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Accident data for the Semantic Web

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ABSTRACT

This paper describes concerns about the documentation, dissemination and use of lessons learned from mishap investigations, impediments posed by current practices, and opportunities for improvement. Lessons are presently developed, documented and stored primarily in narrative form and relational databases, and disseminated in many forms and media, including the Internet. Current practices pose many impediments to maximized development, dissemination and use. Investigation process research and new data concepts behind the Semantic Web, exploited elsewhere, offer potential opportunities to overcome these impediments. To exploit these opportunities, formation of a working group to develop an improved Semantic Web-friendly mishap investigation lessons learning system is proposed. An example illustrating an alternative approach is described to support a reasonable expectation that an alternative lessons learning system could be developed.

1. Introduction: The need

The need to improve adaptive dynamic behavior of socio-technical systems through investigations of accidents, both before and after they happen, has long been of interest (Johnson, 1999). There is even a Society for Effective Lessons Learned Sharing (SELLS) (US Department of Energy, 2003). Maximizing development, dissemination and utilization of "lessons learned" is a continuing quest in many circles (US National Highway Traffic Safety Administration, 2003; Werner and Perry, 2004). One US report describes the need this way:

"NASA stated that it must do a better job of communicating the various lessons learned sources to employees, improving mechanisms to link these sources, and ensuring appropriate training for employees in order to maximize lessons learning"(United States General Accounting Office, 2002).

Some organizations have established lessons learned "centers" or operating feedback systems. They make use of mishap data inputs and inputs from other sources to generate databases with lessons learned for use within those organizations (US Army Combined Arms Center, Center for Army Lessons Learned, n.d.) or by recognized organizations and persons (National Advanced Fire and Resource Institute, 2007; European Commission, 2001). The lessons learned databases focus primarily on activities within the organizations' scope (Dien and Llroy, 2004).

Current investigation practices produce many kinds of outputs containing lessons learned. These outputs range from narrative reports, charts, completed forms, statistical trends or relationships, summary tables and books to bulletins, recommendation letters, check lists, training materials, or e-mail alerts. These outputs are derived by investigators or analysts who draw conclusions from the *investigation or incident data.*

Personal use of public or private lessons learned data is unknown or unreported, quantitatively, but interest in and use to generate new behaviors by individuals seems very limited. For example, one widely respected and emulated public incident lessons learned database with over 700,000 records had 88 search requests by individuals during a recent 6-year period (National Aeronautics and Space Administration, 2005). How many individuals in world process industries would buy a 334 page, $US80 book (Kletz, 2001) to find lessons learned that might apply to their tasks and then internalize all of them to change their behaviors? How frequently do individuals change their behaviors due to desired interpretations of generalized training, procedures, standards or regulations? Nobody knows. Data about acceptance of recommendations does not address whether lessons from investigations actually produced changed behaviors that improved safety, so assessments of present practices must rely on anecdotal evidence of users and observers or investigators. However, few would argue that present practices maximize investigation lessons learned dissemination and their use to bring about changes by all who might benefit from the data.

These circumstances suggest that prevailing lessons learning practices for the development, communication and use of lessons learned from mishap investigations merit examination. The examination should determine impediments to better performance, if a better lessons learning system might be developed, and how that might be accomplished.

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2. Present lessons learned practices

What is the present lessons learned "system" and why does not it maximize learning from current data?

2.1. Mishap lessons learned practices

Contemporary lessons learned practices reflect various "accident causation models." At present, investigators acquire, document and report "facts" or data in many forms and formats, in many diverse and often isolated systems (Sklet, 2003). These data are used by investigators and analysts to piece together a description and explanation of what happened, usually in narratives or on forms, using natural language. Such accident data also form the basis for conclusions about causes, cause factors, root causes, and other cause-oriented findings, from which investigators and analysts derive findings and recommendations. Findings and recommendations constitute the "lessons learned" from an investigation. Analysts then abstract, code, characterize, aggregate or otherwise refine or condense them. They are then "published" internally or made public in various kinds of media as reports, articles, papers, books, stories, graphics, training materials, check lists, etc. They also find their way into procedures or standards and regulations. The "published" data are then preserved by storage in organizational files or computerized databases for retrieval and subsequent uses at a later date.

Dissemination practices vary, but generally can be categorized as (a) electronic and (b) non-electronic written, verbal and graphic dissemination. Electronic dissemination is achieved with computers and computerized databases, e-mails, and Internet sites. Non-electronic dissemination is achieved through published or internal investigation reports, tables, checklists, on-the-job training, safety meetings, standards, training sessions, codes or regulations, and books, for example. End users' learning and ultimate changes depend on the content, access to and assessment of these lessons plus other considerations and tradeoffs, but they would not occur at all without availability of the investigation lessons.

Investigation data are also used for research to develop lessons learned in the form of historical trends or statistical correlations, using statistical analyses or data mining techniques. The data are also frequently abstracted or characterized to generate lists of causes and causal factors referenced in investigation report databases, safety digests and investigation software.

2.2. Impediments to learning

What are the shortcomings of the present lessons learned practices?

A 2004 paper (Werner and Perry, 2004) cited several observed barriers to effective *capture and use* of investigation lessons learned. These barriers could be summarized as:

- Lessons are not routinely identified, collected and shared across organizations and industries;
- Unorganized lessons are too difficult to use, because there is too much material to search, it may be formatted differently for different reports, it is not quickly available, or work pressures do not allow time or resources to find it;
- Reuse is rather ad hoc and unplanned;
- It is often hard to know what to search for or how to find useful documents; and
- Taking time to search for, identify, access and then learn from them within an organization is a problem.

Users and managers identified additional impediments, including irrelevance, cycling of a company practice or instruction, repetitive lessons, suspect tools, and lack of evidence that lessons are being applied toward future success (Cowles, 2004).

No previous substantive research addressing the *development of lessons learned* during investigations is known to exist. Analyses and criticisms of contemporary investigation practices abound in the literature.[1] Investigation problems such as investigative perspectives, conflicting objectives, flawed assumptions, scope, biased data selection, interpretation or representation of observations, logic errors, vocabulary, language ambiguities, premature conclusions, quality control, recommendation development and implementation, and overlooked lessons learned problems have been reported in detail (Hendrick and Benner, 1986). Each investigation problem contributes to flawed development and use of lessons found during investigations.

Personal observations during investigations over a 35-year span, impediments cited above and analysis of reasons investigation recommendations were not implemented, suggest several underlying impediments preventing maximized development and dissemination of lessons learned. These underlying impediments could be characterized as:

- Current perceptions of investigation data needs that limit data presently available for sharing;
- Natural language barriers that lead to diverse source data content and structures, impeding identification of relevant behaviors as lessons;
- Data that are lost due to software obsolescence; and
- Liability concerns that motivate a desire to withhold accident data from publicly accessible sources.

2.2.1. Perceptions of data needs

Perceptions of what investigation data should be acquired and disseminated are based on contemporary "accident causation models." These models and the view of the accident phenomenon behind them may be the greatest impediment to learning. Investigation models, purposes or mandates shape those perceptions. Investigation processes are not designed with the goal of informing all those who need to initiate new behaviors. Currently investigation practices focus on determining the cause or cause factors, multiple causes, problems, and "root" causes, for example, from which investigators or analysts infer lessons learned to address with recommendations. Outputs typically do not provide lessons data in a form from which individuals can quickly derive the specific behavioral changes they need to make. In other words, the target audience is spoon-fed selected changes deemed desirable by the "experts," in the form of recommendations.

2.2.2. Natural language barriers

The preponderance of current accident data is documented using natural language, rather than a "professional language" like those that exist in mathematics or music or medicine or other professional fields. This usage tolerates wide variations in the vocabulary, morphology, syntax, meaning, context and level of abstraction of documented investigation data. That variability impedes manual analysis, machine comparisons and tabulations or rule-based manipulation such as rational concatenation of elements, or interoperability, machine access and machine presentations of the data.

In these circumstances, many investigation data schemes provide accident data definitions, to indicate intent and improve consistency. Data improvement efforts have typically been directed at enhancing data uniformity of meaning, with guides, dictionaries, glossaries or check lists defining words and terms (European Community, 2006). However, most lack a defined data *structure*

[1] Many such papers are found at http://www.iprr.org.

for data that are documented. If any do, they ignore the syntax and other variants, or treat them in isolation from the other impediments, without attacking the more fundamental data structure definition need. The result is that today, almost any kind of data format and structure is found in accident investigation findings, recommendations and lessons learned, despite the increase in software applications (Benner, 2007) that require more rigor. Also most lessons learned system narrative outputs currently have low information density.

2.2.3. Software obsolescence

Years ago, documentation of digitized investigation data and records observed by the author was stored on an IBM 360 system with proprietary software, and later on other systems with Wordstar and Dbase II. None are in use today. The software used to prepare those records has been made obsolete by changed hardware, operating systems and software, little of which is fully backward compatible. The point is that software and media obsolescence should be considered with lessons learning system changes.

2.2.4. Liability concerns

Use or misuse of contemporary mishap data in litigation is a concern of many private organizations. A common reaction is to retain the data within the organization. Incident data are aggregated in voluntary reporting systems, but only when sufficiently abstracted for cause or synopsized to mask concrete identities of individual behaviors involved, as in the US Aviation Safety Reporting System (ASRS) which accepts .csv or .xls formatted spreadsheet or tabular input data as inputs to its system (National Aeronautics and Space Administration, n.d.). The impeding effect of this decision on dissemination of investigation lessons learned is obvious: users with a need to know are faced with balkanized systems that impede retrieval and use. Forced disclosure, through regulation or litigation, does not resolve the data needs and language issues.

2.2.5. Other impediments

Other reported investigation deficiencies (Hendrick, 1986) that impede development, dissemination and use of investigation lessons learned include:

- Data gaps in incomplete descriptions or explanations of what happened, leading to unlearned lessons;
- Logic errors in sequencing or coupling elements of descriptions and explanations, or in the conclusions drawn from the data, leading to misleading or inconsistent lessons;
- Misinterpretation or misrepresentation of observations due to unsuspected biases, unwarranted assumptions, ambiguities, ambivalence or unknowns, leading to unjustified or misdirected lessons;
- Biased data selection to fit predetermined hypotheses, prior experiences, anticipated litigation posture or obstinate mind sets, obstructing potential new lessons;
- Generalizations or abstractions masking actionable details about lessons learned, leading to users' misinterpretation or disregard of lessons;
- Premature conclusions leading to inadequately investigated or misdirected findings and incompletely defined lessons.
- Rarely, deliberate falsehoods or omissions, leading to false outcomes.

Present practices pose other problems, including observed inability to apply statistical analysis methods to derive findings from an episodic occurrence, and risks inherent in waiting for sufficient occurrences to discover valid statistical relationships.

2.3. The challenges

The challenge for safety professionals is to get valid mishap-based lessons learned knowledge into the hands of everyone who need it quickly and efficiently, to enable them to improve future performance. Ideally, all lessons that can be learned from investigations should be made accessible universally, with their context, for everyone whose behavior should change to achieve safer and better task performance, so all have the opportunity to act on or learn from the applicable lessons.

Each impediment cited poses numerous research challenges to achieving this goal; any changes need to address these challenges.

The challenges must focus on development of specific lessons that can be derived from accidents or incidents through investigation, and can be applied to specific work, supervisory, managerial, oversight or regulatory practices in specific circumstances. Specificity is needed to enable informed lesson relevance evaluation, change formulation and consideration with other tradeoffs that enter into the ultimate decision to achieve risk reducing behavior changes. That is true of simple or complex activities.

The subsequent analyses of specific lessons, if aggregated, might enable analysts to derive generic lessons or trends. However generic lessons must always be interpreted and reduced to specific behaviors by end users before they can be internalized to change existing or planned behaviors. Generic analysis issues are beyond the scope of this paper, but will be addressed by an investigation of strategic decisions affecting lessons learning system design and performance.

2.3.1. Define user data needs

The first challenge is to define who the primary end users of lessons learned data should be, and then what lessons learned data would best serve those users. Only individuals can produce new behaviors, in themselves, in objects they design or operate, or energies they manage. The investigation community owes priority attention to disseminating lessons learned to all individuals whose behaviors could benefit from that new knowledge.

2.3.2. Overcome language barriers

A second challenge is to overcome the natural language barriers that produce such diverse investigation data inputs and outputs, so the identified data needs can be produced and delivered to personal users in a form they can internalize readily and directly. This will require a satisfying grammar, structure and format for investigation input data from which mishap process descriptions and explanations are developed, and from which the lessons learned are developed. A satisfying grammar, structure and format must support investigation data sequencing, coupling and logic testing during investigations, and the machine storage, access and presentation of outputs in unambiguous behavioral terms.

2.3.3. Restructure system framework

A third major challenge is to define the structure and content of the lessons learning system. It must satisfy user needs, while also enabling enduring machine documentation, processing, remote access, interoperability, and utilization to achieve timely, efficient presentation of readily internalized lessons learned behavioral information. It is clear the causal framework within which present practices develop investigation lessons learned has not satisfied these needs. That suggests the necessity to seek a new framework.

2.3.4. Transition challenge

A fourth major challenge is the development of the system that would accommodate the transition from present practices to any newly devised lessons learning system. This includes the challenges inherent in devising a comprehensive new lessons learning system such as resources, management, staffing, control, access, and ownership, which also must be recognized and satisfied.

3. Potential opportunities

To address these challenges, any potential opportunities to improve lessons learned dissemination and use merit exploration. The exploding use of the World Wide Web to improve productivity in many fields is clearly such an opportunity waiting to be explored. Other opportunities such as previous research or developments to improve *investigation processes* or new investigation software also merit consideration.

3.1. The Semantic Web

Safety professionals should be aware of changes occurring in information dissemination that offer them new opportunities to improve safety. For example, the Semantic Web (Berners-Lee, 2007) is an evolving extension of the World Wide Web, in which web content can be expressed not only in natural language, but also in a format that can be read and used by software agents. This would permit them to find, share and integrate information more easily. Based on progress shown, innovations related to the developments supporting the Semantic Web are creating new opportunities in many fields.[2] Developments at the World Wide Web Consortium (W3C) such as Extensible Markup Language (XML) for use on the Internet are designed to describe data and focus on what data is. Language such as XML makes possible the introduction of self-contained, stand alone, "free-floating" data that can be utilized for analyses or displays in whatever ways are desired to meet the user's needs. Another aspect of the opportunity offered by the Semantic Web is the ability to present text data in forms that can be readily visualized (Neumann, 2007). Experience in the definition and utilization of such data is already widely available, due to work in other fields by W3C working groups.

3.2. Prior research

Some research has been aimed at improving investigations and the presentation of investigation data. However, lessons learned dissemination and use research is sparse. Johnson's, Weaver and Perry's, Cowles' and Aviation Reporting System works are constrained by accident causation models and the causal framework of the existing worldviews of accidents, investigation and safety.[3] Research outside that worldview, which would focus on the *lessons learning system* rather than on *lessons learned*, is indicated to enable a major improvement in the lessons learning processes' performance. The General Systems model offers one potential alternative framework.

Experience in the definition and utilization of Web-friendly data is already widely available, as a result of developmental work in other fields by W3C working groups. While content remains a challenge, the structural research results seem to offer a viable opportunity for progress to help develop an improved investigation-based lessons learning system.

3.3. Organizing to address the challenges

Improving safety by addressing these challenges and opportunities will require the capabilities of diverse experts. To organize those capabilities, the need for an Investigation Lessons Learning System Working Group is indicated. Its task would be to develop an investigation lessons learning system that overcomes the impediments of current practices cited above, and delivers lessons in a repeatedly accessible and readily assimilable form to all individuals who could benefit by it.

The achievements of the World Wide Web Consortium (W3C) working groups suggest a model for the organization of such a group. The mission of the W3C is to lead the World Wide Web to its full potential by developing common protocols that promote its evolution and ensure its interoperability. The W3C is organized for and oversees the development of web standards. Web standards exist for programming languages, operational systems, data structures, communications protocols and electrical interfaces. The W3C follows processes that promote the development of high-quality standards based on the consensus of the membership, Working Group Team, and public. W3C processes promote fairness, responsiveness, and progress: all are facets of the W3C mission.

The W3C processes are described in a W3C process document, posted on the Internet (W3C World Wide Web Consortium, 2005). If there is sufficient interest in a topic, the process is initiated. An initial step would be the convening of an international or intercontinental workshop or conference, to gauge the interest in lessons learning system development. After a successful workshop and discussion on an advisory mailing list, the W3C director would announce a working group charter.

The impediments to dissemination and learning cited are offered as a possible general agenda for an initiating conference. Further analyses of dissemination and learning impediments should be entertained as they are identified and defined. The aim of such a conference or workshop should be at least a preliminary identification of potential data users, data needs and data structure options that a formal working group or activity might pursue. A working group should draft a list of "shall be" or "should be" mandates for investigation lessons learned data development and its structures to facilitate machine utilization.

4. A research example

An example developed during research to improve investigation processes and lessons learned creation, documentation, and dissemination shows the potential feasibility of pursuing alternative approaches. The example invokes a paradigm shift from contemporary causation models and investigation models to an input–output and behavior-based investigation model. This shift affects the investigation process from which lessons flow, the formulation of the lessons learned by the investigators, and the dissemination of those lessons, their accessibility and assimilation.

4.1. User data needs

Prior noteworthy studies by Johnson, Ladkin (Ladkin, 1999) and others, attempting to apply rigorous logical reasoning to investigation reports, have demonstrated problems with large narrative reports and suggested remedial options. However, their focus has been primarily on the logic and presentation problems with the information in the reports, rather than lessons learned data needs, grammar or structure employed in investigations. Past and current improvements are aimed primarily at achieving data *logic and consistency*, and enhancing relational database machine analyses of data and text mining (Pelandeau and Stovall, 2005) to identify trends, identify safety improvements and prevent accidents. What data should be gathered, documented and made available directly to end users of lessons produced by investigations?

[2] For a list of examples of applications in Europe, see XML Applications at Work (2007) at http://www.softwareag.com/xml/dt/default.htm. Their widespread use in commerce suggests they are not likely to become obsolete in the foreseeable future.

[3] Their emphasis is on improving existing reports, rather than the lessons learning system.

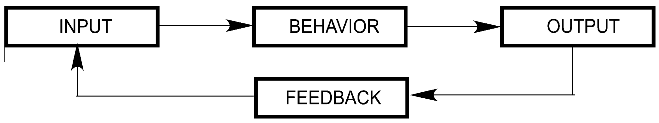

Fig. 1. Behavioral adaptation of general systems model.

Since behavioral change is the ultimate lessons learning system goal,[4] it was postulated that *behaviors* and their *relationships during accidents* that produced the unintended outcomes was the information end users need, and should be the research focus. ESReDA also indicated "benefits from a behavioral approach" (ESReDA Working Group Report, 2005). To ensure a systematic approach, the General Systems Model was selected as the general framework, modified to reflect the behavioral focus.[5] See Fig. 1.

During the research it was found necessary to distinguish between data definitions offered to support current practices, and data structure definitions needed for the Semantic Web. *Data Definitions* in the form of natural language glossaries, dictionaries, checklists or entry instructions define the data so data providers know what data the system or forms designer wants from the provider. These definitions focus on static attributes of single event data. They are provided for use in entering data on specific forms, relational database entries or narratives. *Data structure definitions* on the other hand, specify the grammar, format and attributes of each stand-alone data element, with no reference to coordinate-based databases. Data designed and defined for a specific coordinate-based database has somewhat limited utility because of the ambiguity and abstractness of the natural language of investigation data entered.

4.2. Behavioral data documentation during investigations

During investigations, investigators create "building blocks" they use to construct a description of what happened and explanation of why it happened. Unfortunately many kinds of building blocks are used for this purpose, including building blocks created for investigation software, resulting in many of the problems cited. The most fully formalized *behavioral* investigation building block available, originally developed for manual implementation by prior research, was selected for this research (Benner, 2002). See Fig. 2.

4.2.1. Behavioral building block example

The general format in Fig. 2 has the further advantage of having well-defined data elements, grammar and structure. By transforming investigators' observations and other inputs into this actor + -action-based building block format, behaviors could be documented, organized, linked, tested and utilized to show the logical flow of interactions needed to produce observed outcomes. Building block coupling is essential for showing interactions among behaviors; coupling depends on structural consistency.

4.2.2. XML investigation building blocks

To adapt these manual building block elements to the Web, they were configured in an XML document structure. The resulting XML document structure is shown in Fig. 3. Note that it can be read by humans and machines.

Note that conditions are not included as elements; all the elements and attributes refer to actions or behaviors. The rationale for excluding conditions was that conditions remain unchanged until someone or something acts on a condition to change it. Thus the focus led to behaviors in the form of actions that changed conditions.

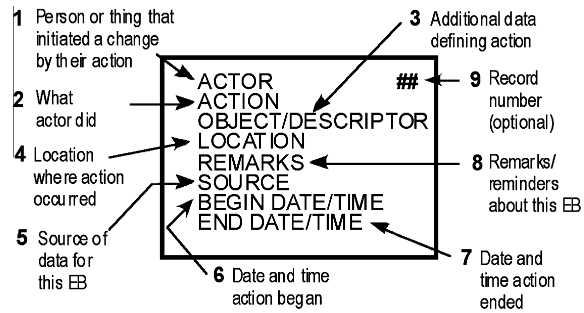

Fig. 2. Behavioral investigation building block.

```
<?xml version="1.0"?>
<mesblock unique_id=""> (9)
        <actor></actor> (1)
        <action></action> (2)
        <object></object> (3)
        <location></location> (4)
        <start_time type=""> (6)**
                <year></year>
                <month></month>
                <day></day>
                <hour></hour>
                <minute></minute>
                <second></second>
                <millisecond></millisecond>
        </start_time>
        <end_time type=""> (7)
                <year></year>
                <month></month>
                <day></day>
                <hour></hour>
                <minute></minute>
                <second></second>
                <millisecond></millisecond>
        </end_time>
        <source></source> (5)
        <remarks></remarks> (8)
        <nstest> </nstest>***
        <link></link>****
</mesblock>
```

* Numbers in parentheses refer to Figure 2 legends
** type is used for attributes of tag
*** nstest is used to indicate whether link passed necessary and sufficient logic tests
**** link tags are used to document coupling with other XML documents

Fig. 3. Investigation building block elements in XML document.*

4.3. Building block uses

XML event building block (EB) files with data entry and editing software were developed. Then software to machine read the XML files was developed to generate several kinds of graphic event flow charts, glossaries, input–output links among two or more coupled EBs, jump maps, sortable and filterable tabular EB displays, and parsed text files (Benner, 2003). Display data were machine converted to web-compatible graphic files that could be processed for distribution on the Internet. Examples of hard copies or Internet files of the outputs mentioned are available upon request directed to the author.

Web pages were created to provide for the remote entry and capture of XML building block data with any W3C compatible computer browser. These data files were stored on web sites for participating investigators to edit and use. Data files were concatenated, printed or saved and stored as graphics files for

[4] Reference The Wildland Fire Lessons Learned Center states the goal this way: "A lesson is truly learned when we modify our behavior to reflect what we now know."
[5] A Knowledge Management framework was also considered but it poses similar impediments.

dissemination on the Internet as they were created. Thus all investigators on the case could see the status of an investigation in real time. At the end of an investigation, the completed data could be presented graphically, in tabular form or as text phrases for inclusion in reports.

The ability to easily concatenate XML-based EB files permits concurrent conduct of investigation tasks and individual file preparation duties by two or more investigators. Their data files can be combined into one project file as new data contributions become available. When more investigations are documented, aggregated data files for groups of investigations are created. The aggregated files enable tabular listings of all event building blocks, which can be screened to find common event building blocks across all the incidents in the "master" file. The screened list offers detailed information and context about each building block's inputs and outputs in the file.

4.4. Event set displays

For lessons learning purposes, one of the most promising outcomes of this research is the process of developing "event set" displays of coupled building blocks. All the behavior inputs necessary to produce a mishap outcome could be displayed in a *systems-based* tabular form, in the sequence they occurred. This searchable display provided every input to each behavior disclosed by the investigation, and also every output that each behavior produced. It has been termed an "Event Block Input/Output (EBIO)" array, as shown in Fig. 4.

Fig. 5 is a sample of a display from a work file analyzing a model accident investigation report published in an industry investigation guide. It illustrates the EBIO structure.

This example is from a work in process. Note the gaps in the flow of inputs and outputs that need to be resolved before the investigation is closed, as indicated by the investigator's comments. If information is neglected or withheld, the gap becomes evident in this display. Also note the incomplete necessary/sufficient logic tests. When the gaps are closed and tested, the input–output flow should define how those behaviors advanced the mishap process toward the outcome. Users should be able to associate these behaviors with their own if they have relevant tasks in their workplaces.

Please note that "cause" plays no role. Unambiguous input behaviors and output behaviors in the form of specific actors and actions describe and explain the accident process. When posted on the Web, individuals can search EBIO files concatenated from many cases, for event sets involving their tasks, and see behavior sets or pairs to avoid or modify. This direct association and recurring accessibility should facilitate internalization of the lessons displayed and their use. That research is ongoing.

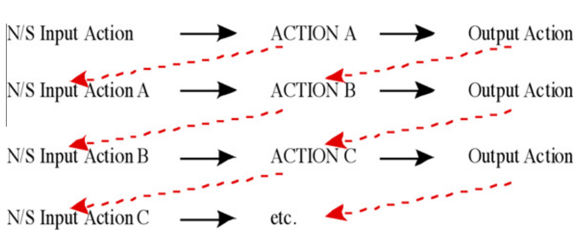

Fig. 4. EBIO array of event sets*. * *Patent pending.*

4.4.1. Conducting investigations

Acquisition of data to support development of lessons learned is difficult. The graphic, tabular and EBIO displays created from the XML building block files help investigators reduce such difficulties with continuous feedback during investigations, by displaying the flow of coupled actions or behaviors created from the investigation data already acquired. Thus they systematize and integrate the iterative data gathering and analysis tasks as the investigation progresses, but differently from traditional practices. At the conclusion of a successful investigation, ideally all behaviors should be linked. Any gaps in the flow of the actions or incomplete necessary/sufficient logic tests indicate a need for better understanding (e.g., more data) to complete the investigation or, possibly, unobtainable data. They offer guidance for interviewers by showing what each actor did during the accident process, with gaps indicating behaviors not yet identified, as in Fig. 5. They produce assimilable lessons learned as concrete behavioral data sets, with transparent logic.

4.4.2. Disseminating lessons learned

This EBIO display provided a way to disseminate investigation "lessons learned" data, in a high information density format. Each behavioral input/output/output event set offers a concrete description of *part* of a mishap process, which if replicated elsewhere can play a role in another accident or near miss, or process inefficiency. It provides the *context* for each behavior, with no expert interpretation needed. Concatenated case files can identify behavioral event set patterns within or across activities. Direct access to such behavioral event sets on the Web would enable all with a need to know, including designers and writers of specifications, procedures, standards, regulations, guides and training materials, for example, to avoid their replication. Repeated access would facilitate internalization of behavior changes.

The degree to which such non-judgmental descriptions would reduce perceived threats from external disclosure or sharing of an organization's lessons is unknown, and would need to be tested, but they seem more promising than present value-laden outputs.

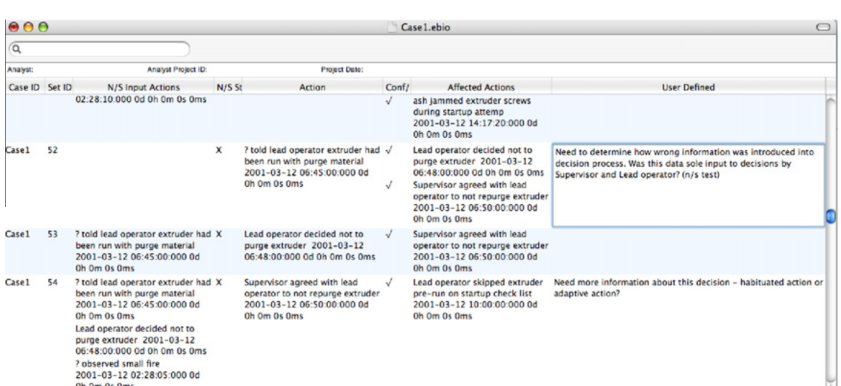

Fig. 5. Example of EBIO for selected event sets.

4.4.3. Minimizing ambiguities

Ambiguities in actor names are easily avoided by naming each actor uniquely. Avoiding ambiguities in documenting the actions is a greater challenge, because of natural language ambiguities in most languages. Consistent verb tense and active voice help, but diligence is required to ensure use of unambiguous concrete action words in the behavior descriptions. Structured building blocks would reduce investigative ambiguities, among other improvements.

5. Conclusions

Current impediments to maximizing development, dissemination and use of lessons learned posed by present investigation practices call for change to ensure the timely development, access to and efficient delivery of needed lessons learned information to all who should know about it and internalize it. This requires a focus on needs of users and collaborative efforts from individuals with a wide variety of expertise. An Investigation Lessons Learning System Working Group is proposed to address this need.

By refocusing on behavior data needed by users of lessons learned and on behavioral inputs and outputs during investigations, an example of a lessons learning system-based alternative to present practices was identified. It enables investigators to develop and users to access task-related lessons learned in a new, direct and readily assimilable way without expert analysts' intervention. This supports a reasonable expectation that an alternative Semantic Web-friendly lessons learning system that overcomes the impediments posed by present lessons learned practices could be developed.

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