Standardizing Safety Investigation Inputs to Reduce Risks

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Abstract

Undesired accidents motivate investigations into what happened to identify safety risk reducing actions. During traditional investigations, source data produced during the accident is documented by investigators into abstractions of its objective reality, which then move through complex, cumbersome pathways into accident reports and then to the data's end uses. This study was motivated by difficulties experienced while trying to reconstruct accident scenarios from accident reports, to define actionable risk-reduction opportunities, and other learning opportunities. The study's challenge was to find alternative source data documentation and processing options that would be more likely to produce investigation outputs with improved utility for all accident data users. By exploiting ideas from other domains, changes to present practices could overcome investigation obstacles to better learning and reduced risks. This paper reports on the potential adaptation of those changes.

KEY WORDS: accident investigation, investigation paradigm, investigation building blocks, investigation data integration, accident analysis

Introduction

Concerns about "end users' utilization of reported accident data arose during the author's study "Fire Risks in Carload/Truckload Transportation of Class A Explosives" for the US Department of Transportation (Benner 1989). That study exposed difficulties recreating useful scenarios of previous accidents from reported data about them. The concern continued to grow, fed over time by the need to employ increasingly sophisticated attempts to glean actionable safety risk-reduction information from accident data with statistical analyses, text mining, neural networking, Bayesian networking and other complex methodological tools. Private exchanges about difficulties encountered by the US Joint Helicopter Safety Analysis Team and reported in its final report (US JSAT 2009). encouraged more detailed study of investigation data user needs and how accident source data finds its way to its ultimate uses. The ESReDA 45 Seminar offers further evidence of the need to challenge current practices.

In this report, the term incident is used to encompass all types of unintended and undesired occurrences, including accidents, incidents, mishaps, fires, explosions, spills, disruptions, upsets, near misses, crashes, collisions, collapses, groundings, and the like.

1. The Study

The study approach was to identify the users of investigation results and their needs, and then trace the flow of the source data produced by the occurrence through present investigation data processing practices, to define impediments to its orderly presentation to and use by end users. Options to overcome any impediments found were then sought.

In addition to literature references the study incorporated the author's observations of over 50 investigations and outputs in many domains over the past 40 years, but in the study's new user context. Previous studies focused predominantly on identifying criteria for, assessing and harmonizing methodological concepts, principles and practices to produce better investigation results (Benner 1982, Sklet 2001, Hollnagel 2008). This study focuses on investigation data inputs and their processing during investigations until they reach end users and become actions by those users, and finding processing improvements.

1.1. Underlying study premises.

This study looks at uses of investigation data for safety and other purposes. Several insights developed during the conduct of investigations, and previous research about safety investigations influenced this study. One such insight is that incidents and similar unintended occurrences are sub-processes within system operations. These sub-processes consist of successive interactions over time among people, objects and energies. Such interactions pose safety risks if they evolve in ways that can produce unwanted outcomes, harm, disruptions or challenges during system operations. Risk-reducing initiatives in systems involve changes to people, object or energy behaviors or behavior patterns so they are less likely to produce unintended operation and outputs. Incidents provide indications of a likely need to review present behaviors in the system. Achieving reduced system operational safety risk levels requires identification, through investigations, of the individual behaviors and interactions that produced the unwanted experiences, and changing them in the future. Data surviving an occurrence, as it evolved over time, can be retrieved to support development of an explanatory description of a specific occurrence.

Finally, to ensure a just presentation of what happened, the roles of each participant in the incident process should be described as precisely as possible.

1.2. Investigation input data.

System operational incidents produce the unique source data from which descriptions of what happened are developed during safety investigations. During traditional safety investigations, incident source data undergoes a transformation into abstractions of its objective reality as it is documented. The documented data constitutes investigation input data that then moves through complex, time-consuming investigation process steps to its many users and subsequent actions (Benner 1980).

1.3. The challenge

Current thinking about safety investigations focuses predominantly on developing recommendations to prevent the incident's recurrence. A gap between reported results of incident investigations and consequent safety recommendations, and implementation of changes at all the levels that can contribute to safety improvement, is widely recognized and is a theme for this ESReDA Seminar. Could present investigation practices related to investigation data documentation and processing be changed to achieve improved incident data utility and impact on safety, and better serve other users?

1.4. The study approach

This study pursued that challenge by adopting a shift in the investigation focus, from a "prevention" focus to a focus on users' utilization of investigation data. With that focus, each of the data processing steps necessary to satisfy users' needs could be examined critically in the context of data flows in the system. The study looked at incident source data and tracked it through the investigation process to its ultimate uses. It treated incidents as creators of original source data that must be transformed, at the lowest level of abstraction, into compatible investigation data inputs to develop a description of what happened. When properly constituted, the description also explains why the occurrence happened, providing an *explanatory description*.

Investigators do not have the luxury of engaging in philosophical debates about actual or objective reality versus perceived or subjective reality during investigations. They are expected to transform the observable realities of the occurrence and data it produced, into "facts" or "evidence" on which to base descriptions and explanations of what happened and subsequent uses. *What is significant is that all actions which follow, from the development of the explanatory incident description to the most remote data uses depend on successful execution of this data transformation task.*

Thus transforming data produced by an incident into the documented "building blocks" (BBs)[1] to build an explanatory description of what happened and why it happened is crucial task. Despite this role, detailed examination of this source data transformation task for incident investigations has not previously attracted much interest.

The data processing pathways identified were then analyzed to find opportunities for improving the data flow. The study objective can be viewed as finding the shortest data pathway for the data produced as the mishap evolved to the actions precipitated by the investigation as in Figure 1.

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[1] Also referred to as "event blocks" in some sources; such BBs can be viewed as defining the term "event" to the exclusion of other meanings for investigation purposes.

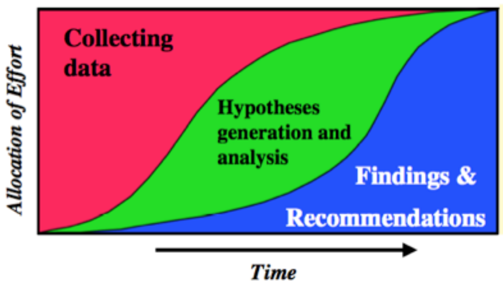
Figure 1. Study Goal: Find shortest data pathway through investigations.

2. Current Data Processing Pathways

Present investigation data pathways in multi-investigator investigations are very complex.

2.1. Investigation Data Origins

The initial input data documentation task involves steps that pose many challenges. First, investigators must locate, observe and interpret residual data surviving the incident interactions. Such data "tracks" may exist in different forms, ranging from changes in physical objects, people's physical states or memories and work done by energies to traces on charts or characters on documents or in digitized records. What should investigators seek and document from those data?



Source:ESReDA Guidelines for Safety Investigations of Accidents

Figure2. Allocation of investigation time

2.2. Basis for present pathways.

Current perspectives and investigation practices for developing descriptions and explanations of what happened are based almost exclusively on one of many "accident causation" models and their implementing methodologies (JRC 2011). The course of an investigation is generally viewed as data gathering, analysis and development of findings and recommendations, as shown in Figure 2.

Investigators "observe," both directly and indirectly, data existing after an incident from sources available after the incident. They then record those observations as "facts" or "evidence" from which hypotheses and descriptions are developed. Both terms are abstract constructs with pre-scientific roots. Both represent modest levels of abstraction on a ladder of abstraction (Hendrick 1987). derived from but not precisely describing objective reality. As presently recorded, facts or evidence can represent objects, object attributes, behaviors, conditions, circumstances, static or dynamic states, changes of states, natural laws, interpretations of observations and expectations, for example. During this data "capture" task, investigators must transform each item of "evidence" they observe into an individual documented investigation input or "fact" for reconstructing what happened. Analysis of those and other inputs leads to a description of what happened. That in turn leads to the of report findings, causes or factors, and ultimately recommendations.

Presently, causes or causal factors or root causes form the primary basis for investigators' recommendations to prevent or reduce risks of future recurrences. Investigators' analyses of what happened lead to recommendations for action to prevent recurrence. Users must analyze report contents plus additional data about their present system to determine a report's relevance to their activities. Then they must identify, select and implement action(s) that will improve performance, or satisfy other actions they might require.

2.3 Present source data processing pathways

The typical source data processing pathway for the documented incident source data is shown in Figure 3. Implicitly, the cause findings are the lessons learned from the investigation, and the recommendations are the ameliorative actions. Thus post-investigation safety actions typically focus on implementing recommendations. Ultimately, if a recommendation is implemented, someone or something changes what they do and initiates new behaviors or develops new habits. Thus the "causes" are presumably removed. Sometimes the new behaviors or behavior patterns are monitored or audited to ensure that the expected improvement has been and will continue to be achieved, until the next incident, when the cycle starts all over again.

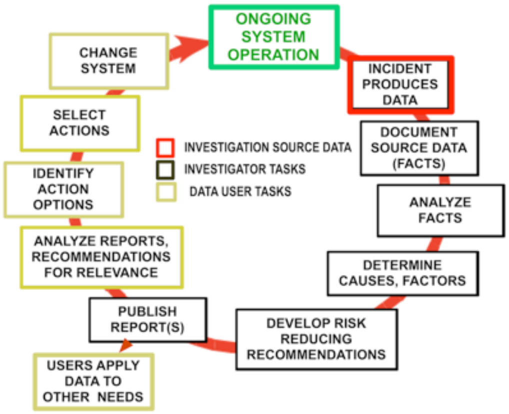


Figure 3. Present source data pathway

If we follow the source data from its origins through the system to its ultimate uses, present practices put source data through many successive steps to arrive at the investigation outputs for end users. This involves tasks such as source data identification and transformation into some form of documentation, organization, integration,[2] validation, abstraction, characterization, categorization, reporting, dissemination, interpretation, selection and implementation. Each task requires time and introduces opportunities for errors, delays, ambiguities, misinterpretations or other problems between the documentation and use of original source data.

2.4. Data uses

Data in investigation reports finds its way to many users. In addition to operational changes, users create or update databases, check lists, job site postings, training, procedures, safety bulletins, meeting topics, claims settlements, software, equipment, performance metrics, and other system functions. Reported data may also be used for trend analyses and other statistical purposes to extract local "causal factors," trends and patterns. Activities beyond system operations and further removed from the incident, such as safety research, fines or penalties, changes to codes, standards or regulations, insurance rates and premiums, litigation, public relations problems, or even new statutes, also depend on the data produced from the original sources. Each use suggests, guides, supports or influences future operations. But all use source data

[2] Integration is used rather than analysis because integration is a less ambiguous description of this task.

transformed into the BBs in the explanatory description in some way. Figure 4 illustrates these relationships.

The pyramid is shown with the peak at the bottom, to emphasize the dependency of everything else on the incident source data and its valid documentation during an investigation. If that base is flawed, the entire structure is compromised. This pyramid, in effect, identifies the investigation data "system" being analyzed.

Terms at high levels of abstraction, like causes, failures, errors and factors, permeate

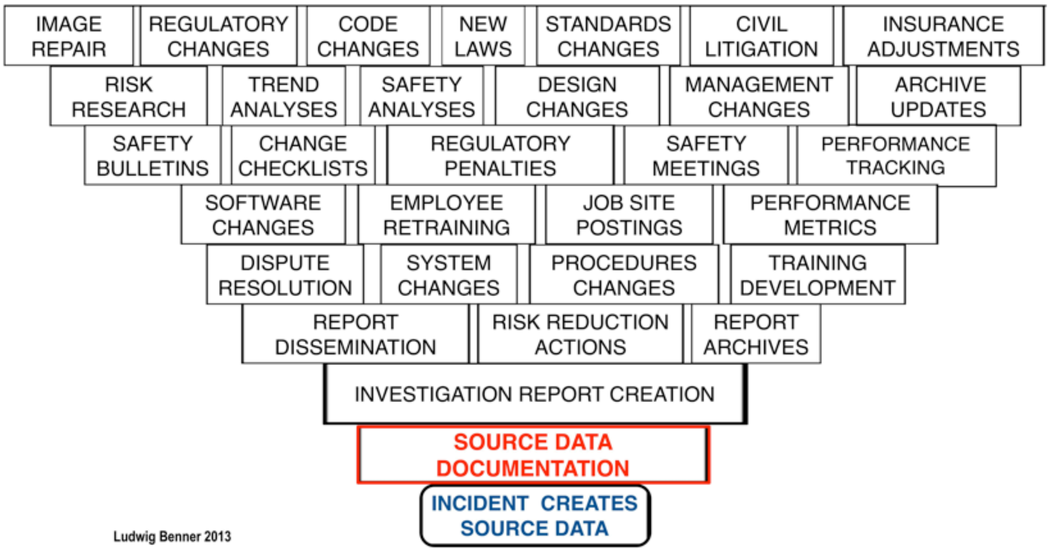


Figure 4. Source data dependency pyramid

present investigation data and reports (Rimson 2003). For practical utilization, this impedes data users, who must "de-abstract" these terms to their lowest levels so they can then compare them to or overlay them on their operational data to determine relevance and their potential action. Present practices introduce other impediments to reported data usage, including language and vocabulary barriers, interjection of extraneous information, abstractions, ambiguity of lessons learned, data archiving, retrieval and usage, reluctance to share the data, data obsolescence, data gaps, logic errors and premature conclusions, described in a previous paper (Benner 2012).

3. Improving investigation data flows

Improvement of source data flows to users would require overcoming existing impediments due to present practices. Figure 3 suggests the key to achieving improved data flows is to focus first on the source data documentation task, and then on its integration into the explanatory description of what happened.

It is important to point out that such a description, until complete, must describe what actually happened and why it happened, as determined by source data about the behaviors of the people, objects and energies that *actually had a role* in the incident. Until that description is completed to the extent possible from surviving data, investigators do *not* need to and nor should they introduce data from other sources, like expectations, intentions, their experiences, regulations, procedures, etc. Their premature introduction is the most frequent source of reported abstractions like "human error," "failed to" and similar judgmental statements that mask valid explanations. Those kinds of "external" data sources should be introduced during the later analysis phases of an investigation, so hidden assumptions in the external data do not distort the incident description. If they must be introduced, as when operational restart demands require identification of needed changes before the scenario is complete, they should deal with verified behavior sets, and not be conflated with the overall incident description task.

3.1 Source data documentation requirements

Any source data involved in the incident must be documented as a "building block" for reconstructing the incident process of interest. To support subsequent investigation tasks, certain attributes of this documented data become significant. To reconstruct an occurrence faithfully, for example, the "building blocks" (BBs) used to define the scenario must be created from the surviving source data. To facilitate building block creation and use, BB design should be amenable to digitized creation. To ensure completeness of the scenarios, the BBs must accommodate all types of data sources as shown in Figure 5. To assure replicability of source data documentation by different investigators, rules for BB construction should define the source data documentation task in precise detail. To enable their logical manual or machine manipulation, parsing and integration into complete descriptions of incident process interactions, the BBs should also be grammatically consistent with each other. To prevent erroneous reconstruction, the BBs must be free of defects, ambiguities, uncertainties or misinterpretations. To have a reasonably useful service life for users, they must support identification of the context of input behaviors, behavior sets or behavior patterns. They should describe objective reality as nearly as possible, of course. To minimize end user "de-abstraction" burdens, and to minimize introduction of investigators' experiential, domain or methodological biases, they should be recorded and pass through the investigation tasks at the lowest level of abstraction, e.g., capable of visualization. To be utilized efficiently in investigators' and end users' tasks, BBs should be functionally useful without further characterization, abstraction or conjecture.

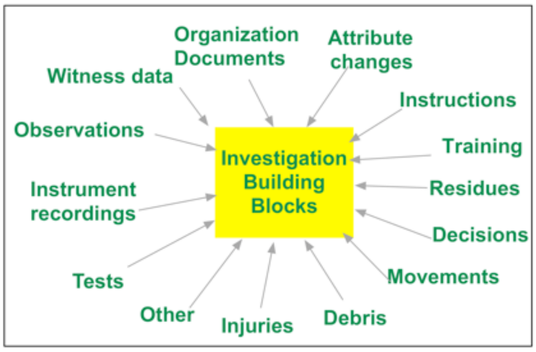


Figure 3 Source data documentation

The BBs should lend themselves to exposing gaps in the understanding of the process interactions that produced the outcome(s), to identify additional data acquisition tasks. To facilitate definition of hypotheses generation needs and their development, they should enable investigators to "see" gaps in data flows. To enable objective quality assurance of the investigation, the BBs and the explanatory description should be logically verifiable from observed source data. The BBs, when integrated into the reconstruction being created, should support the rapid filtering of irrelevant or incompatible inputs during the investigations, whether intentional and unintentional, to minimize flawed descriptions.

3.2. Satisfying source data documentation and integration requirements.

How might these requirements be satisfied? If one accepts the premise that static or dynamic states will change only when acted on by some person, object or energy, two kinds of investigation inputs can provide information needed by users for safety improvement. They are the people, objects and energies that acted during the scenario, and their actions which determined the outcome(s). In other words, who or what was involved, and what they did to produce the outcome(s). To explain what happened, predecessor actions that influenced each involved action in any way must be understood and recorded. Users need the same information to determine their actions. Thus BBs required for reconstruction must contain these elements to provide end users with the data they need to determine its relevance to their activities, and its use for taking their specific actions.

If all inputs to each action are shown, this should explain the incident process, fulfilling both the explanatory and description requirements of an explanatory description. Introducing design or expectations data may be necessary to define outputs/reactions to some actions, but should not be introduced to identify problems with what happened or for other analyses. Such data should only be introduced to advance understanding of what happened, not feed judgments of analysts before the scenario is complete. Problem identification and recommendation development are analytical rather than an investigative tasks. The time for analyses is after the "what happened" is fully understood, unless urgent restart requirements demand piecemeal analysis of verified behavior sets during an investigation.

How should this reconstruction be done expeditiously, to avoid present problems and constraints? An answer is suggested by bringing together several ideas from outside the safety domain. That would include work flow analysis (Taylor 1911), behavioral considerations from social scientists (Jacobs 1961), learning organization development from management literature (Stege 1990), early safety research (Surry 1969, Johnson 1972), system modeling from operations research (Forrester 1961), cybernetics' input/output/feedback modeling (Weiner 1965), displays of complex processes from economics domains (Leontief 1990) and Western music notation systems and movie scripts from the arts,

Taylor's work suggested a way to decompose tasks for both descriptive and analytical purposes. Jacobs and others helped focus on behavioral roles in incidents, and their analyses in safety issues. Senge's insights into learning organization processes led to a focus on learning organizations' investigation information needs. Surrey and Johnson were among the early proponents of viewing accidents differently, and in Johnson's case, coupling investigations to the management issues and risk acceptance. Forrester's ideas about modeling system dynamics contributed to the idea of viewing accidents as processes, in system dynamics terms, and with the ideal feedback model from cybernetics and Weiner, contributed an option to the accident causation model. Leontief's economic modeling led to confidence in the ability to graphically model very complex dynamic systems. The Western musical score was probably the most instrumental in identifying possible options for satisfying incident source data documentation and integration improvement, and pathway simplification challenges.

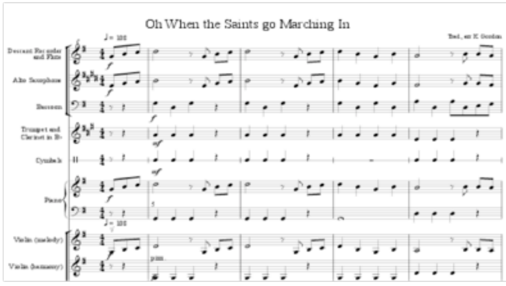


Figure 6. Musical Score sample.

Source: www.ScoreExchange

Musical scores have evolved over many years, and have demonstrated their universality, replicability and durability. A Western musical score documents a complex dynamic process (Figure 6.) The model consists of a standardized time/actor matrix, on which standardized notes defining instruments' actions are arrayed in a manner showing the sequential and concurrent relationship among all the actions. Each note represents a standardized action for an instrument, e.g., what the musician must do. A limited number of standardized symbols specify changes in the notes' delivery.

Notes are the "building blocks" for documenting the description of the process. These building blocks are positioned for each instrument according to their task flow and timing. That matrix array defines the relationships of each actor's inputs to all other actors' inputs. Standardized notations may be added to specify attributes of the action, such as louder or softer. This standardized input/output display in the form of an annotated score describes the individual and collective actions required to produce a composer's intended outcome. In other words, a *replicable* musical scenario can be described by showing each player's actions, as BBs on a time/actor matrix. That describes the expected behavior of each player, both as to the flow of their own sequential actions and to their actions relative to others' actions. If a player does not act as expected, the deviation from the composer's intent is readily identifiable from recordings of the performance and the score.

A score describes the concurrent actions and time frames needed for a continuous musical output, with related actions contained within vertical time columns. Incident processes produce undesired outcomes from a cumulative progression of scattered sequential and concurrent input-output actions or interacting "work flows," unsuited to columnar spatial-temporal integration. Inputs may originate at immediately adjacent or at remotely occurring times. Adapting the score model to incident modeling would thus require a different time coordinate and an additional data processing step of linking inputs occurring over extended time to the progression of output actions, culminating in the last outcome(s). Otherwise the musical score model offers a proven model to adapt for documenting and integrating incident source data. Modified by using input-output links to accommodate input time variations, it could similarly help ensure valid incident models of complex dynamic incident behaviors.

The script and story board for a motion picture or play provides a somewhat similar model. The actors' lines and stage directions for a movie's actors define the scenario or story. The actor's lines, like notes, must be definitive to achieve the director's desired output. In a sense, investigators "reverse engineer" the scenario of what happened during an incident to develop a form of "script" for a "mental movie" of the incident.

4. Applying alternative models

Adaptation of alternative models will require changes in the present thinking about incident investigations and investigation and analysis practices. The main changes will be in the investigation purposes, source data documentation and integration, and delayed analytical tasks. The investigation purpose will have to be expanded to serve all users of incident data.

4.1. Standardizing source data documentation.

To support reconstruction of an incident, investigation inputs created from observed incident source data need to enable the tracking of actions or behaviors that produced successive state changes during the course of the incident. Since a succession of actions is needed to produce the final states, e.g., the outcomes, the focus of the data search and documentation should be on creating BBs consisting of the successive actions or behaviors, rather than the states or state changes from which the actions are inferred.

To support data organization, integration, validation and other investigation tasks, these action BBs should have a common and standardized investigation input structure and grammar, like musical notes, that accommodate data transformation from all kinds of sources. This is feasible if the source data are transformed into BBs with a basic actor/action format. Actions may be recorded directly, or may have to be inferred from post-incident states of objects or statements by people. This documentation task is required for all kinds of incident source data that can be acquired after an incident, including investigators' observations, training instructions, residues and debris, injuries, instrument recordings, tests reports, witness reports and previous statements, decisions, manuals, specifications, photos, policies, admonitions and any other sources.

The BBs should also meet additional criteria such as the following:

1. Content and grammar should enable determination that a BB statement is true or not true, based on observed data and valid logical interpretation and testing.
2. Actors and actions should be described unambiguously, at lowest level of abstraction to enable their visualization, without judgmental or pejorative words.
3. Content should enable logically verifiable temporal and spatial ordering, as on structured graphic displays.
4. Content and structure should facilitate logical linking to show input and output relationships with other BBs, to describe the dynamics of the incident process.

5. Content and structure should enable application of "necessary and sufficient" testing of input/output relationships of all BBs and behavior pairs to show completeness and validity.
6. Content and structure should support their downstream uses by any users.

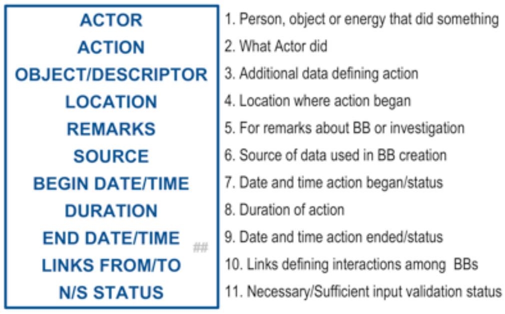


Figure 7. Example Building Block Structure

BBs, BB behavior sets or BB pairs can be used directly, without assigning a taxonomy or classification for downstream tasks and actions, to achieve minimal change sets.

A special word about vocabulary: using ambiguous or abstract words in BBs frustrates input data organization, integration and logic testing before subsequent uses. Plural actor names (the crowd) or passive voice (was struck) or opinion verbs (inadequate) or compound actor names (crowd) or conditionals (if, may) or conjunctions (and/or) frustrate input data integration and validation. This constraint is applicable during development but not necessarily to subsequent analyses of the explanatory description.

One published BB structure (Benner 2012). that meets these criteria is shown in Figure 7. Elements 10 and 11 are needed to satisfy the downstream use and validation requirements in support of machine input/output parsing, processing and reporting.

With consistent BB content and structure, machines can be programmed to provide a glossary of the people, objects or energies that must be described in detail in accompanying source references, to the extent needed by users to determine BBs' relevance to their activities. For example, more information about an involved fork lift, operator or location might be needed to determine whether a reported fork lift operator behavior was relevant to a production line material handling operation or warehouse receiving operation, or maintenance operations, or other fork lift operations. Such static descriptions are usually recorded relatively unambiguously now, and could be added to BBs in the remarks entries. Uncertainties can be handled with "?" placeholders until the supporting data can be acquired.

4.2. Standardizing data integration

Presently investigators are admonished to "analyze" incident data to find causes or causal factors and recommendations. In practice, the investigation data processing task actually begins with the integration of the source data, as acquired. The integration task continues until a compete scenario is achieved. Then users can examine it methodically. It is the scenario with building block relationships, rather than the building blocks themselves that provide the insights and context for subsequent action by data users. Therefore the study emphasized the integration of the data into the scenario. Johnson's saying "if you can't flow chart it, you don't understand it," provides the framework for thinking about the *data organization and integration* to develop a description of what happened (Johnson 1972a) . An investigator should strive to produce an explanatory description of what happened in a form that can be readily understood, supplemented with intentions, design, experiential or other data for analyses, and then used by others.

4.3. Representations of incident scenarios

Incident reports include different representations of what happened, ranging from narrative text to tabular time lines to graphical representations. Narrative representations have one major drawback: sentences present data in a linear manner, with overlapping events requiring extensive readers effort to retain and mentally integrate them. Reader's mental integration capability is quite limited, resulting in piecemeal absorption of the text. Tabular "time lines" pose a similar linearity difficulty for users. Graphical displays, like a musical score, overcome the mental integration constraint when elements are presented serially. They also provide many advantages over other forms of data organization and integration, including economy of words, ease of data integration, visibility of relationships among actions, simple logical validation, timely investigation status checks, compact dissemination, and uncomplicated determination of relevance and use.

The main attraction of the rigorously disciplined graphical input-output presentations of incident explanatory descriptions is the directness of the source data pathway to the end user, from its creation as a standardized building block directly to end users for their analyses and action without impediments introduced by present practices.

4.4. Data integration scheme criteria.

1. The source data transformed into BBs must be organized and integrated by investigators to develop scenarios describing what people, objects and energies did by defining interactions that produced the outcome(s). The author's experience with different graphical data organizing and integrating methods[3] suggests that to do it efficiently, a data organization and integration scheme should satisfy at least the following criteria:

2. Permit the prompt collaborative integration of relevant BBs among investigators, to enhance investigation efficiency.
3. Array the temporal and spatial sequencing of BBs correctly to faithfully describe the succession of behaviors that produced the outcome in the order in which they actually occurred.
4. Facilitate coupling of interacting BBs to define the influence of each behavior on any subsequent behavior(s) during the incident process, and exercise quality control of data integration.

[3] Experience with data analysis structures includes fault/logic trees, fishbone, events and causal factors, Petri net, Why-Because, FMEA, MORT, 5 whys, event diagram, SOL, MES/STEP, Tripod Beta, Top-Set, TapRoot, EBIO, FRAM, STAMP, TLA, among others.

5. Define data still needed during an investigation to maximize investigation data acquisition efficiency and define relevant hypothesis formulation.
6. Expose irrelevant data inputs that do not fit into the process description to suppress irrelevant input data, hypotheses or investigation effort.
7. Enable economy of words to encourage data access and utilization by users.
8. Produce a detailed explanatory description of what happened from the incident source data to minimize introduction of errors, experiential, methodological or domain biases, abstractions, and ambiguities.
9. Maximize transparency of integration to facilitate peer critiques, verification and understanding of the organized data in scenario form.
10. Support logic testing of integrated data to assess the validity and completeness of scenarios, and to ensure just treatment for all those involved.
11. Structure problem discovery and definition to ensure orderly, objective identification of all opportunities for changing behaviors
12. Enable machine parsing and processing compatibility to facilitate library of entries and aggregation into incident experiences and enhance incident data analyses and research output quality,

4.5. Data integration structures.

Today, there are at least 28 different incident data processing structures from which to choose (JRC 2011). The structures vary widely in form, content and complexity from the simple 5 Whys to the complex Functional Resonance Accident Model (FRAM) (Hollnagel 2013). Many provide data definitions, taxonomies or classification schemes. Present practices almost universally conflate the source data integration task with analysis tasks during the development of incident descriptions, by introducing data or *relationships* that were not produced or exposed during the incident, or for abstract categorization purposes

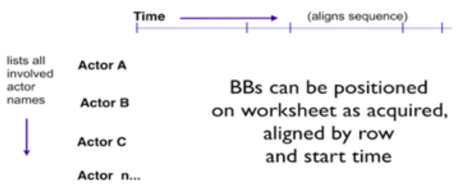


Figure 8. Investigation Matrix

Adaptation of one or more of the existing data processing structures should be feasible, with some changes to those processes. STEP/MES, for example, (Figure 8) seems amenable such adaptation, as it demands and relies on incident source data transformation into standardized BBs with common grammar and structure as inputs to its data integration structure. That BB data integrating structure has essential elements including a time/actor matrix to ensure proper data sequencing.

A second element required to show

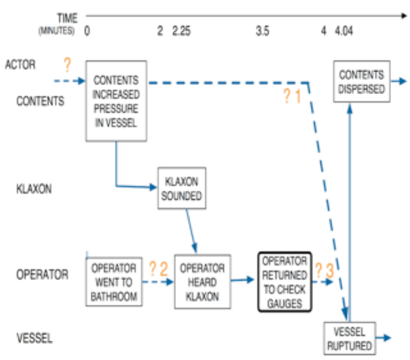


Figure 9 Matrix Links

relationships on the matrix is links based on input-output relationships, from cybernetics. Links can be standardized to indicate their status, as confirmed or tentative (Figure 9.) Links identify behavioral input/output relationships, and can be used for input/output logic testing, including remote "programmer" inputs, to assure description quality. Unlinked BBs may indicate added data acquisition tasks, or hypothesis generation needs, or possibly unrecoverable data.

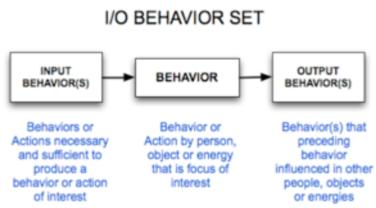


Figure 10 I/O Behavior sets

When all possible input-output links are completed and logically tested for all the BBs on the matrix, the incident description can be considered complete. If all links can not be confirmed, reasons for remaining uncertainties must be explained for users to have confidence in the description.

Linked BBs constitute behavior pairs or sets (Figure 10.) These pairs or sets can provide insights into problem relationships among interactions, and provide a methodical way to ensure that risk raisers revealed by the investigation are not overlooked, or conversely, are not fictitious. These I/O behavior sets provide users with the context of individual actions during an incident, now often lacking in lists of factors or causes.

The standardized matrixes work well with standardized BBs from the incident source data described above. When data documentation and integration rules are followed, and supported by machine processing of the inputs and arrays, matrixes with links appear to satisfy all the demands for developing explanatory descriptions of interactions during incidents (Benner 2007, 2010, 2012a). By working at the BB's low levels of abstraction, the introduction of subjective, biased or spurious inputs to the description can be controlled promptly and persuasively by the investigation leader, making just treatment more likely for anyone involved.

Other integration structures, like Acci-Map and SOL, for example, use time-ordered matrix displays and might also be candidates for adaptation, with additional changes to address other criteria.

The completed standardized input/output descriptions appear to be a common need for all investigation data users. The I/O behavior pairs and sets would provide users with behavior patterns to purge in their systems, or possibly emulate if the outcomes reflect successful intervention in the incident process, as in near misses. The BB's low level of abstraction should facilitate aggregation for trends, patterns and other statistical analyses. Over time, development of actor titles or codes and glossaries should make investigation data sharing less onerous. The addition of chain of custody records might make such safety investigation outputs more attractive to the legal community.

5. Introduction of changes

Present investigation goals and practices are deeply ingrained throughout the world, in part because of their dispersion via the aviation community. Other challenges to making changes are economic. The investment of time and money in the status quo must also be recognized as in obstacle to change. It will be difficult to bring about major changes in those practices, even with growing recognition of their constraints and inefficiencies. Old habits are hard to break. To do so will require a well conceived strategy. That should have high priority especially among users of investigation data.

The first strategy priority is achieving a broad consensus that change is needed. It would seem that a systematic peer review and experimental implementations of the proposed changes would be of value. A gradual shift to permit practitioners time to adapt to the new ways will be essential. Also a way to perform comparative assessments of the results of the new vs. the present practices should be devised and pursued.

A potential starting point for bringing about needed changes might be to encourage rapid adoption of the proposed standardized building blocks, or some close variant, for the inputs to investigations. This would be very likely to contribute to reduced use of abstract and judgmental vocabularies and terms in explanatory descriptions of what happened. When used, the ease and simplicity of their integration and effects on the timeliness of outputs is likely to become apparent to investigators, and their utility to users is also likely to become noticeable. That could help bring about the broad consensus for change, including changing from a causal paradigm to an input output paradigm, start to shorten the data processing pathway, and enhance use of investigation data for risk reduction and other purposes.

If that course is taken, an open source development project for implementation software seems desirable to reduce the incentives for proprietary applications that impede standardization in the field and improved learning.

6. Conclusions and challenges

Difficulties and limitations users are experiencing while utilizing many present incident investigation outputs to find and implement actionable information are well known and increasingly recognized. Those difficulties are due in part to present investigation causation models and practices, and their complex source data pathways to users. To overcome these difficulties, existing investigation models and practices must be replaced by alternative investigation models and changes to investigation practices. Candidate models to adapt are available in other domains such as, for example, the arts, operations research, and systems engineering domains. Adaptation of the musical score and input-output models and paradigm are particularly promising for the documentation and integration of source data produced by incidents, and for improving the data flow pathway from source to end uses, to improve lessons learned performance. Existing initiatives for improving investigation methodologies can be exploited to gradually bring about needed improvements.

The main challenge today is for the research community, investigating entities, software developers and investigation users to acknowledge the need for change, and start to do something about it.

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