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Accident Investigations: Multilinear Events Sequencing Methods

Accident Investigations: Multilinear Events Sequencing Methods

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Difficulties experienced by accident investigators in explaining what happened and why it happened in specific accident investigations are examined. These include problems with delineating the beginning and end of the accident, methods for discovering and testing the relevance of facts of the accident, and methods for presenting the findings of the investigation. Criteria for approaches to resolve these difficulties are suggested. Concepts influencing current methods of research and investigations are discussed, along with their limitations in terms of the suggested criteria. A generalized explanation for the accident phenomenon based on the role of perturbation in an events sequence (P-theory) is proposed, and a charting method for ordering the events of a particular accident is presented. Development of an events indexing system for future accident data collection is suggested.

Over the years, accident investigations have been performed for many different reasons by many different persons with varied backgrounds and skills. The results have been equally varied in terms of quality. Regardless of the reason for the investigation, however, each investigator is confronted by certain recurring questions each time he begins an investigation of an accident. The first of these are: What happened? Why did it happen as it did? These questions give rise to still other questions, such as: What should my investigation encompass? What facts do I need? How do Ianalyze the facts I acquire? How can I explain the relationships among the factors? How should I present my findings?

Despite the vast number of accidents reported on or researched for understanding, there still exists no generally accepted set of answers to these questions that can be applied to the full range of accident phenomena. Approaches to accident investigation seem as diverse as the investigators, who range from highly educated medical doctors and doctors of philosophy and engineering to the relatively less trained traffic policemen investigating traffic accidents. The absence of a common approach and differences in the investigative and analytical methods used have resulted in serious difficulties in the safety field. These include: (1) Barriers to a common understanding of the phenomenon and to the transfer of knowledge about safety countermeasures gleaned from individual accidents; (2) popular misconceptions about the nature of the accident phenomenon; (3) injustices in the determination of culpability of the persons involved in specific accidents; and (4) inefficiencies in the development of safety countermeasures.

The purpose of this paper is to call attention to the need to develop generally acceptable approaches and analysis methods that will result in ***complete, reproducible, conceptually consistent,*** **and** ***easily communicated*** explanations of accidents. These four attributes are suggested as the criteria for any approaches eventually adopted in the field.

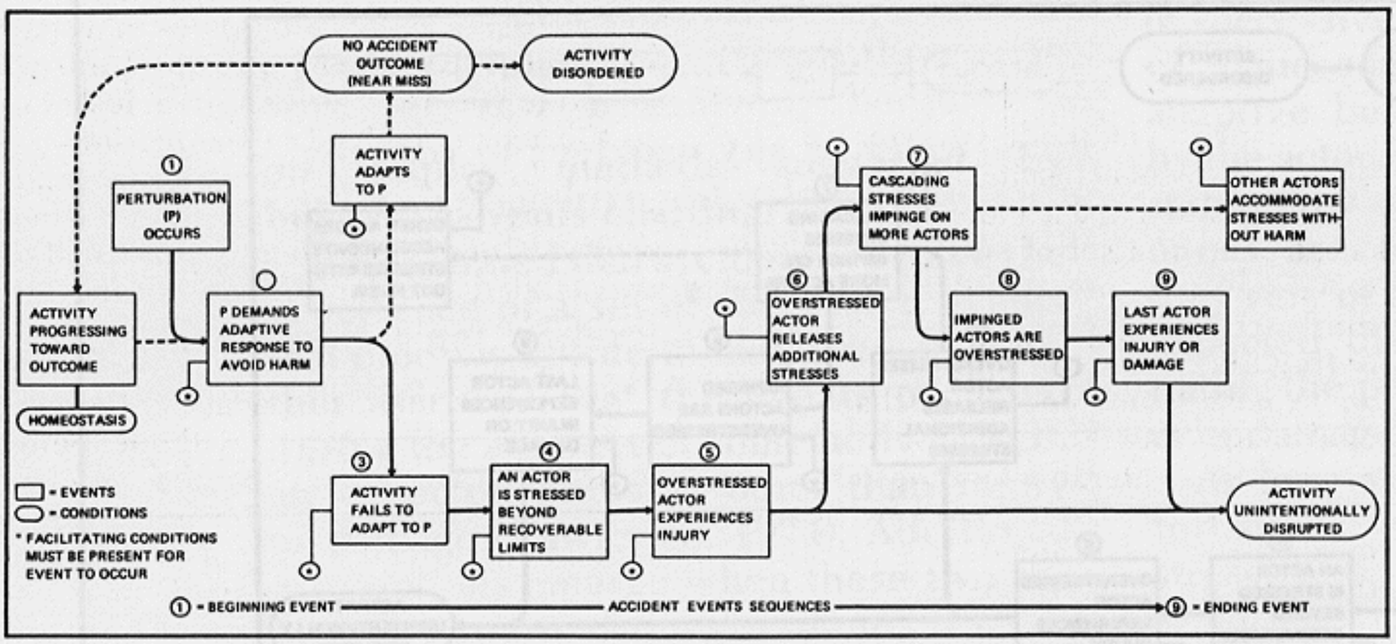
What happened*?* One of the first steps in any accident investigation is to determine what constitutes the "accident" being investigated. It is rare that any investigator defines the beginning and end of the phenomenon he is setting out to investigate. Consequently, the likelihood of achieving reproducible results is sharply reduced. In a search of over 100 papers on accident investigation and accident research, primarily in the transportation field, no clear delineation of the beginning and end of the accident phenomenon could be found.[2]

General agreement exists that an accident involves a sequence of events and that the events sequence must encompass unintentional injury or damage. These characteristics distinguish an accident from other phenomena such as murder, suicide, war, sabotage, and other willful injurious events. But here the conceptual agreement lags. If an accident is indeed an events sequence, what is the first event in the sequence? Or the last? When this is undefined, the historic admonition to "get all the facts about the accident" is understandable, and the difficulty of doing so equally understandable. Clearly, a convention for defining precisely the *beginning* and *end* of an accident is needed.

Another carryover from earlier accident investigators is the chain of events concept, illustrated by the "falling domino" analogy of Heinrich (1936) and extended by Baker (1953). This concept, which implies a linear events sequence for accidents, was, and still is, prevalent in many circles. In the 1960's, development of safety analysis techniques like fault tree and failure mode and effects analysis expanded the chain of events concepts into branched events sequence logic concepts (Driessen en, 1970). This expanded dimension contributed a powerful tool for the investigation of accidents - both historical and postulated. These systems safety analysis methods provided another noteworthy contribution by requiring the documentation of the factors used in the analysis. And, by displaying systematically the events and conditions analyzed, these methods gave visibility to the relationships involved among the described factors. This greatly facilitated the communication of the findings to other analysts, in contrast to the narrative description relied on earlier. As with other methods, however, no criteria were provided for, defining the beginning and end of the accident or for the entries on the charts. The result was that, like earlier methods, only portions of a particular phenomenon were usually examined.

Why did it happen as it did? To the extent that the events sequence developed in the accident investigation was in fact sequential, an insight into the why of the accident began to appear. It is generally accepted that certain conditions must prevail for events en to occur. Recognition of the role of conditions In the accident phenomenon dates back to some of the earliest works in the field. A helpful discussion is provided en Surry (1969). During the course of an accident investigation, however, how can the discovery of the relevant conditions be assured, and, once discovered, how can the relationship be validated? Early investigators probed for the answers to these questions but, like Ames (1928) and Baker and Ross (1960), they seem to have been primarily concerned with accident causes, and thus became mired in considerations of proximity and apportionment of causes, rather than in relationships of conditions to events. Various approaches have been employed in the past, reflecting the disciplines of the investigators to a great extent.

FIGURE 1
GENERAL EXPLANATION OF ACCIDENT PHENOMENON



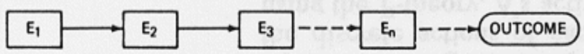
For example, medical doctors have focused on trauma or epidemiological approaches, psychologists on human factors, and engineers on systems (Surry, 1969). Once again, the result was partial treatment of the phenomenon, rather than treatment of the entire events sequence constituting the accident.

Another contribution of the systems safety approaches has been the direct linking of conditions to their related events. Events and conditions are displayed on a chart and the structure is guided by logic gates or and/or gates and linked with lines to show relationships. The methods focus on a single undesired event, however, and provide no time scale to indicate the chronological relationships of events. If this could be overcome, these methods would be most promising for resolving the deficiencies cited above. In summary, these deficiencies are: No criteria for defining the beginning and end of accidents; no structured method for discovering the relevant factors involved; no criteria for defining events and conditions used in the charting methods; and no method for ordering the time relationship of the events.

A very recent adaptation of the systems safety logic tree method to accident investigation should be mentioned here. Johnson (1975) has developed the MORT (Management Oversight and Risk Tree), a method that is used to structure a very broad and detailed check list for accident investigation. This check list facilitates the search for safety problems on the list. As a method for accident investigation, however, any such approach assumes an understanding of the phenomena, which may discourage the search for factors and relationships not on the list. The above deficiencies also remain essentially unresolved by this proposal. Nevertheless, the method used to develop the check list clearly shows the value of charting as a device for communicating understanding of many aspects of the accident phenomenon. The logic tree is also valuable for developing hypotheses to bridge gaps in the investigator's knowledge about the accident events sequence and for guiding the search for evidence in an investigation.

General explanation of the accident phenomenon. It is evident that an underlying problem that must be resolved is the absence of a generalized explanation of the accident phenomenon. To overcome this, a synthesis of those concepts contributing to the explanation of specific accidents investigated by the author is proposed, and conventions for the terms used are suggested. Both rely on a chain of events sequence approach and on display methods suggested by branched events charting.

FIGURE 2
ACTIVITY EVENTS AND OUTCOME
FOR ONE ACTOR



It is assumed that accidents involve the occurrence of a set of successive events that produce unintentional harm. It is further assumed that the events occurred during the conduct of some activity with an expected outcome other than injury or damage (Lawrence, 1974). Additional assumptions emerge when these two are further examined. For example, what is meant by events? Since they constitute the building blocks of the accident, their meaning should be clear so that the investigator describes each event precisely. This is equally true for the other terms employed.

For accident investigation purposes, an event is something that takes place, an occurrence of moment or significance, a happening logically ensuing from or giving rise to another happening. For something to happen, someone or something must bring it about. That someone or something will be termed an actor, and the act of doing something will be termed an action. Thus, an event can be described in terms of an actor and an action. The actor can be anything animate, such as a driver, machinist, or bee or anything inanimate such as a tire, machine, or water. The action may be anything that occurs, such as movement, failure, observation, or decision. Both the actor and the action must be described precisely or quantitatively, without qualitative adjectives, adverbs, or phrases. Events must be described in terms of a single actor and action, which means breaking down the sequence into discrete events that can be so described.

It is further assumed that an activity is occurring when an accident begins. An activity is defined as a set of successive events directed -consciously or unconsciously-toward some anticipated or intended outcome. An activity proceeds toward its outcome in a relatively stable progression of events, involving interacting elements, in the face of varying external influences. This dynamic equilibrium of successive events progresses in a state of homeostasis (Pask, 1963), requiring adaptive behavior or adaptive learning by the actors involved in maintaining the stable flow of events. The external influences are termed perturbations when they vary or deviate from what is usual or expected, disturbing the activity and initiating the possibility of subsequent injury or damage.

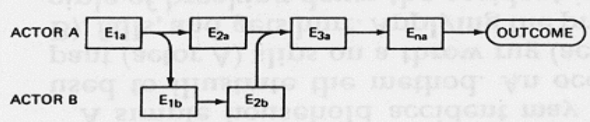
As long as the actors adapt to the perturbations encountered without being stressed beyond their capability to adapt or recover (Benner, 1975) homeostasis is maintained and an accident does not occur. If one of the actors fails or is unable to adapt, the perturbation initiates an events sequence that ends homeostasis and begins the accident sequence. From that event onward, the events sequence may overstress one of the actors, causing injury or damage. These injurious events may in turn initiate other changes or energy releases that overstress subsequently exposed actors, with cascading injury or damage. Until the subsequently stressed actors are able to accommodate the impinging stresses without further harm, the accident continues toward its outcome, governed by the condition of the actors, the events, and the laws of nature. Thus, the accident can be seen to begin with a perturbation and end with the last injurious or damaging event in the continuing accidental events sequence.

If the actors adapt to the perturbation at any time before injury occurs, a no-accident outcome is achieved, even though the activity may be disordered. At present, this result is generally described as a "near miss.

The above explanation provides a basis for defining the beginning and end of any accident being investigated and for developing and ordering the events sequence of the accident. Since it is centered on perturbations and subsequent events, this explanation of accidents will be termed the P-theory of accidents.

Stress may be imposed by change (Johnson, 1975) or by impinging energy (Haddon, 1970).

FIGURE 3
ACTIVITY EVENTS AND OUTCOME
FOR TWO ACTORS

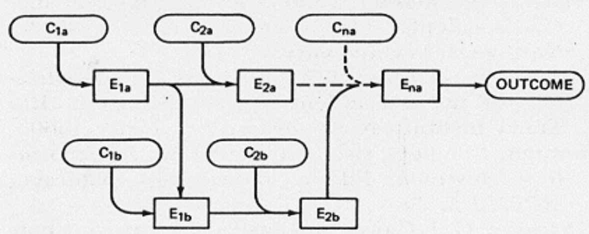


Within this framework, the accident phenomenon can be further explained by the use of a charting technique that displays the events in terms of their chronological relationships (Figure 1).

Displaying accident events sequences. The events charting method described above suggests an approach for resolving the remaining difficulties confronting the investigator. A chronological array of the events identified helps to structure the search for the relevant factors and events involved in the accident and provides a method for testing the relevancy of additional events or conditions encountered by the investigator. This can be achieved by displaying the events in which each actor is involved along a horizontal line. en Since each actor is usually involved in sequential events, the events for each may be displayed in a linear chain of events. Arrows depicting the flow of the events in a logical sequence can link each entry, thus showing the relationship of events to one another. By adding the conditions that must have existed for the events to occur and linking them to the events with arrows, the full explanation of the events for any actor involved in the accident can be shown. By arraying the events associated with each actor in parallel horizontal lines across the chart, with the timing of each event maintained relative to the other events, one can readily see the relationship of each event to every other event in terms of both its timing and its proceed/follow logic. This *multilinear events sequence charting method* provides a way for the investigator of any accident to identify, order, and display the explanation of the relevant factors in the accident. When combined with en the generalized explanation of accidents provided by the P-theory and the criteria for investigative decisions arising from that explanation, the tools for answering the questions faced by the investigator are now available.

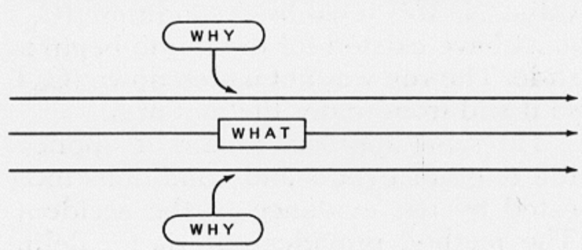
Application of method. Most systems safety charting methods use rectangular boxes to depict events and ovals to depict conditions. Using the arrow convention suggested, Figure 2 shows the events constituting an activity and the outcome of that activity for one actor. When two or more actors produce the outcome, the events are displayed as in Figure 3. Note that the spacing of each event can be used to show the timing of the event in relation to the other events. The arrows provide flexibility because they can be used to show the flow relationships of the events or proceed/follow logic between events. Conditions can be shown similarly (Figure 4).

FIGURE 4
ACTIVITY EVENTS AND OUTCOME FOR TWO ACTORS, INCLUDING CONDITIONS



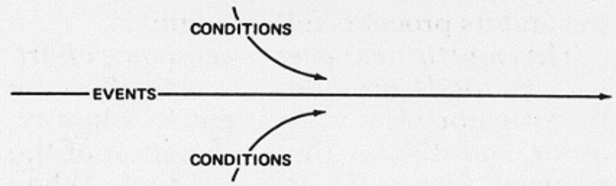
This method for presenting the accident events and enabling conditions is keyed to the time order and logical flow of events present in an accident, rather than just the time order of events suggested by Johnson (1975). The method is summarized in Figure 5.

FIGURE 5
SUMMARY OF METHOD OF PRESENTATION



Tracing the development of enabling conditions in an accident can be accomplished using the same approach. By considering such a condition as the outcome of another external influencing activity, the events producing that outcome can be traced backward in time until the needs of the analyst are met. This sequence can be displayed vertically, above the enabling condition. This approach allows the analyst to explore the factors that might be common to more than one accident and locate correctable circumstances, while separating such factors from the specific accident phenomenon being investigated. The general flow of the charting is shown in Figure 6.

FIGURE 6
FLOW OF CHARTING FOR AN ACTIVITY



A simple household accident may be used to illustrate the method. An occupant (actor A) slips on a throw rug (actor B), falls, and gets hurt. Applying the principle of breaking down the accident into the discrete actions of each actor, and using the P-theory, A's activity (walking to change his location) was homeostatic until he stepped on B. For A, the first event (E_{1a}) in this specific accident is the placement of his foot on B, followed by the unexpected motion of his foot (E_{2a}) when the rug begins to slide. For B, the first event (E_{lb}) is the experiencing of directional stress levels (A's foot placement) in excess en of the frictional shear resistance capability of B with respect to the floor, followed by movement of the rug (E_{2b}) from under A's foot. As this is occurring, A loses his balance or fails to adapt (E_{3a}), falls to the floor (E_{4a}), and suffers injury (E_{5a}). The intended activity terminates with the accidental outcome. For the rug to slip, the coefficient of friction had to have been reduced to some value X; this enabling condition (C_{1b}) must have existed for the rug to begin to slide. The rug was not nailed down (C_{2b}), so it slid from under the foot of A.

The same approach would be applicable to other events and conditions indicated by the evidence in the accident. The method provides criteria for delineating the events and conditions of the accident and for ordering them according to their logic and relative timing during the accident.

Substituting the perturbing, adaptive, stressing, injury, and stress accommodating events in the above display, in whatever detail may be required to fully explain the accident, substantially increases the likelihood of producing a complete, reproducible, conceptually consistent and easily communicated explanation of the accident being investigated.

Conclusions. The development of a generalized explanation of the accident phenomenon is possible and would fill a major need of accident investigators. The multilinear events sequence charting method provides criteria to guide the development of the explanation of specific accidents in a manner that facilitates the transfer of knowledge among accident investigators. By incorporating an event indexing system (Johnson, 1975) into an expanded P-theory model, a method for rational acquisition of accident data compatible across accident types might be devised (Wakeland, 1971). These data could then be applied to the development of accident events sequence models for use by accident investigators, by researchers, and by risk analysts attempting to estimate effects of safety countermeasures (NTSB, 1971). An improved public grasp of the accident phenomenon, which could follow the adoption of the P-theory and the charting methods, would help to resolve the other difficulties cited.

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[1] Ludwig Benner, Jr., is a General Engineer, National Transportation Safety Board, Washington, D.C. The views expressed are those of the author and not necessarily those of the National Transportation Safety Board.

[2] 'A listing of all of the articles searched is available from the author or from the *Journal of Safety Research*.

Epilogue

This paper is one of two* initial reports about over 30 years of inquiries that have contributed to the continually emerging concepts for accident investigation, led to Multilinear Events Sequencing technology for investigations, and introduced a number of innovations. It challenged the dominant accident models and theories drining investigations at the time, and introduced an early process model for accidents; defined the actor/action sturcturing of the building blocks used to describe the dynamics of what happened; introduced a system safety approach for investigations; pointed out that events during accidents occur both in series and in parallel and the significance of the timing those actions; proposed flow charting the entire accident phenomenon to identify, order and display interactions and why they happened, in the sense of what is now known as "defined acyclical graphs"; pointed out the role of adaptative responses to deviations in accident processes and prevention efforts, presaging expanded ideas about system control in recent accident analysis literature; raised the challenge of validating relationships for objective quality assurance (still largely ignored); and suggested that investigations have definable beginning and end attributes.

Subsequent to publication of this paper in 1975, observations of applications of this method disclosed a flaw in this approach. Conditions were included to explain the "why" because that was consistent with the conventional wisdom of the time. Unfortunately, investigators using the MES approach were observed to use conditions as a license to introduce ambiguities, judgments, and conclusions into the flowchart. That in turn frustrated the application of rigorous logical linkages to define and explain interactions that happened, and attempts to apply quality assurance procedures to the flow charts. Worse, it masked the action patterns of people or objects that had to be changed to reduce future risks.

The method was subsequently refined by limiting the worksheets to displaying what happened as event building blocks, and ***excluding conditions***. Conditions, whether static or dynamic states, are produced by the actions by people or objects or energies. Such actions also lead to subsequent events, all of which were required to produce the accident outcomes - harm, damage and loss. Constraining the flow chart to actions enables investigators to perform progressive analyses as the data are acquired, to direct their investigation efforts to specific data gaps, and to do logic tests to identify, define and act on actions or behaviors which posed problems.

These changes were elaborated in more detail in Hendrick and Benner INVESTIGATING ACCIDENTS WITH STEP (1986) and later publications, pamphlets on Accident, Hazmat and Fire investigations published in 1997, MES implementation software published in 2006 and a series of papers analyzing lessons learning systems published since 2007. All are available at www.iprr.org.

With respect to the "conditions" ideas presented here, the paper is obsolete. Unfortunately, implementation of the MES methods in many locations, including MORT-based applications, is based on this 1975 version of MES, rather than the latest technology found in subsequent publications. Readers interested in applying the MES technology are urged to refer to subsequent publications available at this site. As underlying assumptions contintute to be challenged, substantial changes continue to evolve.

* See Accident Theory and Accident Investigation (October 1975)

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