain accidents be investigated. This is a mundane purpose, neutral with respect to the content and procedure of the investigation. However, legislation often does define which accidents are to be investigated and which are not; for example, only those resulting in injury, or that result in lost time at work, may require investigation. These limits on what is investigated are arbitrary in terms of theoretical rationale, and yield a biased sample of events for research.

The second legal sense consists of the identification of safety code violations. Many safety regulations appear to be of the prevention–of–injury type (eg., the use of protective clothing), rather than an accident prevention type. One potential problem with this purpose is that it may foster the mistaken impression that a safety code violation is a cause of the accident. For example, these of a safety line when working above a certain height prevents serious injury by breaking the person s fall, but it does not prevent the fall; therefore, the absence of the safety line does not cause the fall. The cause of the fall is a loss of balance.

2. Describe. This purpose is satisfied by the identification of a complete set of facts relevant to the accident. To fulfill this purpose requires both objectivity and the knowledge of what facts are relevant. An investigation model should provide some guidance with respect to the relevance of facts, and he able to answer the questions, where does the accident begin, how far back in the chain of events should one look, are safety management conditions to be included, and so on. (Some writers have stated, quite seriously, that an accident begins when the victim wakes up in the morning!) Good description of the facts of the case is important for investigation reliability, and reliability of data are necessary for successful accident research.

3. Cause. One can conceive of causes in a variety of ways. One way would be temporal, to consider as a cause of X the immediately prior event(s). Another strategy is to search for the enabling conditions, using a “but—for” criterion (but for the presence/absence of Y, X would not have happened). The identification of cause is a problem of inference, and inference performed by humans is subject to a variety of biases (refer to Sec. D.2). Causal inference based upon a good theory of accidents, or statistical inference, are the preferred

methods for identifying causes.

If an accident investigation model requires the identification of cause, it runs the risk of imposing blame and finding fault as well. Cause can be determined objectively and dispassionately, but human judgment is always involved in blame. For accidents, blame judgments should entail the judgment that “the event should have been foreseen by someone’’ , while cause judgments require only the judgment that a person’s action, or some situation, was a necessary condition for the accident. Since hindsight is so good, we tend to judge most accidents as foreseeable, and the tendency to blame or find fault is increased. An accident investigation model can lead to errors by requiring the investigator to identify the person or persons at fault, rather than requiring a neutral statement of cause.

4. Prevention. An investigation will succeed in this purpose if it can identify those conditions such that, had they been otherwise, the accident would not have happened. By changing such a condition, a future accident can be prevented. Often, recommendations for preventative measures consist of barriers, procedure changes, new safety regulations, and so on. One issue regarding prevention is whether the goal is to prevent the accident, or only the resulting injury. The prevention of injury may be the more simple choice, since to prevent the accident itself would likely require system changes, considerable money, detailed research, etc. To prevent the accident requires a knowledge of its cause; to prevent injury requires only knowledge of the enabling conditions and a means to eliminate them.

5. Research. For accident research purposes, the data obtained from an accident investigation need to be complete and reliable. Also useful for this purpose would be reports that use commonly defined and well understood descriptive terms. Accident research requires a consistent data set, so that the facts of different accidents can be compared, and the facts of similar accidents can be summarized and analyzed together. Accident research should be able to produce the common causes and correlates for certain types of accidents, and to identify a common preventative measure for a large number of accidents. To accomplish this, one needs to know how to group accidents into sets similar enough that a common cause or preventative measure could reasonably be expected to exist. The issue for research is, are there meaningful categories for accidents, and how might we best identify these categories? Without a good classification scheme, an accident investigation model cannot satisfy the research purpose to any great extent, and a good classification scheme would help research greatly.

C. Accident Investigation Models.

In this section four general models of accident investigation will be described; the “domino” model and its variations (Heinrich et al., 1980), the epidemiological model, the fault tree models (eg., MORT; Johnson, 1975), and the multilinear events sequencing model (Benner, 1975). The discussion of these models will relate each to the five purposes of investigation described above, and to the systems theory approach (where appropriate) described in Harvey (1984), and will also consider the strong and weak aspects of each. This section will conclude with a description of Benner’s (1983) criteria for evaluating accident investigation models, briefly comparing his approach with the present one.

1. Heinrich’s domino model unsafe acts and unsafe conditions.

Central to Heinrich’s (1931) original statement of the model is the assertion that the immediate causes of accidents are of two types: unsafe acts, and unsafe conditions — and furthermore, the assertion that unsafe acts of persons are by far the most frequent cause (early estimates, still quoted widely, were that 88% of all accidents were due to unsafe acts). The more remote causes of accidents consisted of the environmental and social conditions, controlled by management, within which the accident occurred. Judging by the sheer number of conceptual descendents, Heinrich’s model of accidents is most widely used at present; any investigation model that includes categories for unsafe acts and unsafe conditions owes at least this dichotomy to his original work.

To illustrate this accident investigation model, examples of categories of unsafe acts and unsafe conditions are listed below. These categories have been used since Heinrich's original work (see Heinrich et al., 1980), and are still used today, virtually unchanged (see Field Instructions — IP—106).

Unsafe Acts of Persons:

1. Operating without clearance; failure to secure or warn
2. Operating or working at unsafe speed
3. Using unsafe equipment, or using equipment unsafely
4. Taking unsafe position or posture
5. Working on moving or dangerous equipment

Unsafe Mechanical or Physical Conditions:

1. Inadequately guarded; guards of improper height, strength, etc.
2. Absence of required guards
3. Unsafely designed machines, tools, etc.
4. Unsafely arranged; poor housekeeping
5. Inadequately lighted, sources of glare, etc.

A salient feature of most of these immediate cause categories is the inclusion in their descriptions of the words unsafe or inadequate to characterize the actions and conditions. The important question, then, for this investigation model, is how are these terms to be defined? For some categories, government laws and regulations may clearly define the proper or safe working conditions and procedures, in which case unsafe, inadequate, and dangerous would be defined as a failure to meet these safety code standards. But where no such independent definition exists, the investigator’s subjective judgment, after the accident has occurred, becomes the basis for deciding what is safe and what is not safe. According to Heinrich’s model an accident investigator must identify one or more unsafe acts or conditions as causes, since only unsafe acts or conditions cause accidents (by definition in the model). Therefore, the investigator is under considerable pressure to characterize some act preceding the accident as unsafe, inadequate, or dangerous, and to do so without regard to its true causal significance. The problem is the lack of independence between the identification of a cause and the occurrence of the accident. Under such conditions human judgment errors (eg., the hindsight bias; see Sec D.2) are easily made.

One step removed from the unsafe acts and conditions in the causal chain, the Heinrich model considers the general work and management “climate” that contributes to or enables the lack of safety, etc. It is this feature of the domino model that has been greatly elaborated in recent years (eg., Petersen, 1975). The basic premise for these expanded models is that some management error, omission, or lack of efficiency causes the majority of conditions within which unsafe acts and conditions can occur (for example, poor supervision, or inadequate maintenance). These expanded models do not contribute anything more toward the investigation of the causes of the accident itself, and therefore discussion of them is beyond the scope of this review. However, these are potentially valuable contributions, because by focusing management attention on the cost—efficiency of good safety practices, these models promote accident prevention procedures.

How well does the Heinrich model of accident investigation meet the purposes outlined above? To the extent that the unsafe acts and unsafe conditions identified in the model are also identified in legislation and regulation, the model can certainly satisfy the legal purpose of investigation. In fact, the close correspondence between this investigation model and the safety code leads one to suspect either that the Heinrich model was designed for this purpose, or that the safety codes were largely informed by the Heinrich model. The expanded versions of the Heinrich model serve this same purpose in those cases in which safety training, routine inspection, maintenance, and process monitoring (eg., of air quality) by management are a requirement of law.

The model appears to satisfy the cause purpose, since it requires the investigator to name the unsafe act or condition presumed by the model to be causal. However, this aspect of the model has serious problems (mentioned above), and its potential for inaccuracy and distortion make it less than satisfactory for this purpose.

In a similar manner, the model promotes a biased description of the events comprising the accident. The investigator is prompted to seek out the unsafe, inadequate, or dangerous aspects of the event, while ignoring facts that are presumed to be irrelevant to the cause of accidents. Such a description cannot be complete, and therefore cannot satisfy the research purpose of accident investigation either. Research cannot identify any new causal factor if the investigation report only contains information about “known” causal factors. In addition, the facts obtained using the Heinrich model cannot begin to provide the detail needed for an analysis of the accident process along the lines indicated by a systems theory approach (Harvey, 1984).

To the extent that compliance with regulations does prevent many accidents, or at least minimizes injury due to accidents, the Heinrich model serves the prevention purpose well, by enforcing the safety code. And since these investigations are capable of producing statistics on the variety and frequency of unsafe, dangerous, and inadequate acts and conditions, legislators have some direct basis for strengthening or otherwise modifying the safety code. However, the model is ill—suited to prevent those accidents caused by factors not already recognized to be unsafe or inadequate, and, as mentioned above, it is ill—equipped to find the unknown or the unsuspected.

In summary, the Heinrich model serves the legal and prevention purposes quite well, is potentially biased in the identification of cause, and is most inadequate for descriptive and research purposes.

2. Epidemiology.

The epidemiological model for the investigation of accidents is an adaptation of the methods used for investigating the incidence of diseases and other medical conditions. So far as I can determine, the goals and methods of the epidemiological approach to accidents have been adopted virtually unchanged from the original medical application. Epidemiology is not a theoretical enterprise; rather, it is mainly a methodological one, and therefore is readily used as a tool for the investigation of accidents. The general purposes of epidemiology (adapted from Lilienfield & Lilienfield, 1980) are (a) to identify the cause or causes of specific types of accident, and (b) to provide a basis for choosing and implementing preventative measures.

The general research strategy is to identify the various person and situation characteristics that are reliably associated with an accident of some type, in order that the susceptibility of persons and the dangerousness of situations can be determined and subsequently modified. The concept of cause, as used in epidemiology, is broadly defined to apply to any variable that covaries with the incidence of the disease or accident in question. Accidents are therefore seen to have potentially multiple causes, but each causal factor need not be thought of as either necessary or sufficient for the occurrence of the accident. A more precise statement of the “cause” purpose of epidemiology, then, would be “to identify factors that are reliably correlated with a specific type of accident”.

The epidemiological method identifies three broad classes of data: information about the agent (the object that produces the accident, or that is in an essential way intrinsic to the particular accident), the host (the person to whom the accident happens), and the environment (the circumstances surrounding the accident that are extrinsic to the agent, yet part of the event; eg., time, location, noise, light). Unfortunately, epidemiology does not itself inform the investigator regarding which sort of characteristics of agent, host, and environment are to become data. But the method imposes no restriction either, and the investigator must be guided by theory or special knowledge of accidents to be found elsewhere. As mentioned above, epidemiology is a method, not a theory. In its application to disease, for example, theory and knowledge of a particular disease informs the epidemiologist that certain host, agent, and environment characteristics are causal candidates, while other factors are most likely irrelevant, thus defining the observations to be made. One can conclude, then, that epidemiology as an accident investigation model can only be as good as the theory and special knowledge of accidents.

In application to accident investigation, epidemiology has little difficulty in producing lists of host and environment factors to be recorded. Characteristics of the host are easy to define, and may include such things as age, height, strength, job training, job experience, accident history, sensory capabilities personal habits, amount of rest, and so on; in short, any relevant property of persons may be included as a host variable. Likewise for environmental features. It is from these lists of factors that the epidemiological method seeks to identify the dangerous situations and the persons at risk for a particular type of accident.

The difficult problem confronting the investigation of accidents by this method is the identification of the agent categories. In its application to disease, the agent is either a uniquely defined virus, bacteria, poison, or other biological unit, or it can be described by a small set of symptoms that are capable of distinguishing one disease from another. The epidemiological researcher can then select cases for study on the basis of the specific agent involved, and discover its host and environment correlates. When applied to an accident, however, describing the agent has proved to be a very cumbersome task, often resulting in an unmanageable number of agent categories while yielding no benefits in terms of data reduction or increased organization.

For example, the adaptation of the ANSI Z16.2 classification of accidents (Government of Canada, 1975) consists of a four—fold classification for accident type, which includes (a) nature of the injury, (b) body part affected, (c) source of injury, and (d) injury event. Many categories and sub—categories are listed for each of these: The nature of injury (eg., sprain, cut, burn), 24 main categories; body part affected (eg., toe, head, chest), 21 main parts; source of injury (eg., body movement, boxes, tools, vehicles), 46 main codes and up to 20 sub—categories for each; and injury event (eg., struck, fall, caught), 14 main categories. To describe accidents by these four sets of variables yields in excess of 300,000 categories of the form ‘‘tool—struck—toe—cut’’ . The question for the epidemiologist is, are the instances in this category similar enough to each other with respect to the host and environment characteristics that one can identify the causal candidates. One can only hope. Certainly, the classification of accidents for the purposes of epidemiological research needs to be re—worked, preferably with an established theory of accident causation to guide the classification process. This problem is considered again, briefly, in Sec. D.5.

How well does the epidemiological model succeed in meeting the purposes of accident investigations? Epidemiology has as its focus all factors that may contribute to an accident, and therefore the model has the potential to describe events very well. Epidemiology does not burden the investigator with causal theories, and so does not have a built—in investigation bias. For these reasons, the model can also satisfy the research purpose, at least in principle; but a satisfactory classification scheme is not yet available, and the model can satisfy research purposes only with a meaningful and simple system for categorizing accidents into similar types.

The purpose of accident prevention can be reasonably well served also. To the extent that the host and environment correlates of some accident type are capable of modification, accidents can be prevented and/or injury minimized. For example, protection for some body part when working on a particular machine is the type of prevention measure that can be derived from an epidemiological study. Similarly, the method could identify the need for special training for some group, or the need for signs or signal systems on a particular machine or process. The recommendations from epidemiology are a product of research, and the efficiency of these recommendations can be improved with improvements in the research potential of the method.

The ability of epidemiology to identify the causes of accidents depends upon the particular theory of accidents that is used to guide data collection. As a method, however, epidemiology can in principle identify causes, in the sense that it can find the reliable correlates of a specific accident type. The identification of cause in this model is a product of research, determined from statistical inference rather than human intuition; judgment and good theory are needed to make good guesses about which accident correlates are causal and which correlations are due to a common unknown causal factor.

Epidemiology by itself serves no legal purpose in accident investigation, except for meeting the general requirement that an accident be investigated. However, the method could be used for this purpose if desired. For example, an epidemiological study of a particular safety regulation (the agent, in this case) would observe the host and environment characteristics associated with compliance and non—compliance with the safety code regulation.

In summary, the epidemiological approach to accident investigation can potentially serve the description, research, and prevention purposes fairly well, and with a complete data base could identify accident causes. Epidemiology does not concern itself with any of the legal purposes. To achieve its potential, the epidemiological method needs the support of a theory of accidents, and in addition needs an efficient and theoretically meaningful accident classification scheme.

3. Fault Tree Models

The fault tree approach to accident investigation is an adaptation of the methods used in engineering to determine the safety and reliability of any machine or system of machines, be it small (eg., a valve, motor, or switch) or large (eg. , an aircraft, a nuclear power plant). Knowledge of each system component and of the process by which each component affects other parts of the system are essential pre—conditions for the use of such a model. This knowledge of the system allows the engineer to identify the necessary conditions for an accident or system failure; for example, to be able to state that failure A will occur if condition X and Y or Z have occurred. By calculating the probabilities of X, Y, and Z (i.e., knowing the failure rates of the components) and by combining these values appropriately (with reference to the relations among components), one can predict the likelihood of failure A (eg., that the probability of a major accident in a nuclear power plant is 1 in 10,000 years). As used in engineering, however, fault tree analysis considers only the contributions of machines, but not those of humans. Adaptations of the fault tree approach to the problem of accident investigation, therefore, have attempted to include human decisions and actions as components of the system. The Management Oversight and Risk Tree (MORT) system (Johnson, 1975) is one such adaptation, and will be used here as an example of this general approach.

A fault tree analysis that includes the operator should do so by considering how the operator interacts with each machine component in the process; in other words, it should detail the operator’s sequence of behaviors (an operating process) at the same level as it details the machine components. However, the human elements in MORT are not considered so much at the operator level, but rather (as the name of the system implies) at the management or supervisory level.

The approach, therefore, tends to maintain a separation between the machine system and human interaction with it. The MORT system asks, in general, what human acts or omissions are the preconditions for a particular component failure. Examples of the questions posed by MORT are; was maintenance or replacement of component parts sufficient to prevent component failure?, was the design of and use of barriers sufficient to prevent energy transfer?, was operator training sufficient to ensure proper machine operation and maintenance?, and so on. The emphasis of this model is on management safety practice and procedure rather than on the details of the behavior of the operator who experiences the accident.

When, using the MORT analysis, the investigator constructs a chart of the management system relevant to a particular accident, a chart capable of identifying all possible contributing factors. For each possible contributor X, the investigator answers the question “was X less than adequate?” An affirmative answer identifies a contributing cause, a management oversight, and furthermore, indicates what improvement would decrease the probability of a repeat accident.

The investigator’s judgment in this case is biased in a manner similar to the bias described in the Heinrich model; namely, that since an accident has occurred, it is presumed by the model that one or more system components must be less than adequate. It becomes too simple for the MORT user to conclude that “if maintenance were more frequent, if supervision were improved, if . . ., this accident would not have occurred”. One has no basis upon which to choose the most important contributing factor, and changing all may be grossly inefficient. In addition, the MORT model includes no standards by which to make these “less than adequate” judgments; the standards used, then, are likely to be either the safety code or the best guesses of the investigator. Either way, an investigation using MORT is really no improvement over a well conducted investigation using an elaborated Heinrich model. The only advantage to MORT may be that the use of a tree diagram to describe the complete operating system may bring to the investigator’s attention aspects of safety management that might otherwise be missed, and a more comprehensive investigation would result.

The MORT approach to accident investigation appears capable of satisfying the same investigative purposes as are satisfied by the Heinrich model, with the added potential to be more complete. MORT very likely can satisfy legal purposes, since regulations seem to be the most readily available set of standards by which to judge the adequacy of conditions. MORT could also make use of industry policy regarding safety, etc., as an additional set of standards for this judgment task.

MORT also seems capable of contributing to the prevention of accidents, because it specifically searches for those areas that need improvement; in fact, accident prevention seems to be its major purpose (Johnson, 1975).

The MORT approach could do a good job of describing the facts of an accident, but fails in this respect due to its focus upon safety management rather than upon the accident itself. The concept of a component failure interacting with human failure (to perceive, or to react) to produce accidents is consistent with a systems theory account of accident causes, but, as mentioned above, MORT does not consider human involvement at this level. The method has potential in this respect, but has not yet realized it.

As a source of research data, a MORT investigation is an improvement over the Heinrich model because MORT imposes a consistent organization upon the information to be included in the investigation. In addition, its potential for yielding a more detailed description of the accident event indicates that some variant of MORT could hold considerable promise for accident research. As a tool for identifying cause, the MORT analysis is very similar to the Heinrich model, and similar comments with respect to biased judgment and reporting apply.

In summary, MORT serves legal purposes and safety management purposes (prevention) reasonably well, although its approach to prevention appears to be broad (the shotgun approach) rather than focused. For the purposes of describing the accident, identifying causes, and conducting research, MORT is at present (and in the words of the model) less than adequate.

4. Multilinear Events Sequencing.

The multilinear events sequencing model (Benner, 1975, 1980, 1983; hereinafter called Benner’s model) was developed largely in response to the inadequacies found in the Heinrich model and other widely used accident investigation strategies. Benner's model is clearly informed by and is consistent with a systems theory approach to accident causation (Harvey, 1984), in that it seeks to identify the events in the accident process from the initial perturbation (a departure from the normal operating process)through to its harmful or damaging conclusion. Unlike other approaches, Benner's model focuses exclusively on the accident episode, although it makes use of the descriptive logic found in fault tree analysis when expanded to consider contributing conditions.

Benner's model for accident investigation consists first in identifying all the <u>actors</u> involved in the accident episode. These actors can be either persons, or an object capable of action (i.e., it can move, emit sound or light, can fail to move when expected to do so, etc.), and the analysis of the accident involved documenting the actions of each actor from the beginning to the end of the episode. The basic unit in Benner's model is the <u>event</u>, defined as a single actor and a single action. The investigation proceeds by organizing these events in time, from the initial perturbation to final injury, with each actor described on a separate time line while maintaining the correct time ordering of events between actors. The results of such an investigation would yield a complete description of the state of each actor at every point in time. To complete this picture of an accident, Benner suggests that the conditions necessary for each event to occur (if known) can be indicated for each event. Unfortunately, Benner is vague when defining these enabling conditions, referring only to “conditions that must have existed for the events to occur” (1975, p. 71). From Benner’s illustration of a condition, it seems that an investigator seeks to answer the question “under what condition C would event E not have occurred?”, and the necessary condition then becomes the absence of C (eg., because the rug was not nailed down (a condition), the rug slipped (an event)). In Benner’s model these conditions are not treated as causes, but rather, as indicating possible solutions for accident prevention.

Benner’ s model satisfies the descriptive purpose very well; not only does it advocate a detailed reporting of events, but it also insists that detailed temporal information be included. In addition, unlike models discussed previously, Benner’s model identifies the temporal limits of the investigation, beginning at the most recent occasion of system homeostasis, or normalcy. However, by making provisions for including conditions in the investigation, the investigator could if desired go beyond these temporal limits and consider such things as safety training, maintenance, barriers, etc.

Benner’s model can also satisfy the research purpose, since the descriptive data are complete and well organized. But Benner’s model, like those discussed above, does not offer an accident classification system. His model seems best suited to a case—by—case analysis of accidents, and does not explicitly provide a means of comparing or aggregating accident cases.

Prevention of accidents can also be well served by Benner’s model, and this can be accomplished in two ways. First, to the extent that enabling conditions are identified, preventative measures could be considered for them. And second, the knowledge about accident process details contained in the “events” analysis may identify the changes that could be made to the human — machine operating system (eg., slow down, speed up, change distance, etc.); in short, the analysis may suggest another way to design the task.

With respect to cause and legal purposes, Benner explicitly asserts that his model does not seek causes, and nothing in the model is defined with reference to an explicit or implicit safety code (eg., the terms unsafe and inadequate are not employed in any definition). Of course, Benner’s model can identify cause, in the sense that it can in principle provide a description of a sequence of events ending in an injury (this sequence becomes the cause), and enabling conditions could constitute safety code violations. But Benner insists that accident investigations that seek causes and/or violations (I think he has the Heinrich model in mind here) generate adversarial relations, when cooperation among all concerned will provide the most reliable description of the events sequences required by Benner ‘ s model.

In summary, Benner’s model for accident investigation can provide quality information for research and prevention purposes, primarily because it provides an excellent description of the accident process. The model explicitly avoids causal and legal purposes, with some justification; but the model can satisfy these purposes by considering enabling conditions in addition to the events sequences.

5. Benner’s (1983) Evaluation Criteria.

Benner (1983) has suggested 10 criteria by which to judge the merits of an accident investigation model. I will briefly describe these, and indicate how each is related to the five purposes of an investigation described earlier.

A model should be realistic (1); that is, it should require a complete and adequate description of the accident. This criterion is clearly relevant to achieving the descriptive purpose. A model should also be definitive (2), by clearly defining what observations are to be made. Furthermore, what to observe should not be directed by the requirements of the data analysis; rather, data analysis should be directed by the nature of the accident phenomena. This criterion serves both the descriptive and research purposes.

A model should also be satisfying (3), comprehensive (4), and disciplining (5). By these criteria Benner means that a method should provide information that can meet the goals of the investigative agency (eg., prevention, or regulation), should not require follow—up investigations or investigations by other agencies, and should use a strict terminology for reporting, such that all parties concerned understand the investigation in the same way. These criteria can promote the legal, descriptive, and research purposes, and further, seem directed toward the overall efficiency of the investigation.

A model should also be consistent (6), in that two investigators of the same accident should produce similar reports; and functional (7), meaning that the investigation should relate directly to the operating system within which the accident occurred. These criteria serve research purposes primarily, but also prevention purposes, since an investigation that relates directly to the work process can suggest modification and improvement in that process. Benner also advocates a model that is direct (8), so that a single accident investigation is sufficient to recommend procedure changes. This criteria serves the prevention purpose, and greatly decreases delays between the investigation and recommendations for change.

Two final criteria, that a model be non—causal (9) and that it be visible (10) seem to be directed toward the goal of good public relations. The non—causal criterion reflects Benner’s fear that finding cause is perceived to mean finding fault, which results in antagonism between investigator, worker, and management, with a subsequent loss of data reliability. The visibility criterion refers to the distribution of the investigation report to all parties concerned, in a form that is understood by all. Such feedback, Benner believes, should increase the appreciation for both accident investigations and the recommended safety procedures.

Of the general models for accident investigation reviewed here, both Benner (1983) and the present author agree that Benner’s model merits the highest rating, and this agreement is achieved even though these two judgments are based upon different evaluation criteria. Benner’s model has an additional advantage, in that there is a close correspondence between it and the systems theory approach (Harvey, 1984) to accident causation.

D. Issues Relevant to Accident Investigation.

In this section I will briefly discuss several issues relevant to the conduct of an accident investigation. These issues will not be resolved here, but are brought forward for the purpose of discussion. It is important to consider these issues regardless of what accident investigation model is ultimately adopted or developed.

1. Gathering facts.

The investigator should be concerned primarily with the facts of the accident, and should beware of confusing facts with inferences, presuppositions, or evaluations. Therefore, an accident report should avoid the use of modifiers such as unsafe, etc., and use evaluatively neutral modifiers only. If an investigation model requires judgments as well as facts, the structure of the report should clearly separate these from each other. The accident model can assist the investigator in the identification of relevant facts by clearly defining the endpoints of the accident episode, and by distinguishing fact from inference and judgment. A fact only approach should promote better description and more useful research data. In addition, many of the reporting biases could be avoided if investigators adopt .this attitude. The accident investigation model and the underlying theory of accidents can guide decisions regarding the facts to be included in the report.

2. Avoiding bias.

Recent research in social psychology has documented numerous errors and sources of bias relevant to human inference and decision making (these are very well presented in Nisbett & Ross, 1980), and several of these are relevant to the accident investigation process. There is a strong tendency, for example, to believe that one could have anticipated, predicted, foreseen, or avoided some event, given the knowledge that the event has occurred (the hindsight bias). An investigator, knowing that the accident has occurred, may believe too strongly that it could have been anticipated and therefore avoided; the result would be to find fault with preceding acts or omissions when this may be unjustified.

Another bias concerns the tendency to seek evidence that confirms a causal hypothesis while ignoring evidence that would or could disconfirm it. An investigator who approaches an accident with the belief that fatigue causes accidents would actively seek evidence for fatigue, but would unwittingly pay less attention to other possibilities. The perceived similarities between accidents may also bias an investigator; for example, because accident A reminds the investigator of accident B, the investigation of A may be inappropriately directed by the conclusions and recommendation from the investigation of B.

The best protection against these and other biases would consist of an investigation model that discourages inference and hypothesis, and encourages fact—finding only. Knowledge of these biases may also alert investigators to the possibilities for bias in their reports.

3. Regulations. As mentioned previously in this review, the violation of a regulation is not necessarily a cause of an accident, and it may be

only of minimal importance to the accident episode. However, the investigation has as a major purpose the monitoring and enforcement of the safety code, and violations need to be found and reported somewhere. In order not to distract the investigator from seeking the facts of the accident, and to avoid bias that may be introduced in the quest for violations, it is suggested that the investigator maintain independence between the legal purpose and the descriptive purpose. This may be achieved by making the legal purpose the last to be satisfied, and by reporting on possible safety code violations only in a separate section of the report.

4. Investigator conclusions.

The issue here is, should an investigator make conclusions, etc., and if so, what type should these be? On—site investigators have accumulated through experience considerable knowledge of accidents, and one should take advantage of this. However, since this informal knowledge is subject to biases of various kinds, it may be better to treat the recommendations and conclusions as informed opinion rather than as additional facts about the accident. Conclusions about the cause or causes of the accident, then, might be clearly separated from the “facts” section. It is the role of research on the facts of many accidents to make unbiased inferences about causes, and efficient recommendations for prevention, and a field report should not be allowed to influence the research product unduly.

5. Accident classification.

To meet the research needs associated with accident investigation, it is necessary to have an accident classification scheme. Such a scheme should allow for the meaningful aggregation of investigation reports into a small number of categories, and these categories should contain accident reports that are similar to each other in some important way. The difficult questions are how to create categories that are useful, and what constitutes meaningful similarities and differences among and between accidents. It is clear that the only model that attempts classification (epidemiology) is inadequate for this purpose.

One step toward solving this problem, I believe, is to consider the variety of operating systems within which accidents occur, and to develop a job or task or process classification for accidents. Systems theory is concerned with process, and so is Benner's model for investigations. Consistent with the theory and the model, a useful classification scheme might categorize accidents by the nature of the task concerned. One could aggregate all accidents that occur while painting, or fixing, or using hand tools, or power tools, or while moving from one job site to the next, for example, rather than a classification based upon the nature of the injury. Intuitively, it seems that there would be greater similarity among accidents that occur while operating a drill, a saw, and a lathe, than there is among all accidents involving a cut to the hand, or that concern damage to some other body part.

E. Summary.

Four accident investigation models were reviewed and evaluated with respect to five commonly cited purposes that they are meant to serve; legal, descriptive, causal, prevention, and research. Of these models, the multilinear sequencing of events approach recently proposed by Benner (1975) was judged the best. Widely used models derived from Heinrich's domino model of cause was found to be poor for descriptive purposes, and subject to biases in reporting. The epidemiological model, also widely used, was judged to be inadequate primarily because it requires a theory for its implementation (this has not yet been done), and because its classification of accidents is unwieldy. Fault tree analyses (eg., MORT) are potentially more descriptive than the Heinrich model, but these too introduce bias and thus far have failed to require that accident episode details be reported.

Several issues were raised concerning the conduct of an accident investigation. Important among these are the necessity for keeping separate the facts, on the one hand, from opinions, inferences, and safety code violations, on the other. It is also important to recognize the variety of biases that can affect human judgment and inference. Finally, it was recommended that efforts be made toward the development of a theoretically guided system for the purpose of accident classification.

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