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Sifting Lessons from the Ashes: Avoiding Lost Learning Opportunities

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Abstract

Recent high-visibility accidents demonstrate that processes for learning costly lessons that should have been identified by investigations continue to under-perform expectations. The accident scenarios of the crash of a Continental-Colgan DeHavilland Dash-8-Q400 at Buffalo, NY; and a FedEx MD-11 at Narita, Japan, a month later, reflect missed opportunities to learn the lessons from similar previous accidents, or analyses by those who might have used that knowledge successfully to avoid the latest crashes. Current processes for identifying, defining, communicating and acting on lessons to be learned are inadequate to take advantage of the opportunities offered by investigated accidents. We undertook a systems analysis approach to define historical accident investigation lessons-learned processes and outputs, and isolate and document the systems' boundaries, functions and attributes. This paper documents our analysis and the insights gained. We incorporated the resulting successful functional elements into a "Lessons Learning System," that identifies a process from generation of lessons-to-be-learned source data to disseminating and applying lessons-learned to improve the learning organizations' safety performance. We analyzed those elements from the standpoints of lessons-learned users, and system developers and designers, which enabled us to define twenty-six desired system attributes and at least eight strategic system design alternatives. We address these immediate needs for improving the lessons learning processes:

- redesigning the form and substance of lessons-to-be-learned source data to improve their usefulness, and
- redefining investigation product specifications to require that lessons learned be an explicit documented product of investigation processes.

Background

"The official motto of ISASI is: "SAFETY THROUGH INVESTIGATION". (Ref. 1)

"**5. ACCIDENT PREVENTION …** Each member shall:

> "5.1 Identify from the investigation those cause-effect relationships about which something can be done reasonably to prevent similar accidents.
>
> "5.3 Communicate facts, analyses and findings to those people or organizations which may use such information effectively …."   (Ref. 2)

ISASI was incorporated 45 years ago and its official motto was adopted at that time. Its Code of Conduct has been in effect for more than 25 years. Recurrence of accidents from similar sources should have been reduced substantially, if not eliminated, had investigations fulfilled the expectations of ISASI's founders. What happened?

What happened has been the recurrence of accidents that bear striking similarities to those that have happened before. We call these recurrences "retrocursors." Unlike "precursors," which presage events to come in the future, "retrocursors" reenact behavior patterns that have led to accidents in the past. At the time of this paper's writing in late June 2009, the most recent of these was the loss of Air France Flight 447 over the equatorial Atlantic enroute from Rio to Paris. Facts are not yet adequate to support any of the many hypotheses, at least two of which have happened before:

- Air Data Inertial Reference Unit (ADIRU) faults resulting from errant input signals, with resulting reversion of control laws from (normal) computer control to one of three degraded levels demanding immediate manual control by the crew in an ambiguous situation. Out-of-envelope airspeed signals could have resulted from pitot tube icing in severe thunderstorm. (Refs. 3-5); or
- Overstress separation of the airplane's vertical stabilizer, and subsequent loss of control. (Refs. 6-7); or
- A combination of both.

Continental-Colgan Flight 3407, a Bombardier Dash-8-Q400 that crashed on approach to Buffalo, NY, on February 12, 2009, and Turkish Airlines Flight 1951, which crashed on approach to Amsterdam's Schiphol Airport thirteen days later, were high-profile retrocursors. In both cases minor anomalies distracted the crews from the principal airmanship rule: "First fly the airplane." Crew distraction accidents have been a bane for decades. (Refs. 8-11)

A third retrocursor was the FedEx MD-11 landing crash at Narita, Japan, on March 22, 2009, that duplicated a similar FedEx MD-11 at Newark, NJ, in 1997. A China Airlines MD-11 crash at Kai Tak in August 1999 exhibited similar operational behavior. (Refs. 12-14)

Why hadn't the lessons that should have been learned from earlier accidents been communicated well enough to the crews and internalized sufficiently to prevent the retrocursors?

Contemporary Lessons Learned Practices

Are there formal contemporary lessons learned "systems" and, if so, why don't they maximize learning from lessons generated by accidents?

Historically, investigators acquire, document and report factual data in many forms and formats, by many diverse and often isolated systems. These data are used by investigators and analysts to piece together a description and explanation of what happened, usually in narratives or on pre-existing forms, using natural language. These accident data comprise the bases for cause-oriented conclusions from which findings and recommendations are derived. Causes, findings and recommendations rarely specify the "lessons learned" from an investigation. (Ref. 15) Analysts abstract, code, characterize, aggregate or otherwise refine or condense the data. They are then "published": disseminated internally or made public in various media, as data bases, reports, articles, papers, books, stories, graphics, training materials, check lists, etc. Published data are stored in organizational files or databases for retrieval and use. They may also find their way eventually into revised procedures, standards and regulations.
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Dissemination practices vary, but include electronic dissemination in computerized databases, e-mails, and Internet sites. Non-electronic dissemination may include hard-copy investigation reports, tables, checklists, on-the-job training, safety meetings, standardization, training sessions, codes or regulations, and books. Deriving lessons from the data depends on someone recognizing the value of the content, and generating and communicating the lessons.

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

We analyzed contemporary "Lessons Learning" practices, focusing on how data are analyzed to isolate and describe the lessons that should be learned. Major inadequacies we observed include:

- Authors variously define lessons as causes, cause factors, findings, conclusions, recommendations, issues, statements or scenarios in texts of narrative reports.
- Authors often obscure lesson data within excessive wordiness and jargon.
- Authors do not explicitly list "lessons learned" as such.
- Analysts rarely categorize investigation data to facilitate end-users' retrieval and use.
- Analysts assume that proposed changes alter system behavior favorably, without testing.
- Lessons are "pushed" to pre-established recipients, but must be "pulled" by other users.

What inadequacies of current lessons learned practices have already been reported? Werner and Perry (Ref. 16) cited barriers to effectively capturing and applying lessons learned by investigators:

- Data are not routinely identified, collected and shared across organizations and industries.
- Unsystematic lessons are too difficult to use because:
    - there is too much material to search,
    - they are formatted differently in different reports, or
    - they're not readily available.
- Applications are unplanned and haphazard.
- "Taxonomy" categories obscure data searches.

We observed two categories of inhibitions to developing lessons learned within the investigation process itself. The more fundamental is a mindset of unquestioned acceptance of "how things have always been done," and can include:

- Archaic accident "causation" models;
- Unwillingness to share investigation data;
- Language barriers that obscure identification of relevant behaviors;
- Data loss from software obsolescence and lack of standardization; and
- Concerns for legal liability.

A secondary category frequently derives from the obstacles above and occurs at the levels of individual investigators and analysts. It includes missing data, biased scope and data selection, logic errors, misinterpretation or misrepresentation of observations, flawed assumptions, and premature conclusions during investigations. Each inhibits development of useful lessons.

Clarification of Terms

"Lessons learned" are often considered to be new knowledge obtained from experience, applied to benefit future performance. The questions arise: knowledge about what? And how can we put it to beneficial use? We find it helpful to think of the new knowledge generated by investigations as clarification of what happened, and why it happened. That new knowledge can be applied to change behaviors of people, systems or energies. This concept distinguishes between the lessons and the learning, identifying the tasks required of those documenting the lessons to describe and communicate them, so that end-users can apply them to initiate desired behavioral changes.

What Data Are Needed to Develop Lessons to be Learned?

Mixed perceptions of the investigation data that need to be acquired and disseminated as lessons may be the greatest obstacle to learning. Accident causation and investigation models influence those perceptions. Current investigation goals do not prioritize information needed by end-users who initiate behavioral changes. Investigations focus on determining "causes:" cause factors, multiple causes, "root" causes, and other easily labeled actions from which investigators and analysts infer lessons and propose corrections. Investigation report authors typically do not provide data in forms from which end-users can derive the behavioral changes they need to prevent recurrence. Instead, the "expert" investigating agencies select changes they deem desirable, and direct them to target audiences of their choice in the form of recommendations.

Challenges to Developing Lessons Learning Systems

The challenges to lessons *learning* systems are to collect accurate mishap-based data, and communicate them quickly and efficiently to end-users that can develop and implement changes. The first challenge is to define the end-users of lessons from investigations and how they would use them. End-users are all entities that can change behaviors that led to an undesired outcome, or initiate new avoidance behaviors, in their operations, in objects or systems they design or operate, or in energies they manage. Current investigation data is designed to fulfill the needs of the agency conducting the investigation. The investigation community would better serve its prevention goal by devoting priority attention to fulfilling the lessons learning data needs of end-users that can apply that new knowledge to changing behaviors.

A second challenge is to systematize investigation data inputs and outputs by standardizing and applying scientific language. Common grammar, structure and format for investigation input data should describe behaviors that constituted the mishap process thoroughly and objectively. Investigators must test behavioral data sequencing, coupling and logic during investigations. That will assure the identified, needed data will be developed and delivered to end-users in formats they can internalize readily and directly, and provide them with unambiguous reasons for changing the behaviors that produced the unwanted outcomes.

A third major challenge is to define the structure and content of the lessons learning system. It must satisfy end-users' needs and, at the same time, support machine documentation, processing, remote access, interoperability among users, and easy access. Its goal should be timely, efficient identification of the behavioral changes needed to effect the lessons that need to be learned, and their delivery to the people who need to learn them.

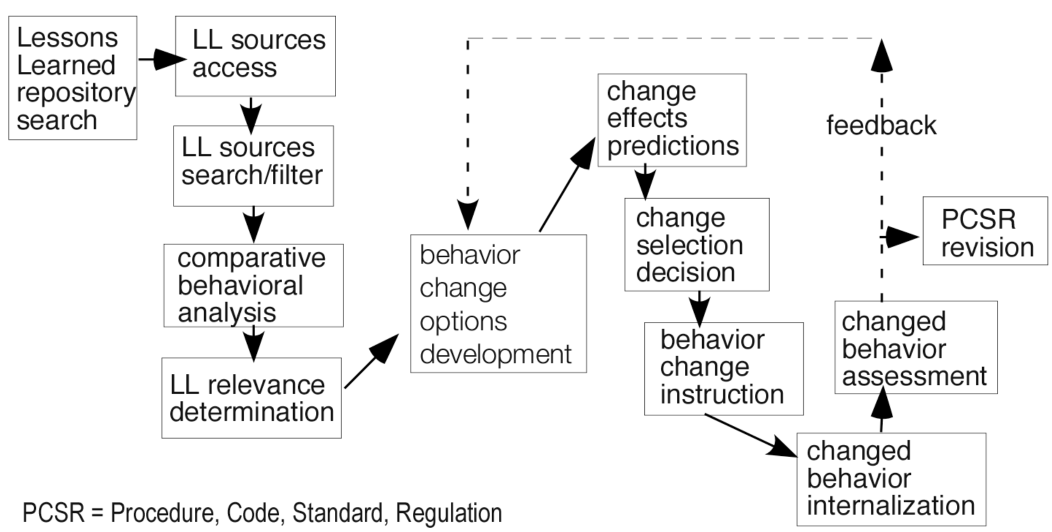

Figure 1. Users' Components of Lessons Learning Model

A Lessons-Learning System

We developed a model of a comprehensive lessons *learning* system from investigations by tracking the functions and tasks required to achieve changed behaviors. The system begins with capturing the lessons-to-be-learned data during the accident process, and ends with an archive of lessons and responses that have been tested and shown to produce effective results.

Users' components of the learning system model are shown in Figure 1. The model assumes that lessons learned are new knowledge developed by investigators about behaviors that interacted during the accident process. Each task can be decomposed further for specific applications.

Lessons Learning System Attributes from Users' Perspectives

What should users expect from a lessons learning system? (hereafter "LLS") LLS users deal with dynamic processes. LLS documentation must be behaviorally consistent with dynamic processes to enable comparing behavior sets, defining alternative changes to behavioral relationships, and predicting effects that changes might introduce. The system should enable translating LLS response options into some form of change management analysis, and into instructions to incorporate the changed behavior in the targeted person, object, energy or process. Therefore, LLS must describe behavioral interactions among people, objects and energies, rather than linear "causes" or abstracted "factors." Ideal LLS attributes include:

- Open to multiple change options.
- Inclusive of context identification.
- Accessible expeditiously to all potential users.
- Backward compatibility with legacy data repositories.
- Minimize elapsed time (Latency) between the occurrence which generate data for LLS, and when the lesson becomes available to end-users.[1]
- Maximize "signal to noise" ratio; *i.e.*, maximizing relevant content.
- Enhanced determination of relevance.
- Enhanced assimilability.
- Scalability: the ability to increase data quantity without sacrificing quality.
- Cost Sensitivity: the value of the system in terms of results it produces.
- Improved acceptance, and more actions initiated, by end-users.
- Performance metrics for behavioral changes.
- Timely repository updating.

Lessons Learning System Attributes from System Developers' Perspectives

From a developer's perspective, shown in Figure 2, investigation components of LLS should support development of lessons-to-be-learned source data with such attributes as:

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[1] Boyd's "OODA Loop" concept (Ref. 17) encourages the strategy of responding to situational feedback to effect immediate changes by bypassing administrative process; *i.e.*, prioritizing the application of new LLS knowledge to change behavior, improve operational efficiency and avoid retrocursors.

- Establish investigation goals to provide lessons that can change future behaviors.
- Establish an input-output framework for defining what happened by LLS data sets that describe behaviors in non-judgmental and logically verifiable terms.
- Focus on behavior data acquisition and processing.
- Specify a structure for input data documentation that ensures data consistency and economy, and facilitates data coupling and support for documenting output LLS.
- Machine supportable input data management, display and expansion, to reduce latency.
- Objective quality assurance and validation processes.

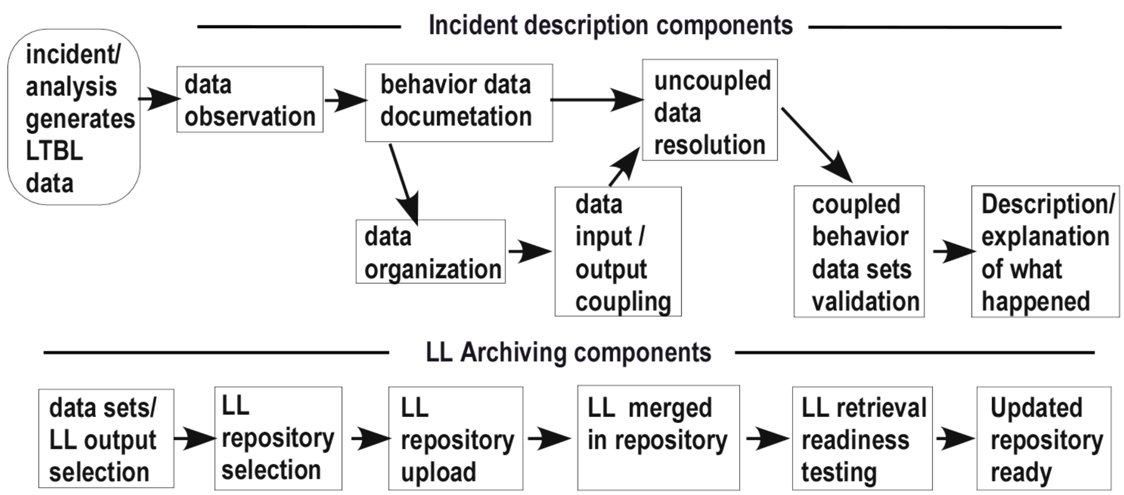

Figure 2. Developers' Components of Lessons Learning Model

Lessons Learning System Documentation Component Attributes

LLS documentation derived from investigation descriptions must fulfill end-users' needs. System attributes should include:

- Requirements that behavioral data outputs provide context, minimize interpretive and analytical workload, maximize signal-to-noise ratio, and reduce latency.
- Provisions for machine processing support, interoperability, and repository uploading capabilities to accelerate documenting and distributing lessons to all collections.
- Establish accessible Internet LLS output data libraries and end-user notification to support both "push" and "pull" data distribution and minimize latency.
- Easy repository access, with search and filter capability to minimize end-user access time, cost and workloads.
- Objective verification and validation to assure quality before dissemination.
- Provisions to modify and update collected data with new knowledge.

Other Observations

During the study of lessons learned processes we noted two other significant observations:

- Special investigating bodies appointed to inquire into specific accidents often address lessons learned explicitly in their reports. (Refs. 18-20) Yet the reports we surveyed by traditional government investigation bodies lack a discrete section addressing, documenting or summarizing the lessons found during the investigation. No standardized guidance exists for doing so. For example, ICAO Annex 13 does not define or otherwise mention "lessons learned." Lack of standardized methodology for reporting "lessons" burdens prospective end-users by requiring them to search and interpret voluminous data with little assurance of finding what they need to initiate changed behaviors.
- LLS require designers to make strategic choices about investigation process frameworks, purposes, scope, and data structures; LLS content, form and language; and appropriate choices of repositories, distribution, updating and metrics. Traditional (or inadvertent) strategic system design choices have adversely affected the utility of current LLS processes, operation and performance.

Conclusions

Contemporary investigation-based LLS have not prevented recurrence of accidents from known behaviors that produced undesired outcomes. Their primary weakness lies in neglecting the knowledge requirements of users capable of changing those behaviors. Current reports are too often inconsistent, ambiguous and vague. Investigating agencies should design LLS to identify and report all the lessons that can be learned from each mishap, record them explicitly for ready access and retrieval, oversee their application where they can contribute to avoiding "retrocursors," and measure the results. The first steps needed to improve lessons learning practices are:

- redesigning the form and substance of lessons-to-be-learned source data to improve their usefulness for users, and
- redefining investigation data product specifications to require that lessons learned be an explicit documented output of the investigation processes.

References

1. ISASI Bylaws, §1.5 (Rev. 08/93)
2. ISASI Code of Ethics, §5 (Rev. 10/83)
3. <http://www.eurocockpit.com:80/archives/indiv/E009424.php>
4. Air Carraibes "*Note Compagnie*" re AB 330-200 F-OFDF dtd 01/12/2008 enroute Fort-de-France, Martinique (FDF) to Paris-Orly (ORY), 31 August 2008. (In French)

5. Australian Transportation Safety Bureau Aviation Safety Investigation Report - Interim Factual AO-2008-070: "In-flight upset, VH-QPA, Airbus A330-303, 154 km west of Learmonth, Western Australia, 7 October 2008"; dtd 06 March 2009.
6. NTSB Aircraft Accident Report NTSB/AAR-04-04 dtd October 26, 2004: "In-flight Separation of Vertical Stabilizer: American Airlines Flight 587; Airbus Industrie A300-605R, N14053, Belle Harbor, New York, November 12, 2001."
7. Transportation Safety Board of Canada Report A05F0047 mod 7-31-2008: "Loss of Rudder in Flight; Air Transat; Airbus A310-308 C-GPAT; 90 nm S of Miami, Florida, 06 March 2005."
8. Video of NTSB May 12-14, 2009, Public Hearing, Colgan Flight 3407 at <www.ntsb.gov>.
9. See <http://en.wikipedia.org/wiki/Colgan_Air_Flight_3407>.
10. Dutch Safety Board Preliminary Report at <www.onderzoeksraad.nl/docs/rapporten/Prelimenary_EN_def.pdf>
11. U.S. Civil Aeronautics Board Aircraft Accident Report SA-387 File No. 1-0031: "American Airlines Boeing 727, N1996, Constance, KY, November 8, 1965," available at <http://dotlibrary1.specialcollection.net/scripts/ws.dll?websearch&site=dot_aircraftacc>
12. See <http://news.bbc.co.uk/2/hi/asia-pacific/7958367.stm>
13. NTSB Aircraft Accident Report DCA97MA055: "Federal Express, Inc., (FedEx) Flight 14, McDonnell Douglas MD-11, N611FE, Newark International Airport, Newark, NJ, July 31, 1997."
14. Report of the Board of Review on the Accident to Boeing MD-11 B-150 at Hong Kong International Airport on 22 August 1999; at <www.cad.gov.hk/english/n2.html>
15. Werner, Dr. Paul & Richard Perry, "The Role of Lessons Learned in the Investigate, Communicate, Educate Cycle for Commercial Aviation." Presented at the ISASI 2004 Seminar; excerpted in *ISASI Forum*, V. 38, #4, October-December 2005, pp. 20-25.
16. Rimson, I.J., "Investigating 'Causes' and Assigning 'Blame'." Invited presentation at the Mary Kay O'Connor Process Safety Center 2003 Symposium, Texas A&M University, October 29, 2003. (available at <http://www.iprr.org/papers/rimsona&mpaper.htm>)
17. <http://en.wikipedia.org/wiki/OODA_Loop>
18. *Report of Columbia Accident Investigation Board,* Volume I, Chapter 8: "History as Cause: Challenger and Columbia." at <http://anon.nasa-global.speedera.net/anon.nasa-global/CAIB/CAIB_lowres_chapter8.pdf>
19. "The Buncefield Incident, 11 December 2005": *The Final Report of the Major Incident Investigation Board,* Vol 1. P. 21 Item 63; (LL Workshop 20 Dec 07) ISBN 978 0 7176 6270 8
20. Davis-Besse Reactor Vessel Head Degradation Lessons-Learned Task Force (2002)*, Davis-Besse Reactor Vessel Head Degradation Lessons-Learned Task Force Report,* publicly accessible only at <http://www.nrc.gov/reactors/operating/ops-experience/vessel-head-degradation/lessons-learned/lessons-learned-files/lltf-rpt-ml022760172.pdf>
21. Benner, L., Jr., "Accident Data for the Semantic Web." Draft Proceedings of the 33rd ESReDA Seminar, Ispra, Italy, November 13-14, 2007.
22. Benner, L. Jr., and W.D. Carey, "Lessons Learning System Attributes: An Analysis," Draft Proceedings of the 36th ESReDA Seminar, Coimbra, Portugal, June 2-3, 2009.