Cultural Influence on the Implementation of Lessons Learned in Project Management

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Abstract: To investigate NASA's process for culture change, we conducted research and analysis of the data in the NASA Lessons Learned Information System (LLIS) from a cultural perspective, and conducted extensive collaborative discussions with NASA personnel and a Technical Advisory Board (TAB) convened for this project. The results of this study indicate that culture change in order to implement lessons learned processes and achieve their benefits has been evolutionary and variable across NASA centers. Our interactions with and analysis of the JPL Lessons Learned Committee indicate that JPL has successfully implemented a comprehensive lessons learned process addressing technical and cultural change challenges. The process should be of interest to the project management community at large. Based on the results of this effort, we conclude that lessons-learned culture change is possible and underway at NASA. Executive-level, systems-based lessons learned guidance and support is critical for NASA-wide implementation of NPR 7120.6. This should facilitate the implementation of the NASA-wide, standard, system-level lessons learned template, to counter the development and use of alternative processes and protocols. Additional progress is possible in system-based processes and cultural areas. For example, the systems-based approach could include built-in incentives, check points, and consistency indicators.

Keywords: Culture Change, Lessons Learned, Systems Engineering, NASA JPL, LLIS

EMJ Focus Areas: Program & Project Management

This effort concentrated on characterizing the lessons learned processes in NASA's organizational culture as evidenced by NASA program and project management (P/PM) case studies. The focus of this effort was on mishap studies that raised concerns that lessons learned were not being implemented effectively toward the design of subsequent missions. This study examined the potential influence of engrained cultural features in this characterization.

A general motivational concern stemmed from specific mishap investigation board reports that NASA lessons learned from past mishaps and programs were not being applied effectively in subsequent programs/projects (General Accounting Office, 2002; Sarsfield, 2000; Diaz Team Report, CPMR Workshop, 2003). A potential cause and key hypothesis explored in this study is that the NASA culture has engrained features that lead its analyses, evaluations and conclusions in a characteristic direction. This study assessed these features as manifest in characteristic safety and risk management methodology, structure, and decisions effectiveness in subsequent P/PM planning. This study also compared and contrasted NASA and contractor/industrial experience and culture in application of lessons learned in subsequent projects.

The primary objective of this research was thus to identify and quantify the impact of lessons learned components of previous mishap investigations, as applied to subsequent mission P/PM risk and safety management processes. This study relied on the NASA's Lessons Learned Information System (LLIS), expert interviews, plus other contractor and industry cases with similar program execution content but different organizational cultures.

This study focused on three of the most frequently cited recurring causal factors for project failures: poor team communication, inadequate consideration and implementation of systems engineering principles for complex/large scale projects, and inadequate management review process in all life-cycle phases of the project. Selection of the areas for this research was based on discussions among our Technical Advisory Board (TAB) in consultation with NASA, and a thorough understanding of NASA's Lessons Learned cases.

Relevance to Program/Project Management Objectives

This work aims to support the safe accomplishment of programs and projects. This is directly relevant to NASA's P/PM objectives and consistent with NASA Procedures and Guidelines, NPG

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7120.5B. Furthermore, this work will advance the state of knowledge of program and project management, require collaboration and data exchange among PM professional at NASA and elsewhere, incorporate the results in graduate-level education, and disseminate these results to the broader community.

By comparing multiple NASA Centers and contractor cultural responses in key risk- and safety-related areas, the results will impact safety and risk assessment, contingency and reserve planning, and decision-making processes of future projects. It is important to know if there are indeed cross-center cultural barriers to the implementation of lessons learned, to quantify the effect, and to recommend changes that will enable benefits to be derived from lessons learned efforts. The results of this effort will apply to on-going projects at NASA and elsewhere to explore their practical application in the target environment. Lessons learned from this initial effort could be used to recommend revisions to metrics, correlations and recommendations implementation processes.

The intrinsic merit of this work is in the value of examining the role of culture in determining (a) how lessons learned are implemented in NASA processes in comparison to contractor or industry cultures; (b) what constitutes successful implementation; (c) what is the evidence that a lesson has been learned and implemented; and (d) the mechanism for truly incorporating changes to best practices. A lesson learned is a lesson forgotten if it is not implemented in a concrete way that reinforces the lesson and/or eliminates the fundamental cause, failure, or flaw.

Research Collaborations

Relevancy of the methodology for this study was anchored in collaborations with a blue-ribbon Technical Advisory Board and NASA personnel active in the lessons learned area. To supplement the traditional literature review, we held direct talks, in person and via telephone, exchanged information via email, and routinely discussed progress and findings with the TAB and JPL personnel. The result was an in-depth understanding and analysis of the NASA LLIS system and the JPL Lessons Learned Committee process for inputting lessons into LLIS. We also analyzed the LLIS data, and conducted human factors studies of the LLIS interface.

NASA/JPL. We initially consulted with the TAB to identify a current NASA program/project test case on which to conduct lessons-learned implementation assessment, and determine application challenges. As recommended by TAB members, we focused on the current JPL processes for managing and implementing projects as the way to infuse lessons learned from past experiences. At JPL it was clear from the findings on the Mars '98 failures that there were deficiencies in defining consistent processes for project implementation. The reviewers saw project management teams inventing and using different approaches and processes to some of the key issues such as communications. This, they concluded, led to high risk and eventually failures. JPL has since undertaken a strong effort to develop processes (and/or practices) that have the lessons infused such that if a team effectively follows a process then it is employing the lessons learned automatically. A second key contact for this study was the JPL Office of Safety and Mission Success (OSMS). The OSMS is intended to reduce the risk and enhance the probability of mission success for both JPL projects and tasks, for both hardware and software, throughout the lifecycle of the work.

Industry and Special Industry-University Cooperation. Collaborations with industrial representatives on the TAB consisted of extensive email exchanges, telephone interviews, and personal meetings. Their advice was solicited on the direction of program, recommendations on case studies, progress review toward stated objectives, and referrals to other company personnel for lessons learned data. Lockheed Martin Space Systems Company (LM-SSC) has a particularly strong interest in this work being conducted for the Universities Space Research Association (USRA). The thrust of this research coincides with critical areas of interest for Lockheed Martin. LM-SSC provided assistance on this project in the form of personnel interviews and questionnaires made available to this project because of the belief that it will be of mutual benefit. LM-SSC has funded projects planned for 2005 and beyond that will provide a continuous link to this work and research. A goal of LM-SSC is to leverage this research with additional internal work that should enhance the value of the product. LM-SSC believes that the innovations expected to come from this particular research project can become an important enhancement to their product lines in project management.

Academic. Collaborations with the academic representatives on the TAB consisted of extensive email exchanges, telephone discussions and personal meetings. Their advice was solicited on the direction of program, quality of the research, and progress review toward stated objectives.

Background and Technical Approach

NASA Program and Project Management Guidance. NASA maintains an extensive list of publications under its Program Management directives (8000 series). Among these, several documents stand out as relevant to this effort: NASA Procedural Requirements (NPR) NPR 8000.4, Risk Management Procedures and Guidelines, NASA Policy Directives (NPD) NPD 8621.1H, NASA Mishap and Close-Call Reporting, Investigating, and Recordkeeping Policy, and NPD 8700.1A, NASA Policy for Safety and Mission Success. NASA has established a comprehensive policy and guidelines for accomplishing NASA programs and projects. The implementing NASA Procedure Guideline (NPG), NPG 7120.5B, NASA Program and Project Management Processes and Requirements, establishes how programs and projects are to be conducted consistent with agency strategic planning. In concert with these guidelines, managers must meet the requirements of multiple stakeholders and customers. The NASA's Process Based Mission Assurance (PBMA) model provides a structured approach to meeting the combined safety, mission assurance, and risk management requirements within program/project management across the program or project lifecycle. The PBMA model builds upon the previously established NASA models of systems engineering and program/process management and complements existing NASA models.

NASA's Lessons Learned Information System (LLIS). Many organizations use lessons learned systems to capture prior knowledge. An elaborate list of lessons learned systems worldwide can be found at http://home.earthlink.net/~dwaha/research/lessons.html, that includes many examples such as:

- FAA
- NASA Aviation Safety Report System
- Licensee Event Report (NRC)
- DoD (Army, Navy, etc.), DoE
- Contractors (Lockheed Martin, Northrop Grumman, etc.)

In addition to the repository of NASA lessons learned in LLIS, there are other NASA knowledge repositories such as the one maintained by Ares Corporation called Process Based Mission Assurance (PBMA)—Knowledge Management System (KMS) (http://pbma.hq.nasa.gov/pbmamaster.html). This repository includes some 200 best practice planning documents, over 110 interviews or "video nuggets" capturing the tacit knowledge of NASA and aerospace industry experts, and over 1,000 links to NASA, DOD, DOT, DOE, NIST and other lessons learned resources.

A report made to the Subcommittee of Space and Aeronautics by the General Accounting Office, "Better Mechanisms Needed for Sharing Lessons Learned," (GAO-02-195) is valuable to this research as it analyses the LLIS, and presents methods and suggestions for improvement. This report provides insight into the present state of affairs within the enterprise. The report also discusses cultural resistance and the attitudes of those working within NASA. Another important issue this report addresses is the need for an effective and well defined management structure, and authority by the senior executives of NASA to take initiative and develop a knowledge management effort at NASA, that has proven to be successful at other large organizations. The key findings of this report are:

- There is no assurance that lessons learned are being applied;
- There is unfamiliarity with lessons learned across centers/ programs;
- Cultural barriers inhibit sharing, capturing, and submitting lessons;
- There is an apparent lack of support from agency leaders;
- Success in industry comes from commitment to knowledge sharing.

An earlier report submitted to the Subcommittee of Space and Aeronautics by the General Accounting Office (GAO-01-1015R) was basically a lead-in to the report cited above. This earlier particular report presents survey results of different project/program managers on the topic of lessons learned sharing. This report is significant in its insight into NASA management and potential barriers hindering the complete and successful implementation of the LLIS. This study solicited views of NASA program and project managers about various topics such as:

- Collection, sharing, and application of lessons learned
- Strengths and limitations of NASA's lessons learned processes, procedures, and systems, including NASA's Lessons Learned Information System (LLIS)
- Challenges or barriers to the sharing of lessons learned
- Suggested areas of improvement

A very revealing finding of this study is that, whereas respondents were very familiar with lessons learned from their local projects and programs, this familiarity quickly dissipates among centers.

Lessons-Learned Literature Review and Analysis. An excellent paper by Aha and Weber (2000) discusses effective design of intelligent lessons learned systems. The paper discusses the different issues in implementing a lessons learned system in general in any organization. Another applicable study was conducted at the University of Alabama, Huntsville, by William W. Vaughan studying the technical standards at NASA prepared for the SpaceOps 2002 Conference in association with the World Space Congress 2002, Houston, Texas. This article discusses how the NASA standards were designed and when the major turnarounds were achieved. It also describes the different implications the technical standards have on different sectors of NASA—one of them being capturing and preserving the engineering lessons learned and best practices in industry. This work enables correlations between technical standards and their effect on the implementation of knowledge management. It also provides some insight into the development of the LLIS and the underlying assumptions made at the start, allowing us to determine whether or not they still hold. This article discusses the importance of lessons learned and best practices, the difficulty in finding relevant lessons learned while engaged in an engineering project, and NASA's efforts to alleviate this difficulty. The article contains recommendations for more expanded cross-sect oral uses of lessons learned with reference to technical standards. This article further discusses the links between technical standards and lessons learned so that they can be absorbed into a system as soon as is practically possible. This research provides a new direction of thinking for lessons learned implementation.

NASA participated in a workshop organized by the European Space Organization (ESA), ESTEC, Noordwijk, the Netherlands, that featured many presentations on lessons learned systems. Much of the work presented on lessons learned was being conducted in Europe. The conference was comprised of different European space agencies, and was mainly for the purpose of evaluating and informing of the use and advantages of a type of ALERT system that enables all the organizations to track different types of failures at different levels, e.g., operations and defective manufacture even at the supplier level. This work provides a perspective on how others are addressing lessons learned systems and ideas for improvement. This report has other references to journals and other publications useful for lessons learned research.

It is interesting to note that the NASA Office of Logic Design has created its own webpage for archiving lessons learned within the agency. This web page clearly shows there is an effort within NASA to promote lessons learned and encourage people to come forward with their findings. The problem with this approach is that the project managers and engineers may not want to come forward with lessons learned for fear they may be stigmatized as a result of the failure reported, that in turn prevents the effective sharing of knowledge. An interesting article was written by an ex-employee of NASA (Jerry Madden, retired, Goddard Space Flight Center) in which he describes the 100 most important lessons learned for project managers in NASA (http://appl.nasa.gov/ask/issues/14/practices/ask14_lessons_madden.html). His article discusses a broad range of topics, from not taking the working environment lightly to how to manage budgets and handle the workforce effectively. This article sheds some light onto different aspects of the NASA work culture.

Recently, a 2004 survey of NASA culture published at http://www.nasa.gov/about/highlights/culture_survey.html highlighted some key themes:

- Overall, NASA has strong work-group level teamwork and communications;
- Overall, NASA has improvement opportunities in upward communications about safety and in employee perceptions about the extent to which the organization cares about employees;
- Overall, there is little variation among NASA locations, among offices within NASA locations, or between programs.

The Executive Summary of the report also pointed out that:

- NASA personnel are committed to safety, but NASA's culture

is not fully supportive of safety; open communication is not the norm, people are not fully comfortable raising safety concerns to management.
- People do not feel respected by the organization—technical commitment does not translate into organizational commitment.
- Excellence is treasured in technical areas but not in management, support, or communications.
- Integrity is understood, but there are mixed signals from management about raising issues.

Other excellent references on lessons learned include Anbari, et al. (2003), Gill and Garcia (2002), Johnson, et al. (2000), Secchi (1999), Sells (1999), and Vandeville and Shaikh (1999).

Case Study on NASA-Related Lessons Learned Research Results

We researched NASA's LLIS contents for its database and historical evolution. We traced its early development in Code Q with limited capabilities, to its assignment to HQ, Chief Engineer's office and expanded use, and its expected continued development to a knowledge management system—the NASA Knowledge Network (NEN). We further examined and graphically reviewed the data for each Center in order to determine trends and study variations in the lessons learned approval process. A summary of our results is shown in Exhibits 1–4. Exhibit 1 shows the frequency of time to approval and indicates that the approval time for lessons learned can vary from as few as six months to as much as four years or more. Upon further review, we determined that this variation was strongly center-dependent as shown in Exhibit 2. JPL prioritizes each lesson learned candidate and then assigns resources on the basis of relative priority. Hence, a topic assigned a high priority because of high potential impact on a flight project is dealt with more expeditiously than one of lower priority. This prioritization assures that the approval lag is only as short as it needs to be. We further found that the entry of lessons learned into the system seemed to correlate highly with mishap events, as shown in Exhibit 3. The encouraging result was that the approval time has been steadily decreasing for all centers, and is currently approaching 90 days, as shown in Exhibit 4.

JPL Lessons Learned Process. This study's success story in lessons learned is characterized by JPL's progress from the Mars Climate Orbiter and Mars Polar Lander mishaps in 1999 to the Mars Explorer successes in 2003. Beginning with the creation of the Mars Climate Orbiter (MCO) Mishap Investigation Board (MIB), JPL has been focused on implementing cultural and system change. The MCO Phase I Report, released in November 1999 identified root causes and factors contributing to the MCO failure. The "Report on Project Management in NASA" by the MIB in March 2000 recommended a "culture shift" by focusing on four categories, or themes, that in addition to the Mars Program at JPL were also "applicable to other programs throughout NASA" (p. 36). The four themes were people, process, execution, and technology.

The major noteworthy actions and outcomes related to lessons learned include:
- Culture change based on lessons learned via development of systematic new project and process management tools and practices
- Clarification of major responsibilities of project managers concerning project quality, schedule and budget, and understanding of interactions and trade-offs
- Codifying and standardizing practices, and development of procedures
    - Corrective Action Notices
    - Design, Verification/Validation and Operations Principles for Flight Systems (D-17868)
    - Development of the Flight Project Life-Cycle concept and its enforcement of its multiple reviews
        - Concept Review, Preliminary Mission & System Review; Project/System Preliminary Design Review; Project/System Critical Design Review, Assembly, Test, and Launch Operations Readiness Review; Mission Readiness Review; Post Launch Assessment Review; and Critical Events Readiness Review
    - Flight Project Practices (Revision 5, 2/27/03)

We then interacted with several members of the JPL Lessons Learned Committee (LLC), participating in numerous meetings including attending a meeting of the LLC itself. The LLC manages the lessons learned process and input to the LLIS for JPL projects. JPL has been conducting such procedures and training for the past three years, and has benefited from the success of the lessons learned process and culture change. Our interactions with and analysis of the JPL Lessons Learned Committee indicates that JPL has successfully implemented a comprehensive lessons learned process addressing technical and cultural change challenges.

NASA is now placing more emphasis on lessons learned, and NASA released in March NPR 7120.6 The NASA Lessons

Exhibit 1. Frequency of Time to Approval

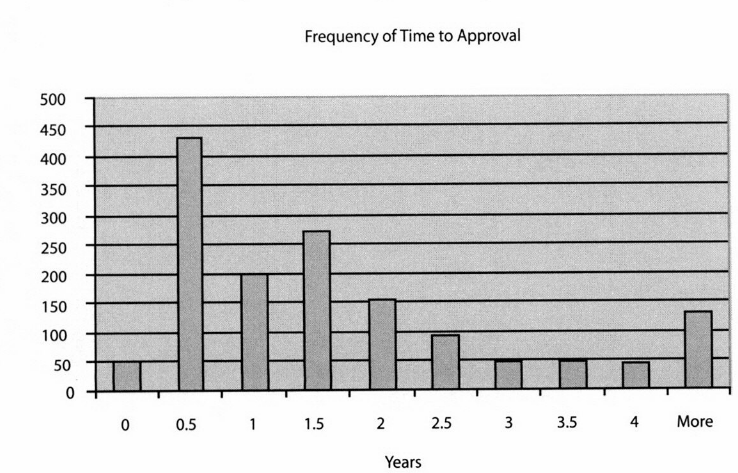


Exhibit 2. Variation in Approval Time by Center

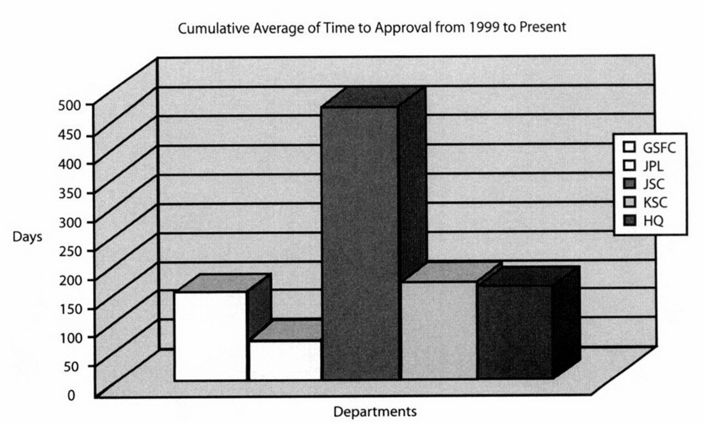


Exhibit 3. Correlation of Lessons Learned Submittal and Approval with Mishap Events

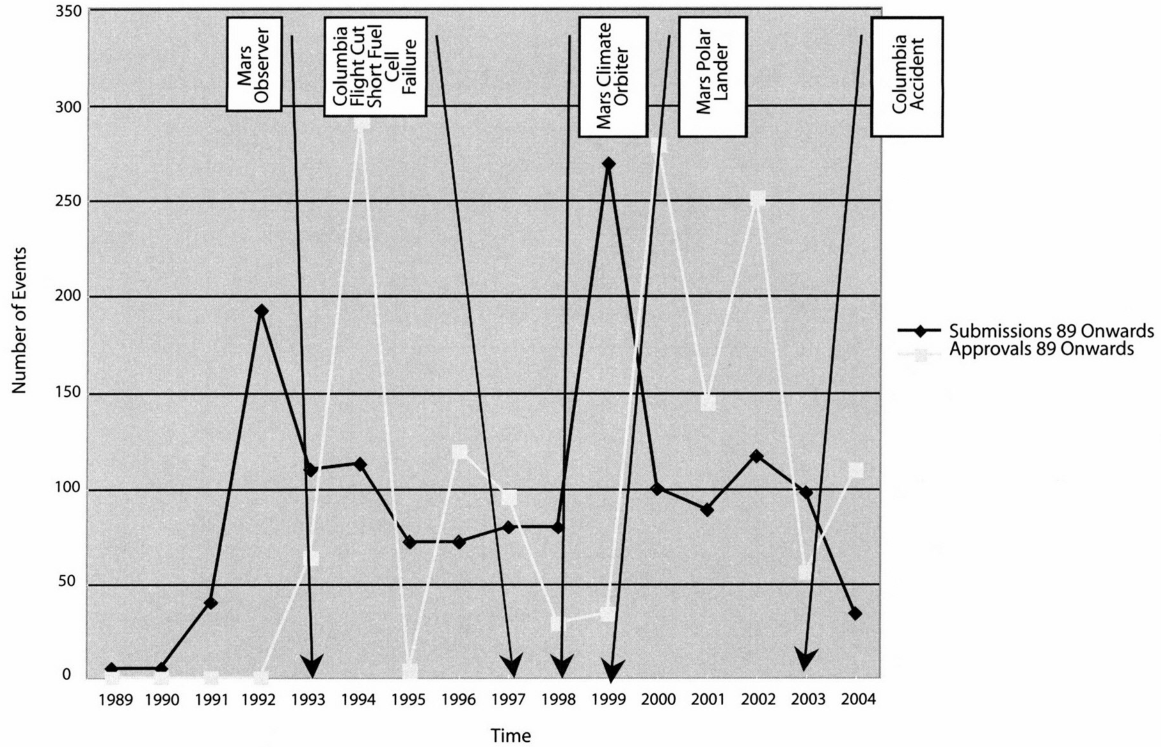
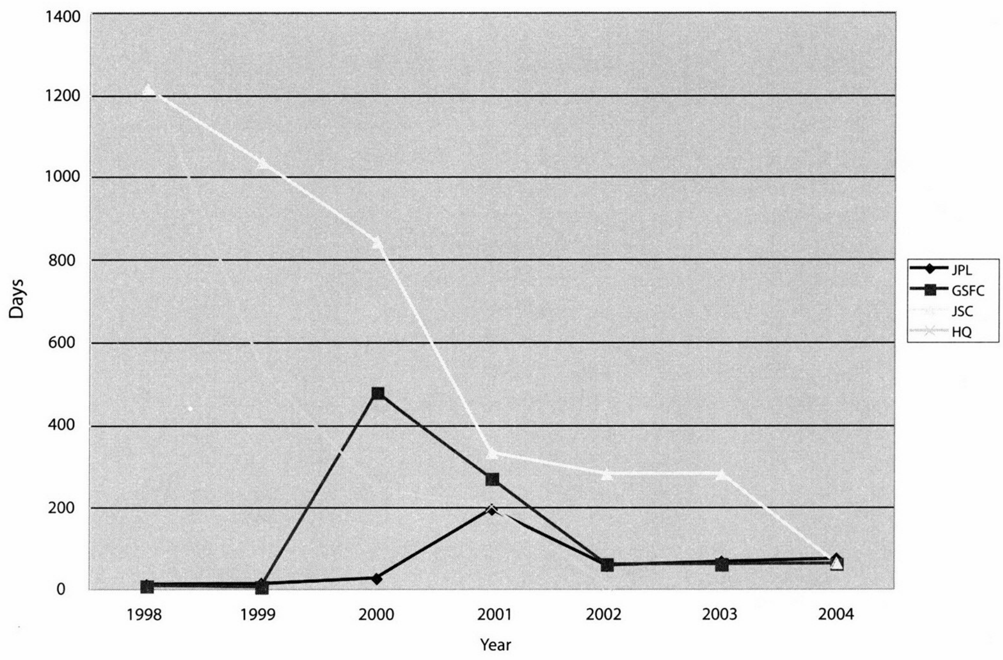


Exhibit 4. Progress in Reducing Approval Time

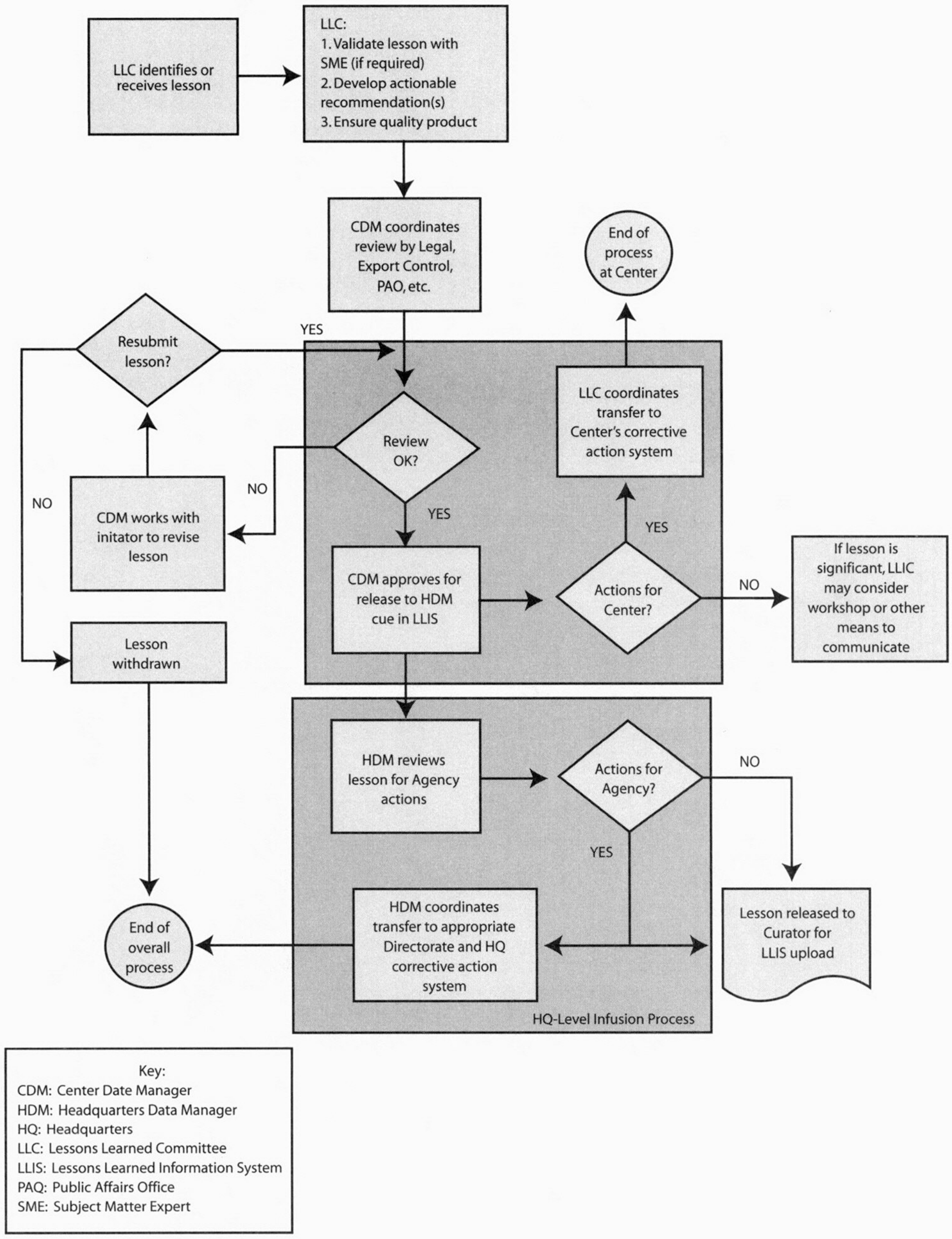


Learned Process, that mandates a formal NASA-wide lesson learned process. The process flow chart is shown in Exhibit 5. An important facet of this requirement document is that NASA centers implement a closed-loop process in order to infuse lesson learned into business practices.

The results of these interactions and analyses indicate that NASA-wide lessons learned culture change is possible and under way. Executive-level, systems-based lessons learned guidance and support is critical for NASA-wide implementation of NPR 7120.6. This should facilitate the implementation of the NASA-wide, standard, system-level lessons learned template, to counter the development and use of alternative processes and protocols.

Our research further led us to a parallel effort at JPL to increase the effectiveness of the LLIS in its upcoming upgrade to a knowledge-based system, currently named the NASA Knowledge Network (NEN). The NEN will provide a new portal with new tools and capabilities for improved searching and access to information, such as metadata insertion and mining. A flow chart of the new system is provided in Exhibit 6. NEN is in the final stages of beta testing before release. It will lead to a modernization of the LLIS with current information technologies, and address IT aspects of lessons learned. It will, however, only have limited address of system-level issues of the lessons learned process.

Exhibit 5. NASA Lessons Learned Process Flow Diagram (Figure A-1 from NPR 7120.6)



Summary and Conclusions for Project Management

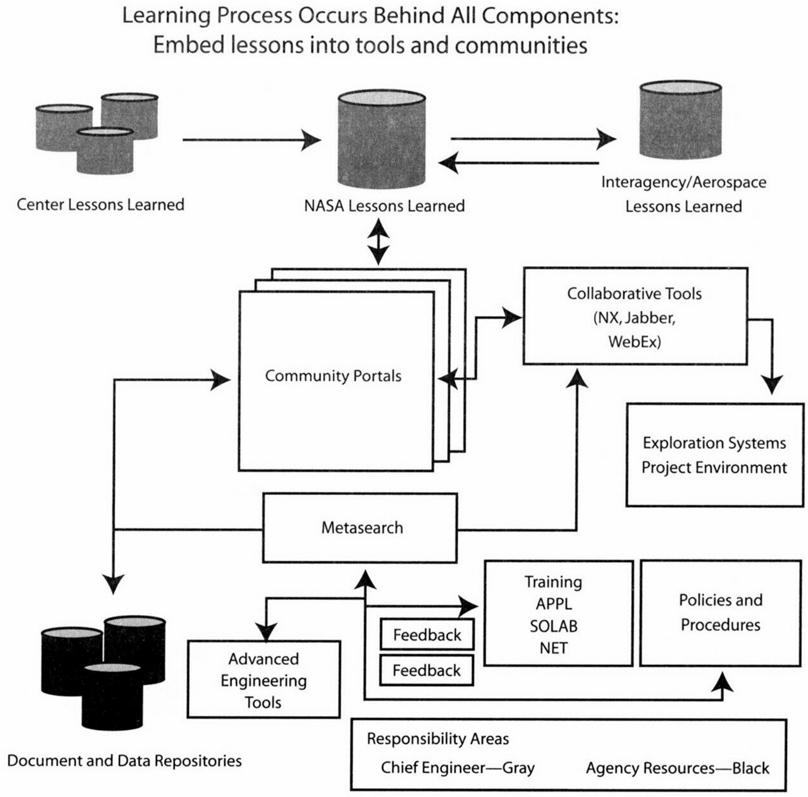
NASA mishap investigation boards have identified the numerous technical lessons learned from accident events, and have identified the need for NASA culture change in order to reap the benefits of these lessons. To investigate this, we conducted research and analysis of the data in the NASA LLIS, and conducted extensive collaborative discussions with NASA personnel and this project's TAB. The results of this study indicate that culture change in order to implement lessons learned processes and achieve their benefits has been evolutionary and center-dependent. Our interactions with and analysis of the JPL Lessons Learned Committee indicates that JPL has successfully implemented a comprehensive lessons learned process addressing technical and cultural change challenges.

Based on the results of this effort, we conclude that lessons learned culture change is possible and underway. NASA's NPR 7120.6 will provide executive-level, systems-based lessons learned guidance and support critical for effective implementation. This includes the implementation of a standard, system-level lessons learned template across the organization, to counter the development and use of alternative processes and protocols.

This study focused on three of the most frequently cited recurring causal factors for project failures: poor team communication, inadequate consideration and implementation of systems engineering principles for complex/large scale projects, and inadequate management review process in all life-cycle phases of the project. These areas are applicable in a wide range of programs and project management conditions. Key findings in each of these areas include:

- Communication Between Centers
  - General inability to effectively collect and disseminate lessons learned
  - Project managers lack awareness of lessons being learned in other centers
  - Lessons are learned mainly through group meetings and project reviews
- Project Review and Management Processes

Exhibit 6. NASA Engineering Network Prototype Study (Courtesy of JPL)



- Importance and priority of collecting, sharing, and use of the lessons as a key component of NASA management goals and objectives is not clear
- Incentives, resources, and appreciation of adding to/referring to lessons learned are not present
- The perception that discussion of problems is not welcome, or problems are too easily dismissed, reduces lessons learned contributions

- Implementation of Systems Engineering Concepts
  - There are redundant/exclusive/varied systems for sharing lessons within NASA despite the existence of LLIS
  - Different methods/processes/systems exist for review and approval of lessons learned for input into LLIS
  - Lessons learned systems engineering design lacks incentives and feedback

This study's success story in lessons learned is characterized by JPL's progress from the Mars Climate Orbiter and Mars Polar Lander mishaps in 1999 to the Mars Explorer successes in 2003. The major noteworthy actions and outcomes related to lessons learned include:

- Culture change based on lessons learned via development of systematic new project and process management tools and practices
- Clarification of major responsibilities of project managers concerning project quality, schedule and budget, and understanding their interactions and trade-offs
- Codifying and standardizing practices, and development of procedures.

The findings from our research and collaborative discussions with NASA personnel and the study's technical advisors indicate further progress is needed to overcome challenges in three areas:

- Organizational
  - Management-driven initiatives and systems-based processes are needed to effectively collect and share lessons
  - The value and importance of lessons learned to organizational goals needs to be emphasized and put in practice at all centers
- Tools and System Processes
  - There is a need for better lessons learned information technology tools and project management lessons learned review processes and check points
  - A systems-based approach should include built-in incentives, check points, and consistency
- Cultural
  - The notion that lessons learned are not apt, relevant, or useful, and that there is insufficient time for lessons learned input to system or use from the system
  - Communication of lessons learned among centers and HQ is incomplete, leading to inconsistent sharing, learning, and application of lessons

Again, these findings are applicable across a wide range of P/PM circumstances.

One of the major barriers to lessons learned utilization is efficient access to relevant information. Our findings indicate that a new knowledge management system is in the final stages of beta testing before release to upgrade the LLIS. The new system will modernize the LLIS with current information management tools and technologies, addressing the information technology aspects of LLIS. It will, however, only have limited address of system-level issues. The new knowledge management system will provide a much-needed upgrade of the LLIS. Its use can facilitate culture change as part of a systems-based approach. Human factors-based human-computer interface design significantly enhances the usability, acceptance, and effectiveness of such a system. Human factors perspectives and advanced information management technologies offer significant potential for addressing culture change barriers, enhancing the usability of knowledge management systems and increasing the effectiveness of the overall lessons learned process.

References

Aha, D.W., and R. Weber, Intelligent Lessons Learned Systems: Papers from the AAAI Workshop, (Technical Report WS-00-01), AAAI Press (2000), at http://www.kmlab.fiu.edu/Papers/Intelligent%20Lessons%20Learned%20Systems.pdf.

Anbari, F., A. Bradley, J. Cable, W. Donahue, J. Drueen, P. Jones, S. Lee, D. McCarthy, J. Niehoff, H. Reed, P. Roming, and P. Weiblen, "Best Practices and Lessons Learned Working Group Report Panel Participants," CPMR Workshop (December, 2003), at http://cpmr.usra.edu/workshops/niehoff.ppt.

Construction Industry Institute, *Modeling the Lessons Learned Process, Technical Report Research Summary 123-1*, CII, Modeling Lessons Learned Research Team (1997).

General Accounting Office, "Better Mechanisms Needed for Sharing Lessons Learned," Report to the Subcommittee on Space and Aeronautics, Committee on Science, House of Representatives (GAO-02-195), visited at http://www.gao.gov/new.items/d02195.pdf.

Gill, P. S., and Garcia, D., "NASA Technical Standards Program and Implications for Lessons Learned and Technical Standard Integration," prepared for the SpaceOps (2002) in Association with the World Space Congress 2002, http://www.spaceops2002.org/papers/SpaceOps02-A-T5-24.pdf.

Johnson, C., L. Birnbaum, R. Bareiss, and T. Hinrichs, "War Stories: Harnessing Organizational Memories to Support Task Performance," Intelligence: New Visions of AI in Practice, 11:1 (2000), pp. 17–31.

Sary, C., and W. Mackey, "A Case-Based Reasoning Approach for the Access and Reuse of Lessons Learned," *Proceedings of the Fifth Annual International Symposium of the National Council on Systems Engineering* (1995), pp. 249–256.

Secchi, P. (ed.), "Workshop on Alerts and Lessons Learned: An Effective Way to Prevent Failures and Problems," Technical Report WPP-167, European Space Agency, www.estec.esa.nl/CONFANNOUN/99c06 (1999).

Sells, A., Proceedings of the Society for Effective Lessons Learned Sharing's Spring Meeting, (1999), www.tis.eh.doe.gov/ll/sells/proceedings399.htm.

Vandeville, J.V., and M.A. Shaikh, "A Structured Approximate Reasoning-Based Approach for Gathering 'Lessons Learned," *Systems Engineering, 2*:4 (1999), pp. 242–247.

Weber, R., D.W. Aha, L.K. Branting, J.R. Lucas, and I. Becerra-Fernandez, "Active Case-Based Reasoning for Lessons Delivery Systems," Proceedings of the Thirteenth Annual Conference of the International Florida Artificial Intelligence Research Society, AAAI Press (2000).

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