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Failure to Follow Written Procedures

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16. Abstract

Most tasks in aviation have a mandated written procedure to be followed specifically under the Code of Federal Regulations (CFR) Part 14, Section 43.13(a). However, the incidence of Failure to Follow Procedure (FFP) events continues to be a major issue in aviation maintenance. This report details the results of Phase 1 of a two phase effort. In Phase 1 we used over 100 literature sources to identify human factors causes of FFP events, developed a classification system of FFP events (TAPES), categorized 154 FFP events reported in the Aviation Safety Reporting System (between 1999 and 2015) and 94 National Transportation Safety Board Accident reports (between 2005 and 2015), and identified the common challenges facing aviation maintenance operators. Results showed that the top three areas of concern were the validity and availability of the procedure documentation, the difficulty of the task being performed, and the organizations social rules/norms. Phase 2 of this work will apply the developed classification system to FFP events taken from semi-structured interviews of aviation maintenance personnel. Results of Phase 2 will identify best practices for mitigation FFP events in aviation maintenance environments.

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LIST OF ACRONYMS

CRM..Crew Resource Management
FAA .... Federal Aviation Administration

EXECUTIVE SUMMARY

Most tasks in aviation have a mandated written procedure to be followed specifically under the Code of Federal Regulations (CFR) Part 14, Section 43.13(a). The rule is clear: use a manual for all work. However, the incidence of FFP events continues to be a major issue in aviation maintenance, despite considerable research over many years. A review of the issue by Drury and Johnson (2013) noted that *"Procedure not followed" re-occurs with depressing regularity in incident and accident reports in aviation*." Recent Federal Aviation Administration (FAA) studies have confirmed this finding. For example, Banks, Wenzel, Drechsler, and Crayton (2013), reviewed over 650 reports from the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS), and compiled and reviewed over 40 reports from both the public literature and from FAA Technical reports over the last 25 years.

In 2015, a Failure to Follow Procedures (FFP) research effort across aviation maintenance operators was commissioned by the FAA to (a) examine the primary and contributing factors associated with aviation maintenance operators failing to follow procedures (called Phase 1), and (b) develop mitigation strategies for reducing FFP events (called Phase 2). This report details the results of the Phase 1 effort, which consisted of three tasks.

Task 1

Identify the human factors causes of FFP events. Task 1 resulted in the development of a classification system called TAPES, which was based on the 5 human factors categories most relevant to the classification of FFP events:

1. The maintenance task being performed (T)
2. The actor(s) who are performing the task (A)
3. The written or electronic procedure document used for the task (P)
4. The environmental context in which the task was performed (E)
5. The interactions between people in the broader organization beyond the immediate actor, called social (S).

Each of the 5 categories were then broken into different sub categories, which are documented in further detail within the body of this report.

Task 2

Categorize the human factors associated with FFP events reported in the ASRS (154 events between 1999 and 2015) and National Transportation Safety Board (NTSB) databases ASRS (94 events between 2005 and 2015). For the purposes of this research effort, a distinction was made between a willful disregard for following procedures and an actor's attempt to follow procedures. While the former is reported, TAPES was used to classify only the latter. For the ASRS data base the top 3 categories were

1. <u>Procedure Documentation</u> (58%) - The documentation was not readily available, not up to date, or poorly written.
2. <u>Task being performed</u> (14%) - The actor was having difficulty with the maintenance task and an error was made.

3. Social (12%) - The organization's inefficiencies in the management of work, norms governing how work is done, and the time pressures associated with work.

For the NTSB database the top 3 categories were

1. Task being performed (25%) - The actor was having difficulty with the maintenance task and an error was made.
2. Social (12%) - The organization's inefficiencies in the management of work, norms governing how work is done, and the time pressures associated with work.
3. Procedure Documentation (6%) - The documentation was not readily available, not up to date, or poorly written.

However, 32% of the NTSB records contained insufficient information for the purposes of classification. This is in contrast to the ASRS data set, which had only 1% of records of the records containing insufficient information. Thus the ASRS results drove the search.

Task 3

A list of the common challenges facing aviation maintenance operators was created in Task 3 as they related to the top 3 categories identified by TAPES (Table 7). An example from each category includes:

1. Procedure Documentation - Procedures may not be validated because of time constraints and perceived cost considerations. Also the task may not be available to observe while the procedure is being written.
2. Task being performed - Training may be cursory or poorly-implemented as it is not seen as a priority.
3. Social - As management changes and the maintenance becomes more competitive, there will always be pressures on mid-level managers and end-users to sacrifice the procedure following policy to a norm of expediency.

It is recommended that the results of Phase 1 be used in conjunction with the current Safety Management System requirements governing aviation maintenance operations. While larger businesses associated with providing aviation maintenance are likely to benefit from the integration of this effort along with other advances in maintenance research, it is unlikely that small business will be motivated to do so. Thus, the Phase 2 effort focused not only on the development of best practices for reducing FFP events but how to best communicate that information across a range of aviation maintenance operations.

FAILURE TO FOLLOW WRITTEN PROCEDURES

WRITTEN PROCEDURES IN AVIATION MAINTENANCE METHOD

Most tasks in aviation have a mandated written procedure to be followed specifically under the Code of Federal Regulations (CFRs) Part 14, Section 43.13(a). The rule is clear: use a manual for all work. However, as Drury and Johnson (2013) noted, *"Procedure not followed* re-occurs with depressing regularity in incident and accident reports in aviation." Johnson and Avers (2014) listed Failure to Follow Procedures (FFP) as the number one cause of maintenance mishaps. An FAA study regarding major malfunctions that occurred within 90 days of a heavy maintenance check found that the number one reason for malfunction was the failure to comply with maintenance documentation (Johnson & Watson, 2001). As Rankin (2008) noted, failure to follow instructions was the primary cause of maintenance errors reported through Boeing's Maintenance Error Decision Aid (MEDA). This non-following of written procedures is not limited to aviation maintenance, as Landry, Jacko, and Coulter (2006) showed for pilots. Walker (2005) reported similar findings in an analysis of offshore oil rig accidents. Overall, 31% of accidents involved maintenance procedures, 55% of those were classified as FFP. Clearly, FFP is a problem that is common across industries using procedures and a problem that is not decreasing with time.

With this background, it is not surprising that the FAA's focus goes beyond merely listing FFP as a cause of accidents. Rather, detailed reasons beyond the causes are sought in order to properly address and mitigate such events. In Schroeder et al. (*in press*) a rationale was provided such that, a detailed review and analysis of the available literature on FFP could be conducted. This report is organized into three separate but related tasks. In Task 1, we developed a classification system for FFP events based on the extensive literature (See Task 1 for references) both within and beyond the aviation maintenance domain. In Task 2, we used this classification system to analyze two disparate databases of incidents/accidents to identify frequencies of the various factors contributing to FFP events. In Task 3, we integrated the database analyses, findings from the technical literature, and the classification scheme to derive a priority listing of CFs. These priorities and CFs were re-cast into Good Practices to be used to reduce Failure to Follow Procedure (FFP) events.

Task 1

Understanding the Processes Involved in Procedures

The purpose of Task 1 was to conduct a detailed review of the literature on FFPs to identify previously employed interventions, the timing of such interventions, and their resulting outcomes on aviation maintenance FFP events.

The FAA's early work on aviation maintenance and inspection errors following the Aloha Flight 243 accident in 1988 generated considerable human factors research and applications through the Office of Aviation Medicine. The Aloha Boeing 737 lost part of its upper fuselage through a series of inspection and management failures, highlighting the possibility of airframe cracks that escaped maintenance inspection that resulted in catastrophic failure in the air. As part of this work Drury, Prabhu, and Gramopadhye (1990) performed a large number of task description/task analysis activities in the area of visual and non-destructive inspection, producing a generic task description of the inspection process. This was later expanded to include maintenance procedures as well as the inspection alone (Drury, 2005). However, the approach taken for the current work looked beyond the function/task description of the final performer to explore the entire context of how work is performed. In the current literature analysis, many of the errors, issues, CFs, Challenges, and Best Practices involve processes beyond the final use of a procedure by the inspector or AMT. The most common examples from the literature included:

- Procedures are not used because …they are out-of-date
- [Standard Operating Procedures] are typically written to fulfill an organizational requirement rather than to provide utility to technicians.
- … [procedures] have not been written to cover the task at hand.
- …[Organizational Policy] was unresponsive to employee's suggestions

These, and many more, have been seen as CFs to FFP events, and thus need to be addressed in a comprehensive endeavor to reduce the incidence of adverse events. To do this, a literature review was conducted for the purpose of identifying CFs and developing a classification scheme for FFP event reports.

Task 1 Method

Literature Relevant to Failure to Follow Written Procedures (FFP)

Two main sources of literature were accessed for this task:

- Literature previously compiled by the CAMI Human Factors team as part of the overalleffort on evaluating FFP events
- Literature compiled both from much of the prior work in the area by C. G. Drury at SUNY Buffalo, and direct searches based on *Ergonomics Abstracts* and *Google Scholar*. In addition, Applied Ergonomics Group Inc.'s (AEG's) experience and contacts in the fields of chemical processes, chemical weapons demilitarization, nuclear power plants, and the UK's Health and Safety Laboratories has provided additional reference material beyond AEG Inc.'s own experience in procedure and documentation design in aviation maintenance.

The combined literature review process yielded over 100 books, reports, published papers, conference proceedings papers and URL sites relevant to the issues and/or contributing conditions to FFP events.

The first analysis grouped information under the following headings:

- **FFP Scenarios:** Vignettes of Task, Operators, Machines, Environment and Social conditions (TOMES) that had led to actual FFP events, usually events with unwanted outcomes or for which recovery was required. A typical scenario is "User tries but fails to follow procedure as user misses performing one task."
- **FFP CFs:** Reasons the authors found, or postulated, for the occurrence of the FFP event. These could be at any level of depth of abstraction, or at multiple hierarchical levels. A typical Contributing Factor is "Un-validated/prototyped procedure."
- **FFP Good Questions:** Where the main focus of literature was on evaluating or analyzing FFP events, the issues were typically expressed as investigative questions. Because these questions implied CFs, they could be re-written in Contributing Factor form. A typical Good Question is "Do users have an appropriate and known plan to improve or optimize procedures?"

- **FFP Best Practices:** Where a piece of literature made specific recommendations, these were classified as Good Practices, or the more common term Best Practices. They often implied CFs, but presented these in the form of solutions or mitigations. A typical Good Practice is "Procedures are available when needed and users can always find the correct procedure."
- **FFP Challenges:** Possible reasons why good/best practices were not followed by the AMT. They represent the negative side of Best Practices. A typical challenge is "Need a process to improve response time for operator issues."

Task 1 Results

The Classification Scheme

The next step was to organize and classify literature grouped into the FFP Scenarios heading into coherent patterns. For example, one set of reasons for FFP is that the procedures provided are not the best way to perform a task. Examples of this from four literature sources are:

- A procedure that is ponderous and is perceived as increasing workload, and/or interrupting smooth flow of tasks, will probably be ignored.
- Where rules are perceived as overly restrictive, skilled individuals may think they can violate the rules with little risk to their safety, and the resulting violations are likely to become routine. Procedures not used because they are difficult to use.
- *Unintentional violations* arise from procedures that are either too difficult for people to follow, errors arising from not using the manual, or incorrectly applying the procedural steps (out of order, did not reference manual, etc.).

Therefore, all of the examples above represent a procedure that is difficult to follow, for various reasons, and can thus become part of an overarching scenario or Contributing Factor.

Three classification schemes were tested on these data to determine which categories should be included in the developed schema. The first were the empirical set of scenarios from the UK's Health and Safety laboratories, the second was the 5 Ps system developed by CAMI and discussed by Hollomon, Drechsler, and Crayton (2015) , and expounded on in a 2017 report (Schroeder et al., *in press*), and the final was the characterization of Violations, originally found in Reason (1997) and seen in the Health and Safety Executive's (HSE's, 1995) *Improving Compliance* document and the website skybrary (www.skybrary.aero) in its document *Assessing Procedures.* From these, and specific examples of aviation maintenance FFP events, (e.g., Pearl and Drury, 1995, pp 127-165) noted, "Mechanics do not use workcards for frequently performed checks, i.e., A- checks and below. They have memorized these checks, 'gaining a feel for items to check' through frequent repetition." Boring, Gertman, and Le Blanc (2011, pp 1720-1724) noted, "Performing steps or substeps in the wrong order…" the new classification schema was created that included both a bottom-up classification (e.g., HSE, 5 Ps schemes above) and top-down classification (e.g., Reason's Violations) and can be seen in Table 1.

Table 1. Final TAPES Classification Schemes for CFs

TAPES Classification	Definition
Task	The actual task performed by the actor
Actor	Those involved in conducting aviation maintenance tasks, including the AMT, MX supervisor, job inspector
Procedure Document	The written or electronic document used by the actor to perform the task
Environment	The conditions surrounding the task to be performed, including physical layout, thermal / visual environment etc., excludes the documents used
Social	The interactions between people in the broader organization beyond the immediate actor

As a guide to better understand the role each CF plays in an overall classification, factors were tabulated through classifying databases such as ASRS in much the same manner as Wenner and Drury (2000) did for ground damage incidents in aviation. Once completed, a combination of procedural deviations (also called scenario outcomes) and contributing factors were added to the developed classification schema (Figure 1).

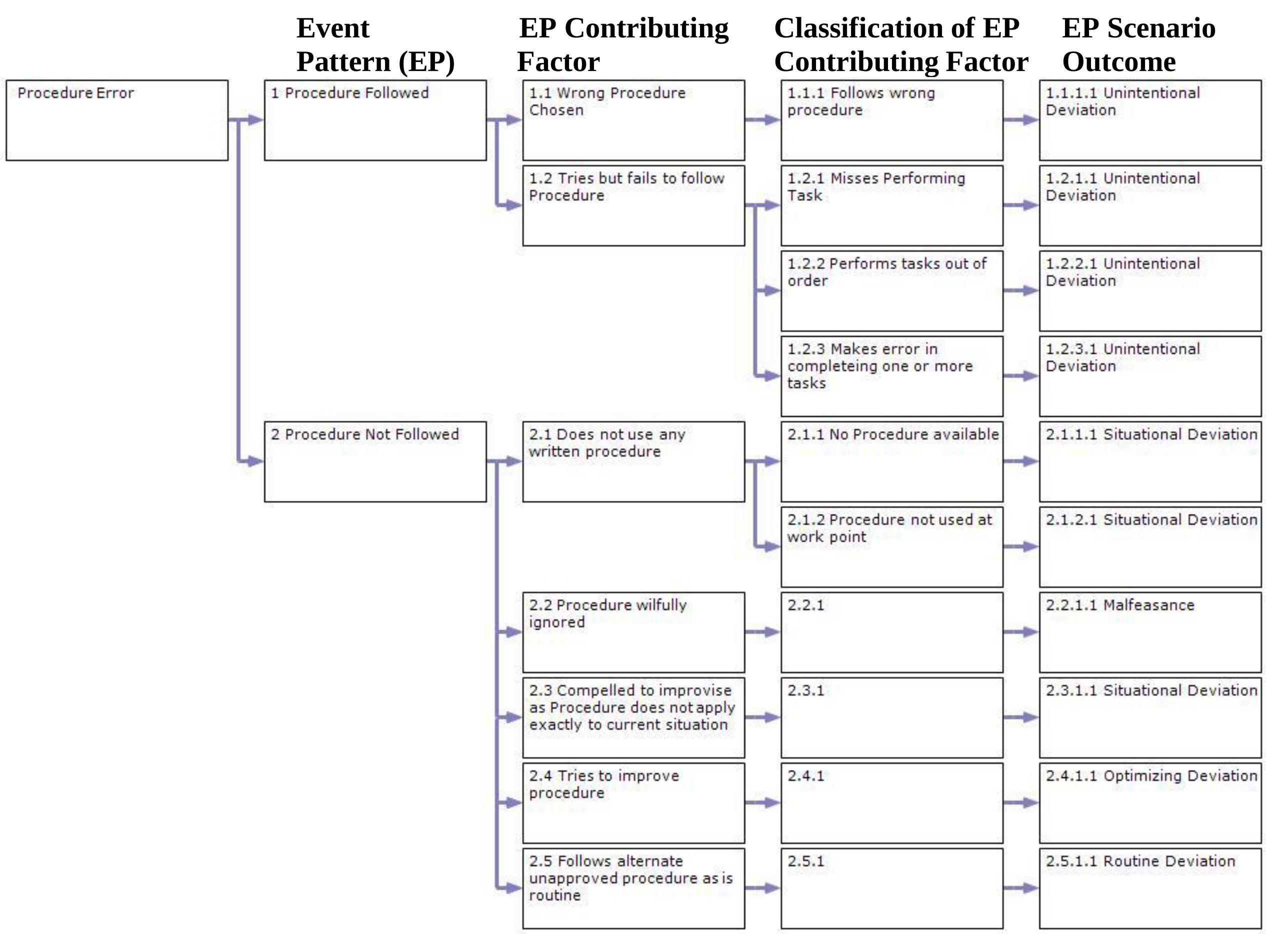

Figure 1. Logical decomposition of procedure errors with associated deviation categories.

These groupings naturally lead to the groupings in Table 1 where the extensive list of CFs found in the literature were identified and consolidated. For each classification category, a Left-to-Right diagram was created (similar to Figure 1) where errors could be logically decomposed (see Appendix A).

Task 2

Given the development of the TAPES classification system, it was necessary to apply it to practical scenarios to test its usefulness in aviation organizations. Both the ASRS and NTSB databases mentioned in Task 1 supplied the necessary components of error reporting such that Event Patterns could be identified and logically decomposed. The ASRS database was comprised of event reports of technical documentation and procedural errors occurring between January 1999 and December 2012 (Hollomon et al., 2015). This date range was chosen to maximize event reporting years, the number of events (prior to 1999 reports/events totaled less than 24), and the number of identifiable CFs (where events with limited information that did not provide enough detail to identify CFs were not included in the analysis). The iterative process for selecting the key variables for this database is shown in Table 2. One limitation of this approach was that this database query showed bias toward technical documentation. Since this limitation may have resulted in reports that overrepresented errors associated with technical documentation, it was important to ensure that other sources gathered did not also replicate this potential bias. Therefore, conclusions regarding the magnitude of influence that technical documentation may have in FFP events are not drawn in this research.

Table 2. Selection Criteria Used in the ASRS Database Queries

Reporter Organization	Reporter Function
Air Carrier	Inspector
Air Taxi	Instructor
Contracted Service	Lead Technician
Corporate	Other/Unknown
FBO	Parts/Stores Personnel
Fractional	Quality Assurance/Audit
Government	Technician
	Trainee
Primary Problem	**Contributing Factors**
Chart or Publication	Chart or Publication
Logbook Entry	Logbook Entry
Manuals	Manuals
Procedure	Procedure

The NTSB database included 871 procedure-related accidents that were investigated between January 2005 and December 2014. These accidents involved maintenance as a causal, Contributing Factor, and/or significant finding by the NTSB.

Task 2 Method

Modifying the Classification Scheme

To ensure that the ASRS events were coded consistently, two independent coders worked together extensively as has been done in other traditional inter-rater studies. Each ASRS report was coded for Event Pattern (i.e., final outcome error) and CF. Some reports had one Event Pattern and one CF, while others had multiple CF codes. This highlighted the flexibility in the use of the TAPES schema as, has been noted previously, errors rarely occur in a vacuum. The final coding scheme was presented as a set of hierarchical categories in Appendix B.

Selection of Databases

Sampling for event coding. Both the 871 procedure-related NTSB accidents and 650 ASRS reports were used to determine both the usefulness of the classification schema, and to identify CFs of FFP in the aviation maintenance environment. To ensure there were not differences between FAR parts, the reports were sorted for each (Table 3).

Table 3. Frequency of Operating Under each FAR for ASRS and NTSB Databases

FAR Part	Common Name	NTSB (%)	ASRS (%)
091	General Aviation	769	14
091K	GA Fractional Owners	2	0
121	Scheduled Carriers	9	611
129	Foreign Sch. Carriers	1	0
133	Rotorcraft, Ext Load	8	0
135	Commuter Aircraft	36	16
137	Agricultural Ops.	40	0
145	MRO's	0	2
Public Use Aircraft (PUBU)	Assorted	7	0

As the aim of the present study was to develop and validate a classification scheme from which focused interventions could be derived, a sample of 150 events from each data base was examined such that the overlap between the two data sets (i.e., between Part 91 and Part 121) were maximized. Thus, the ASRS data was mainly Part 121, but all of the Part 91 and Part 135 cases were coded, for a total of 154 cases. For the NTSB data, depending on data quality (i.e., codable details), all Part 121 and Part 135 cases were sampled with the remainder coming from Part 91 and a few from Part 137. The overall findings were compared across data sets, with focused comparisons made for each specific FAR contributing to the data.

Task 2 Results

Classification of the ASRS Sample

As noted above, 154 cases were sampled, covering events between 1999 and 2014 representing each of the FAR parts (Table 4).

Table 4. Comparison of case and Contributing Factors for each FAR from ASRS.

FAR	Number of Cases	Number of CF's	CF's per Case
91	14	19	1.36
121	124	208	1.68
135	16	18	1.13

Results showed (Table 5) that No Error Made combined with the Procedure Followed, represented 95% of the errors within the ASRS sample. This finding makes sense for ASRS reports where reporters often report an incident that *may* have led to an accident but did not. Reports were overwhelmingly categorized as Procedure (58%) issues. This finding was not surprising given the search criteria were biased toward technical documentation issues. Task, Actor and Social categories were classified much less frequently. The fewest reports were classified as Environmental. This finding may reflect the view point that the ASRS database is not the appropriate tool to report environmental constraints. Therefore, it was determined that within the reports in our sample, AMTs typically tried to follow the procedure as written, but the physical document was usually referenced as the primary contributor to the event.

Table 5. Summaries of Frequencies of Each Event Pattern and Contributing Factor for ASRS

Event Pattern		Event Pattern Contributing Factor	
Procedure Followed	69%	Tries but fails to follow Procedure	60%
No Error Made	26%		
Procedure Not Followed	5%	Wrong Procedure Chosen	7%
		Procedure Followed	3%
		Does not use any written Procedure	3%
		Follows routine unapproved Procedure	1%
		Procedure does not apply exactly	<1%

TAPES Category		TAPES Category Contributing Factor	
Procedure	58%	Physical Document	38%
		Document Writing and Production	18%
		Document Revision	2%
Task	14%	Problems with Task as Found	7%
		Errors Made During Task Performance	7%
Social	12%	Organizational Effectiveness	5%
		Local Norms	4%
		Organizational Pressures	2%
		Organizational Policy	1%
Actor	9%	Actor Background	4%
		Actor Current State	4%
Environment	7%	Physical Space for Task	1%
		Thermal Environment	1%
Unexplained Error	1%		

***FAR Part analysis*.** The next comparisons were made to determine if differences existed between data from the three FAR types. That is, do specific FFP events occur based on the FAR Part that is conducting the maintenance? To test this question, first a Chi-Square analysis was conducted to determine whether AMTs reported following procedures more in one part than any other. This analysis found a significant difference between FAR Parts ($\chi^2(2) = 7.5$, $p = 0.024$). Therefore, by examining the means of Followed Procedures across Part, it could be seen that Part 91 AMTs reported following procedures significantly more than all other Parts. Second, to determine if certain categories in the TAPES classification schema contributed to FFP events differently by Part, a Chi-Square test was conducted. The results showed no difference between the three Parts ($\chi^2(2) = 0.1$, $p = 0.95$). Therefore, the overall conclusion from the FAR Part analysis of ASRS data was that there were differences in *outcome error* (EP Scenario Outcome, See Figure 1) but not in CFs.

The primary purpose for creating a classification scheme was to determine what Challenges exist and the Best Practices for mitigating those challenges. Therefore, the CF frequency counts were used to determine the greatest contributor to FFP events. It was determined that the most frequent EP was "Tries but Fails to Follow Procedure" within the Procedures Category. Thus, the overall findings showed that the "Physical Document" and the "Document Writing and Production" were the greatest contributors to events reported. Again, this was not surprising considering the search criteria for the events coded within the ASRS database identified events specific to technical documentation (see Table 2).

Classification of the NTSB Sample

The NTSB maintenance-related accident database supplied by FAA/CAMI was sampled so as to maintain the greatest compatibility with the ASRS database sample described above. Thus, the sample comprised all of the 9 Part 121 cases, and 36 Part 135 cases to ensure maximum coverage of scheduled carriers. In addition to these, 49 Part 91 cases were sampled across a 10 year span from 2005 to 2015.[1] As with the ASRS data, the numbers of CFs per case were found to have a similar distribution as the ASRS data. In contrast to the ASRS data, the NTSB data were significantly different from a Poisson distribution ($\chi^2(2) = 15.0$, $p < .001$). That is, there were more cases with only one contributing factor (more than 70 of 94 cases). This outcome was to be expected given the goal of an NTSB investigation is to uncover a primary contributing factor and often does not continue to delve into lesser CFs.

All data were analyzed similar to the previously reported ASRS database results section (Table 6). These analyses found that "Procedure Followed" occurred at the highest rate (74%) with the CF Classification "Tries but Fails to Follow Procedure" occurring at the same rate as reported in ASRS reports. That is, those individuals who were performing the task had a procedure physically with them, and they attempted to follow it as written, but failed to fully perform the task as written. Within the ASRS data, there were more "Error not Classifiable" entries than expected in the NTSB reports. Similarly, there were more "Unexplained Error" findings in the CFs category than were expected.

[1] Note that the full dockets prior to 2009 were no longer available on the FAA web site, so that the data on many cases were quite sparse, especially for contributing factors.

Table 6. Summaries of Frequencies of Each NTSB Event Pattern and Contributing Factor

Event Pattern		Event Pattern Contributing Factor	
Procedure Followed	74%	Tries but fails to follow Procedure	60%
Error not Classifiable"	15%		
Procedure Not Followed	11%	Wrong Procedure Chosen	14%
		Procedure willfully ignored	7%
		Does not use any written Procedure	2%

TAPES Category		TAPES Category Contributing Factor	
Procedure	6%	Document Writing and Production	3%
		Physical Document	2%
		Document Revision	<1%
Task	26%	Problems with the task as found	21%
		Errors Made During Task Performance	6%
Social	15%	Organizational Effectiveness	13%
		Organizational Pressures	<1%
Actor	3%	Actor Current State	2%
		Actor Background	<1%
Environment	<1%	Physical Space for Task	2%
Unexplained Error	32%		

A Chi Square test was conducted to determine whether FAR Parts reported EPs differently. Results showed that EPs did, indeed, change based on FAR Part ($\chi^2(2) = 15.0$, $p < .001$). When examined further it was determined that this difference was likely due to the relatively large number of Unexplained Error for Part 91 as well as the relatively large Any Other factors for Part 121. However, these analyses underscored what was already known about the NTSB data; that Part 121 accidents generated more detailed reports with supporting CFs, than did the other two FAR Parts. Interestingly, Part 135 showed the greatest percentage of Unexplained Error.

Just as was conducted with the ASRS database, frequency counts were used to determine the greatest contributor to FFP events in the NTSB database. However, due to the general nature of the reports, or due to the format investigative report, the CFs were too general in nature to be specifically associated with particular EPs. Since the two databases provided differing levels of detail, it was determined that the ASRS reports (the more detailed database) would allow us to develop the most meaningful Challenges and Best Practices (shown in Table 4).

Task 3

Validating Databases

To generate a prioritized list of Challenges and Best Practices, the ASRS and NTSB databases were combined with the literature examined in Task 1 to derive a broadly-based prioritization of both Challenges and Best Practices. The coding for the TAPES scheme developed in Task 1 was used again for consistency (Table 1).

Task 3 Method

Deriving Challenges and Best Practices

Using the data from Task 2 to drive priority areas for Challenges, Best Practices, and Good Questions, each of the literature sources was summarized and relevant lists were placed into three tables: EPs/CFs, Best Practices, Challenges, and Good Questions. As noted in Task 2, each source listed multiple CFs for events. Therefore, to structure the CFs, the TAPES classification scheme was also used to organize Challenges and Best Practices along with their reference source. Results provided a frequency count of each CF. However, it should be pointed out that the counts do not represent independent data points, since several papers from the same reference source on the same topic might mention the same items. As far as possible, potential bias was avoided by limiting multiple counts from the same authors or organization. Following this analysis, Challenges and Best Practices were derived.

Task 3 Results

Determination of Challenges and Best Practices

Findings showed that the Procedure category was the most prevalent issue related to events, followed by Social and then Actor. Task and Environment categories were considerably less frequent in the literature than the other three components. Bringing these findings together into an overview from the most frequent to least frequent, it was clear that the Procedure and its design/control/revision is a necessary first step to reducing the incidence of FFP events. Though the ASRS data base was biased toward technical documentation, it is natural to target the physical document by which AMTs complete their tasks in order to ensure they have the necessary instructions to complete their tasks accurately. This finding appeared in all analyses and was the largest CF in all except the NTSB incidents. Following Procedures in importance was the Social system surrounding the maintenance activities. Specifically, the primary issues included the inconsistency in enforcement of procedures policy, failure to provide a procedure for a task, and doing little to mitigate time pressures on actors performing the task. Actors were found to contribute less to FFP events than Procedures and Social. However, when they did, it was because they lacked training, experience, and showed a tendency to "cut corners." The Task itself was less of a CF than the previous two categories, which may reflect a perspective that tasks are an inherent part of the job and therefore cannot necessarily contribute to incidents in the same way Procedures or Actors do. Finally, Environment was not often cited apart from the visual environment.

Table 7 shows the resulting Best Practices and Challenges derived from the analyses conducted in Tasks 1 and 2.

Table 7. Recommended Best Practices and Accompanying Challenges Compiled from All Sources

Best Practice	Challenges	Example
Procedures are technically accurate.	Current written procedures may not reflect the exact configuration of the aircraft due to less-than-perfect record keeping.	Inaccurate procedures lead at best to confusion and delay, at worst to FFP errors. It can be particularly difficult in Part 91 maintenance operations to ensure that each aircraft worked on has adequate records, specifically when maintenance has been performed elsewhere. For Part 121/135 operations, the sheer volume of procedures can be daunting.
Procedures are designed to conform to Human Factors guidelines for content, organization, readability, and graphics.	Changing formats does not have a high priority in maintenance organizations. Waiting until a planned automation system arrives can be a good excuse for inaction.	HF-based guidelines are readily available from many sources listed in the Reference section, e.g., Drury (2009). They have been proven to both reduce errors and be more acceptable to end-users. After so many controlled demonstrations of the benefits of using HF design best practices, there is no longer any reason *not* to use them.
Procedures incorporate explicit input from users, i.e., AMTs and inspectors with direct knowledge of the tasks.	Engineers producing procedures may assume that the OEM-provided information is adequate. They may also have little time to consult current users. Finally, they may not respect the expertise of on-the-ground knowledge provided by users.	Procedures are often derived from OEM sources, modified for local use. However, there is no guarantee that both the OEM and the engineers modifying the procedures have performed the task themselves. A current user who knows the task will be able to incorporate changes learned on-the-job that could be improvements if approved by engineering.
Procedures have been validated by observing their use in detail.	Many procedures are not validated because of time constraints and perceived cost considerations. Also the task may not be available to observe while the procedure is being written.	A procedure produced with validation is a theory, perhaps a good theory but that has not been determined until validated. It does take time and effort to find a user and follow a good validation process, but the cost of a single error or ambiguity far exceeds the costs involved in validation.
Procedures are kept up-to-date.	The procedure revision process adds to the workload of those engineers tasked with procedure production. When revisions are user-driven they may be seen as optional.	There are frequent complaints about the revision process, e.g., too prolonged, no feedback to users. Revision is often given cursory attention by engineers as this is the most expeditious way to reduce their workload. However, dissatisfaction with the revision process itself and its outcomes undermine trust and confidence in the procedure process as a whole, potentially leading to less-rigorous use of procedures.
Procedures are used only as needed, and at a suitable level for professional users.	Procedures are often seen as the automatic solution to errors in task performance, although	As noted in Task 1 report, AMTs and inspectors can work at skill-based, rule-based, or knowledge-based levels. Rule-based implies procedures but is only effective when the conditions of use exactly match the

Best Practice	Challenges	Example
	other solutions need to be considered.	task at hand. Hence the number of "Existing Parts installed incorrectly" events. Consideration is already given to skill-based activities in procedures, e.g., not telling an AMT how to wire a castle nut. This means that consideration of skill-based performance and even knowledge-based performance must be given to highly professional employees such as AMTs and inspectors. This means writing for the range of users, perhaps at different levels for those new to, or returning to, a task.
Organizational policy on use of procedures is in place and is enforced by all levels of management as well as by peers.	Although a high-level policy may have been written, it may not have been communicated to all levels. Also, the policy may be tempered in application by expediency of completing work to a deadline. Peer-to-peer communications may be awkward/unusual in strict policy enforcement.	A high-level policy does not guarantee compliance. As management changes and work becomes more competitive, there will always be pressures on mid-level managers and end-users to sacrifice the policy to a norm of expediency. Procedure users may be implicitly or explicitly rewarded for meeting deadlines despite the policy.
Procedures are available when needed and users can always find the correct procedure.	Procedures may not be available instantly due to technical or managerial problems, or even lack of responsible personnel on a night shift. The user may not be able to locate the procedure even if it is available.	In the day-to-day running of a facility, the procedure may not be instantly available to the user who is then tempted to work without a procedure, use a similar but not identical procedure, or use a known outdated procedure rather than be the cause of dispatch delay.
Users are insulated from time/production pressures.	Time/production pressures are always important in an organization. As organizations become leaner, this pressure will increase.	Although time and production pressure exist, they should not be allowed to influence quality. The technical term is Speed-Accuracy Trade-Off (SATO), meaning that accuracy for many tasks decreases as speed increases. In high-reliability organizations (HRO's) all actors have the ability to stop the process when an error is likely to occur. Aviation maintenance and inspection should be no exception as the consequences are high and well-known to all actors and the organization.
Users are trained appropriately, experienced, and knowledgeable.	Training may be cursory or poorly-implemented as it is not seen as a priority. Recurrent training is important. The test is knowledgeability, not	Training and experience comprise fitting-the-actor-to the-task, a necessary second step after are fitting-the-task-to-the-actor, i.e., optimizing the task and its environment. They are not a substitute for good procedure design, good workplace design, or good

Best Practice	Challenges	Example
	merely a signed-off training experience.	organization design. Most aviation maintenance organizations already have procedures in place to record training and experience, but occasional corner-cutting occurs in the name of flexibility of task assignment. Zero tolerance in appropriate here.
Users have an appropriate and known plan to improve or optimize procedures	People using procedures often see a “better way” to perform them. If they have no simple process to officially optimize the procedure they will often go ahead and change the procedure without due oversight by engineering.	It is a natural instinct to try to improve the work system, and end-users of procedures are no exception. They will see ways to make the task better, quicker, easier by performing the task diligently. The danger is that this desired innovation meets frustration and perceived apathy when a change suggestion is made and not responded to in a timely manner thus encouraging the use of local norms that deviate from written procedures. This is not only technically dangerous but it also undermines confidence in the whole procedure system. Errors are the inevitable result.
Procedures are in a medium suitable for use at the working point.	If the procedure document is bulky or difficult to control at the work point, there is a natural tendency to leave it in a safe area and perform the task from memory.	Excessively long, bulky, or repetitive procedures are seen as tiresome by end users, leading to ignore the at-site use of the procedure, especially in constricted areas or adverse weather conditions. Better HF design of the document or medium, e.g., laminated cards or smart phones, have been shown to encourage use at the work point rather than working from memory, again resulting in reduced error rates. Improved compliance with procedures is accompanied by increased confidence in the procedure system.
There is a known policy to deal with incorrect or incorrectly installed parts on the aircraft.	It can be quicker and easier for the user to improvise a procedure from a knowledge base than to work through layers of management to try to solve the problem at hand.	An experienced AMT or inspector has a good knowledge of what to do if the procedure does not exactly match the situation as found. Using this knowledge instead of following the arduous process for locating a correct procedure is error-prone behavior. A known policy, consistently enforced, can prevent such seemingly expedient behavior.
A high-quality visual environment is provided, including aids for seeing inaccessible work points.	Better hangar and task lighting can be seen as adding costly frills to appease grumbling AMTs. Also, control of task lighting is cited as a problem of hoarding good flashlights or even misappropriating them.	Good lighting and good aids for seeing around intervening structures are effective in reducing errors and improving job satisfaction. There are known and proven techniques for lighting design in aviation maintenance, but users rarely express the need for appropriate lighting, seeing the current situation as a norm unlikely to be changed for the better.

The derived best practices and challenges were purposefully general in that we sought to create a set of guiding principles that could be validated through a data collection phase in future work. Another justification for the generality of the items was to ensure that they could transcend FAR Part. That is, providing a high-quality visual environment in practice would be different for Part 91 vs. Part 121 maintenance operations.

DISCUSSION

The purpose of this study was to examine existing classification schemas for maintenance specific errors (commonly referred to as FFP events) and to add to their utility by incorporating reported data via ASRS and NTSB incident reports. The outcome of this work provides a classification system (TAPES, Appendix B) which is both broader and deeper than previously proposed schemas and that is applicable specifically to aviation maintenance events.

The development and utilization of the TAPES system has two key benefits with regard to FFP events in maintenance operations. First, the literature and event reports concur that errors are due to more factors than incorrect manuals or inadequate guidance. Therefore, the TAPES classification system addresses the complicated patterns of contributing factors and their resulting errors, which can arise when real maintenance is performed on real aircraft (as opposed to the fictitious scenarios played out in training courses). By examining errors at this level, the aviation maintenance industry is supplied with evidence for possible FFP countermeasure strategies that address real CFs.

A second benefit to using the TAPES system is the ability to create Best Practices that address FFP events. When errors are classified appropriately, Challenges are identified and Best Practices naturally emerge. Thus, taking the time to examine what steps to take to reduce and prevent FFP events will directly result in cost savings for maintenance organizations due to reduced FFP events. This, in turn, promotes longer term Best Practices that may be facilitated industry-wide.

FUTURE DIRECTIONS

This report highlights the challenges and issues of FFP, which have been researched and uncovered spanning the past 30 years. It is unfortunate to note that these challenges and recommendations have not changed a great deal in that time period. This highlights a systemic problem with the way in which FFP events are addressed both within the literature and in the hangar. Therefore, it seems pertinent that the future of addressing FFP events center on the following: classifying errors such that practical Countermeasures and Best Practices may be derived, the effectiveness of derived countermeasures and Best Practices, and quantifying cost savings in an organization from implemented countermeasures and Best Practices.

SUMMARY

The intent of the report was to review the previous literature on FFP events, integrate event reports that identify FFP as an outcome, and create a more specific classification system that categorizes root causes of FFP events within aviation maintenance. Within the scope of that effort, we used the classification system to identify CFs and possible Best Practices that can be used to target and mitigate FFP events industry-wide. Finally, we recommend a plan for future research that transforms the TAPES classification system into a practical tool to derive countermeasures and best practices. Phase 2 of this research will utilize a wide range of first-hand accounts of FFP events and gather a practical assessment of the effectiveness of the Best Practices identified in the current report. The final products of this research will provide the tools, guidance, and information necessary to ensure practical application to the maintenance community.

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APPENDIX A

Logical Groups for Contributing Factors Found in the Literature:
Iteration 1 of TAPES Classification System

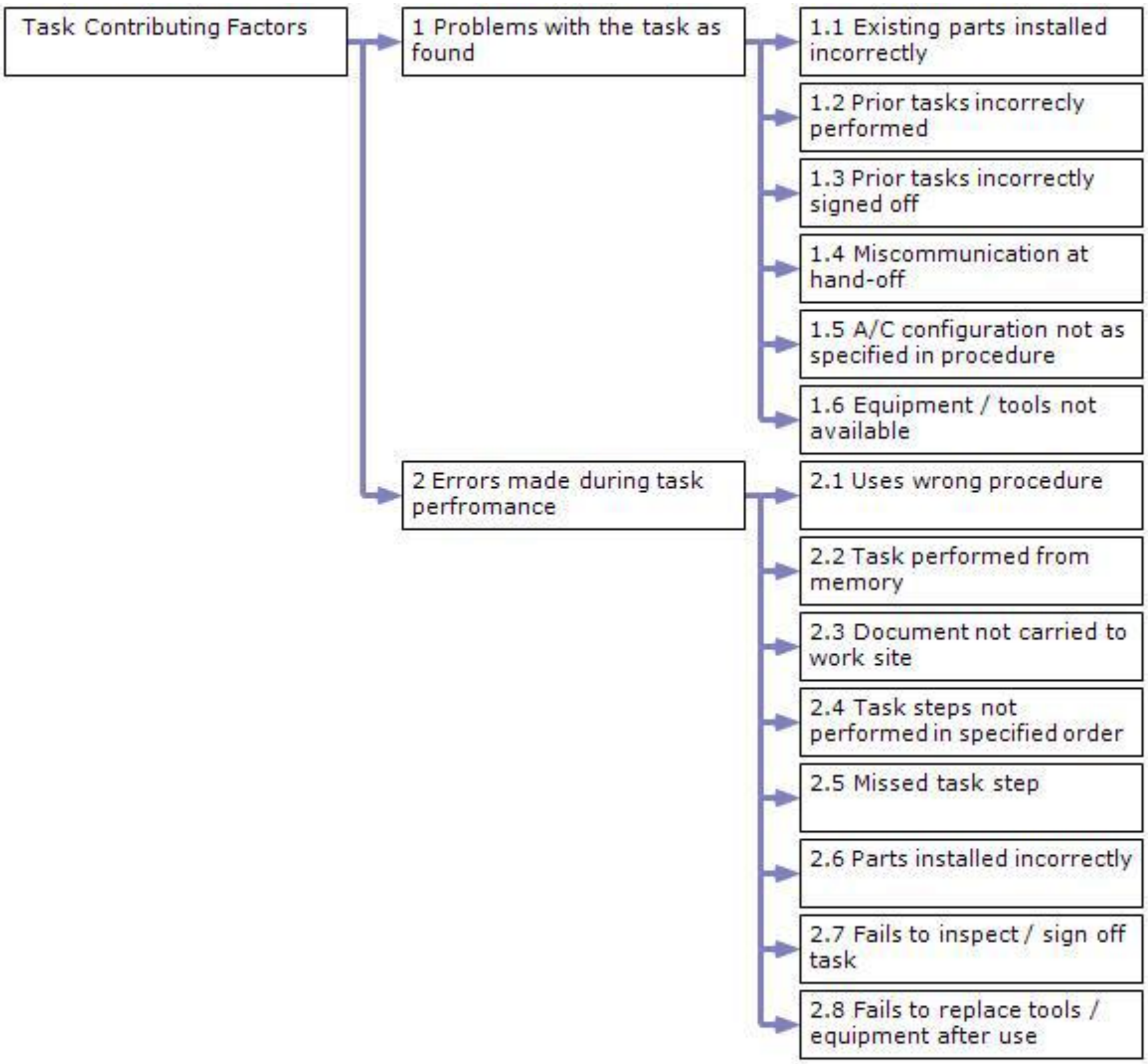

Figure A1. Hierarchical structure for Task Contributing Factors.

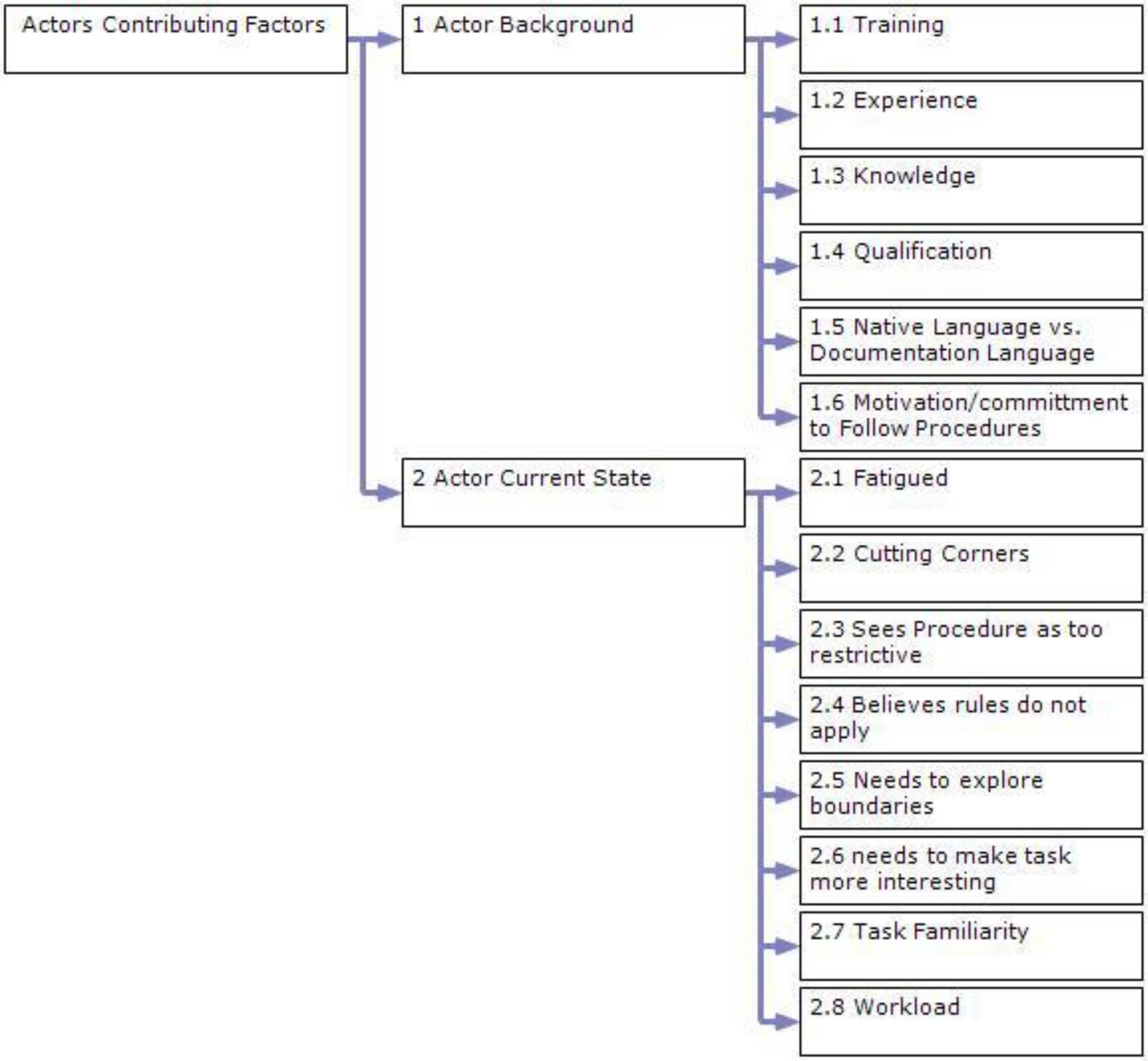

Figure A2. Hierarchical structure for Actor Contributing Factors.

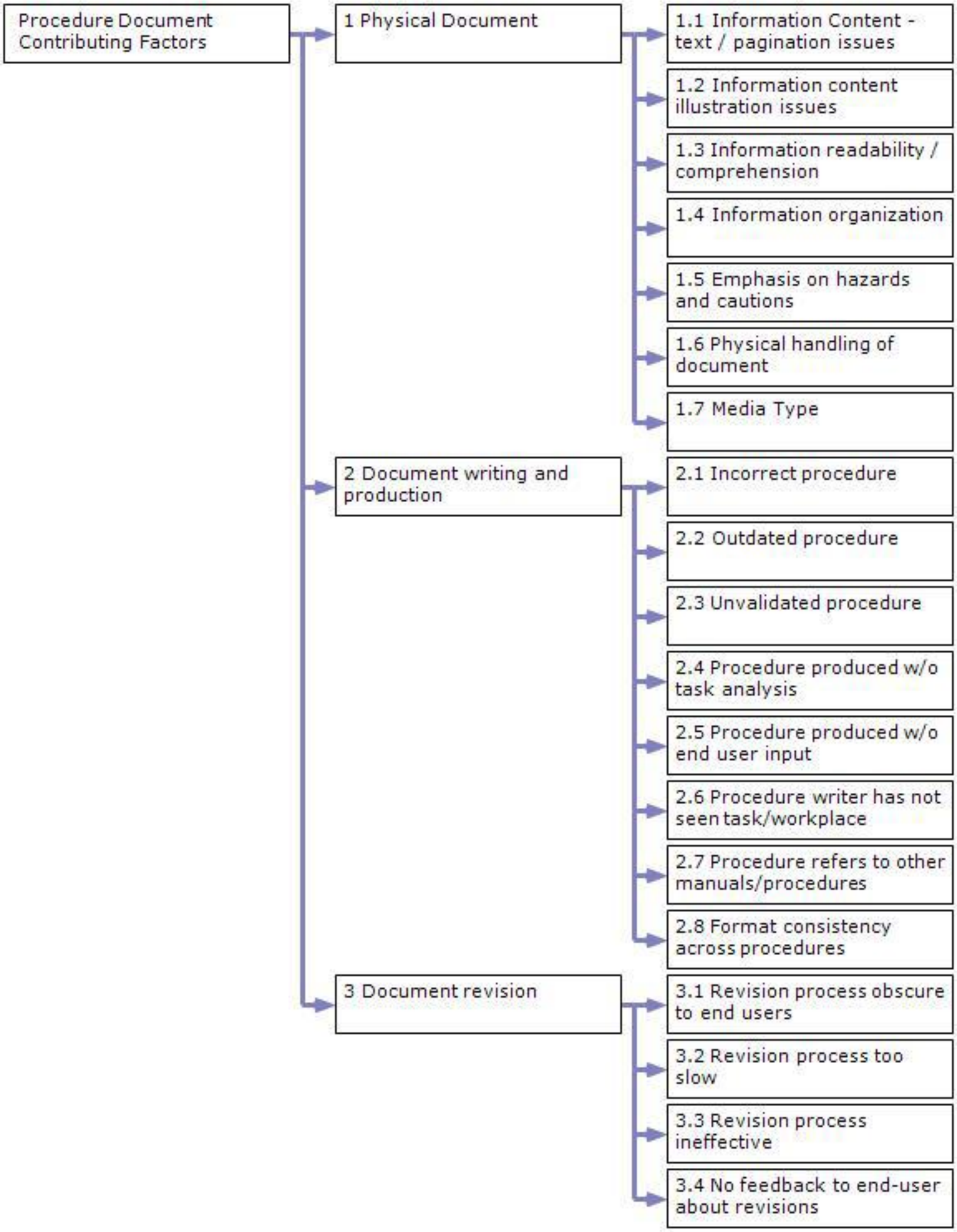

Figure A3. Hierarchical structure for Procedure Document Contributing Factors

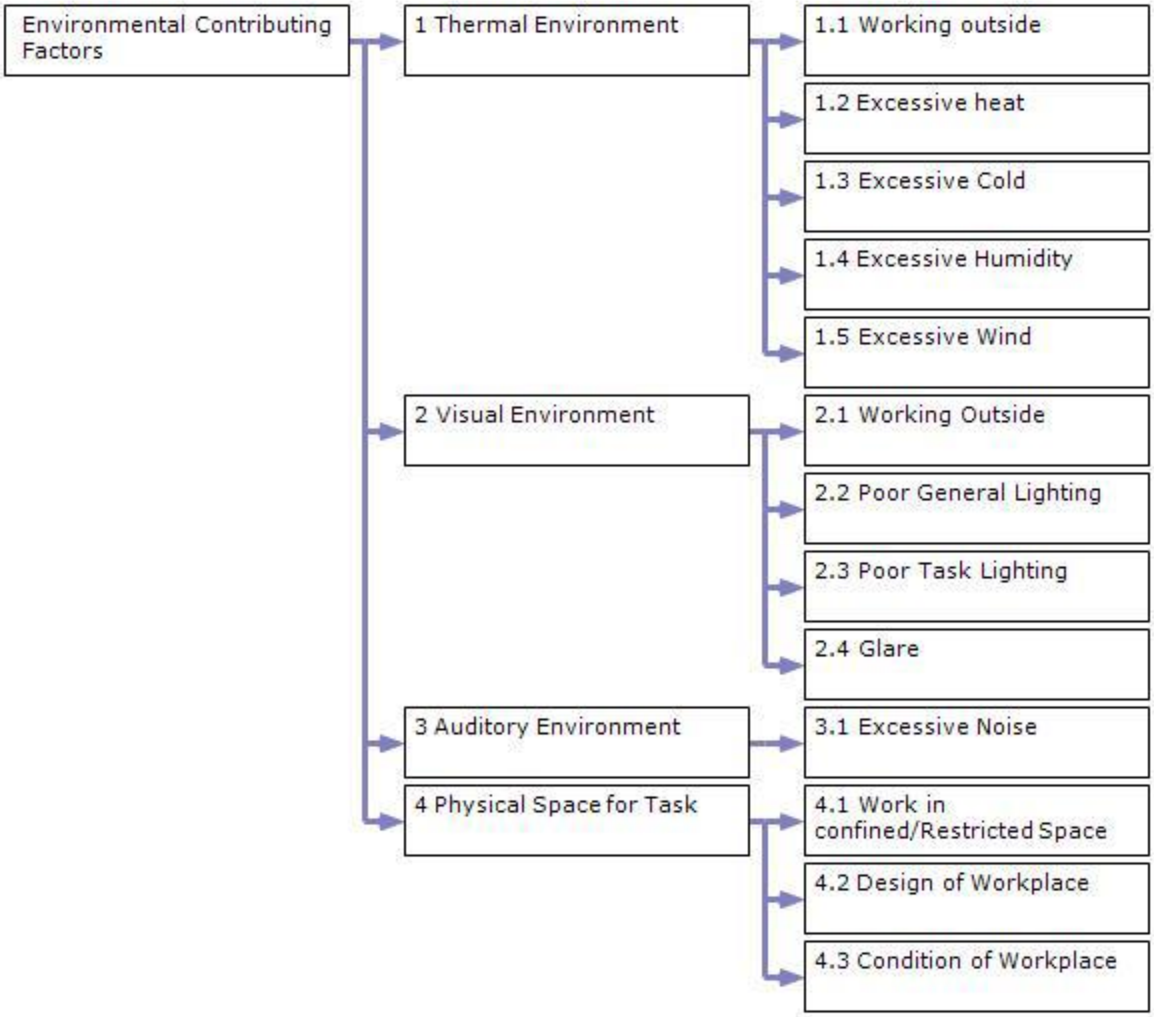

Figure A4. Hierarchical structure for Environment Contributing Factors

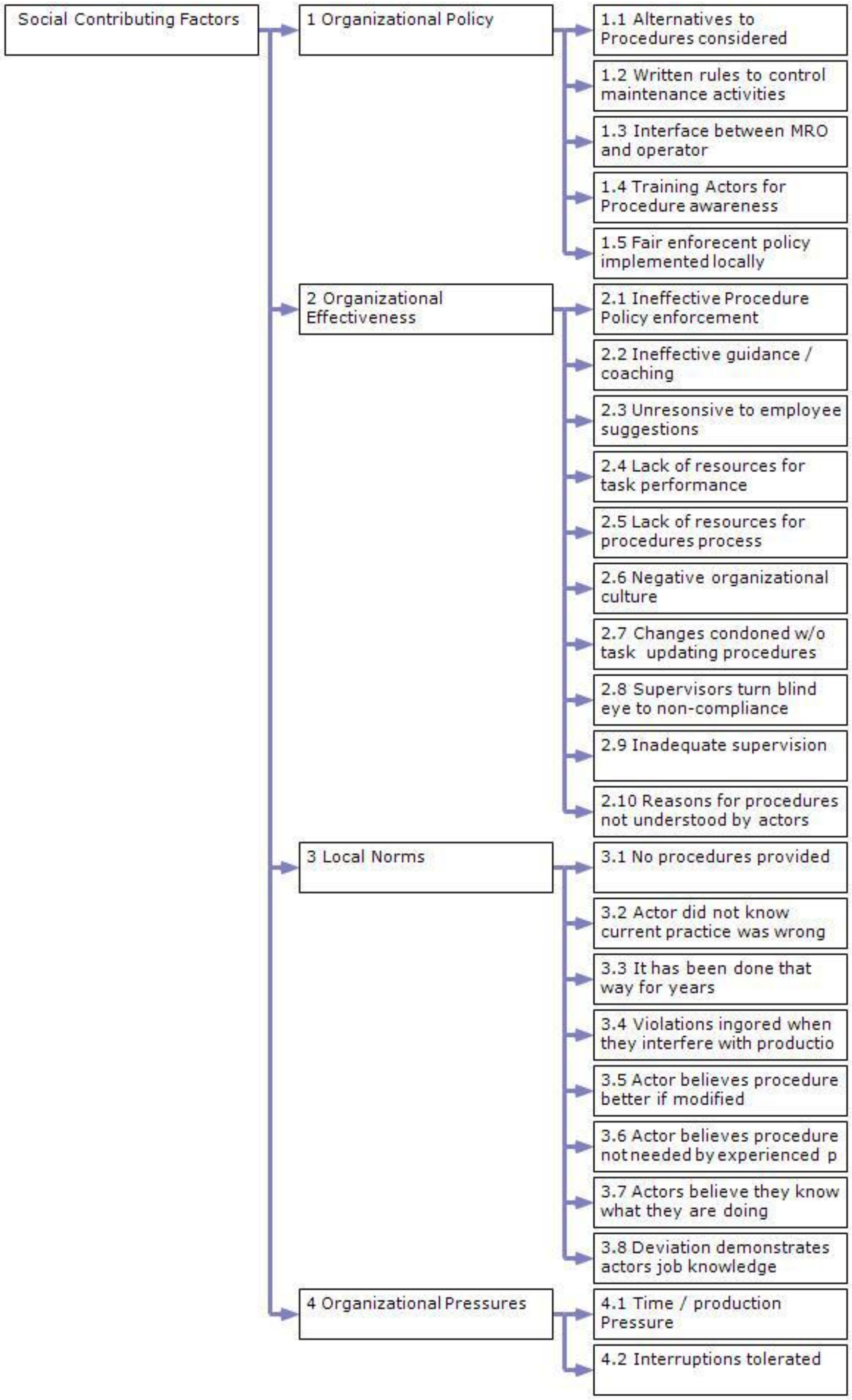

Figure A5. Hierarchical structure for Social Contributing Factors

APPENDIX B

Final Classification Schema for Event Patterns and Contributing Factors Specific to Maintenance Operations: Iteration 2 of TAPES Classification System

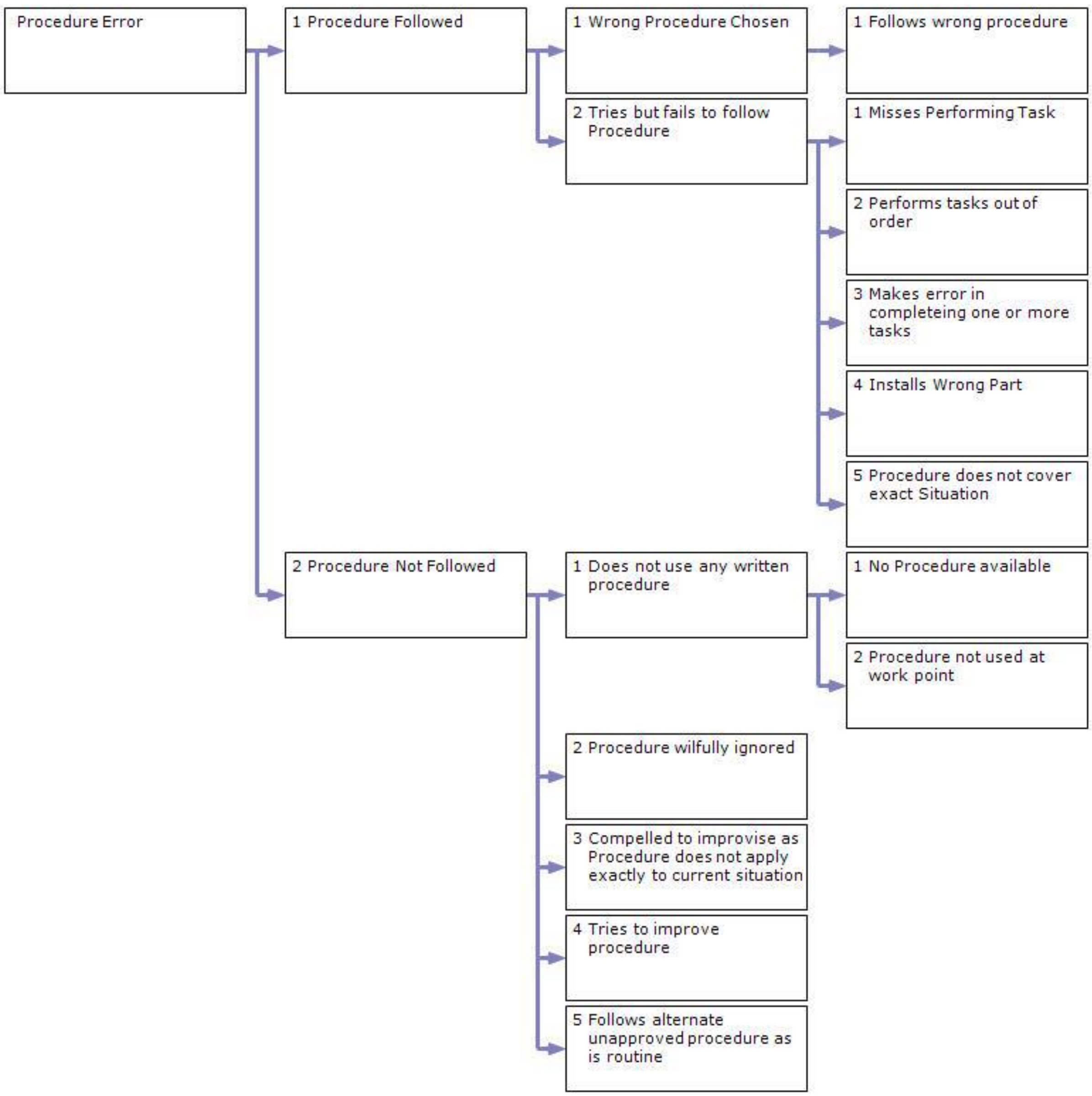

Figure B1. Procedure Event Pattern Classification Scheme.

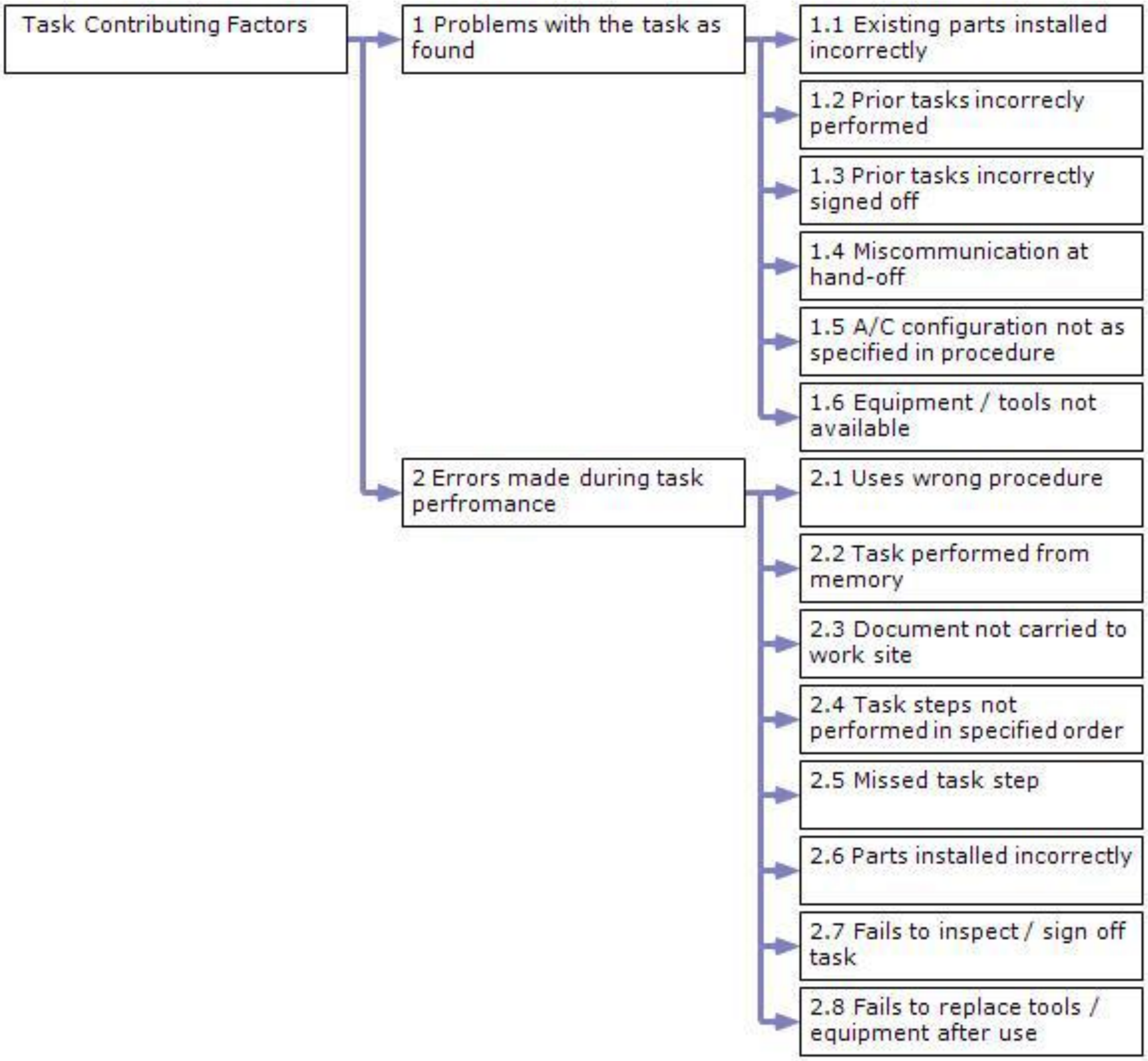

Figure B2. Hierarchical structure for Task Contributing Factors.

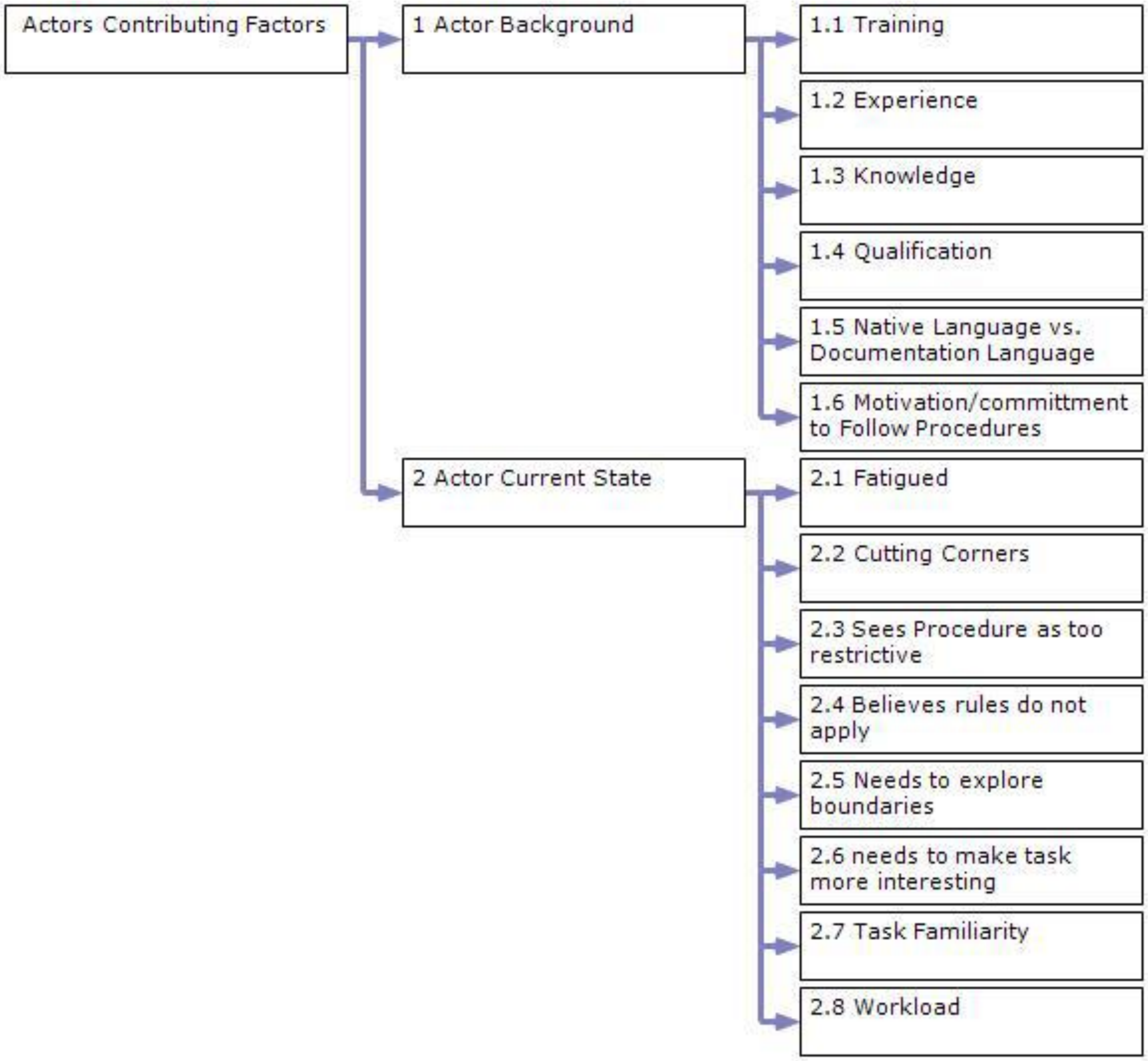

Figure B3. Hierarchical structure for Actor Contributing Factors.

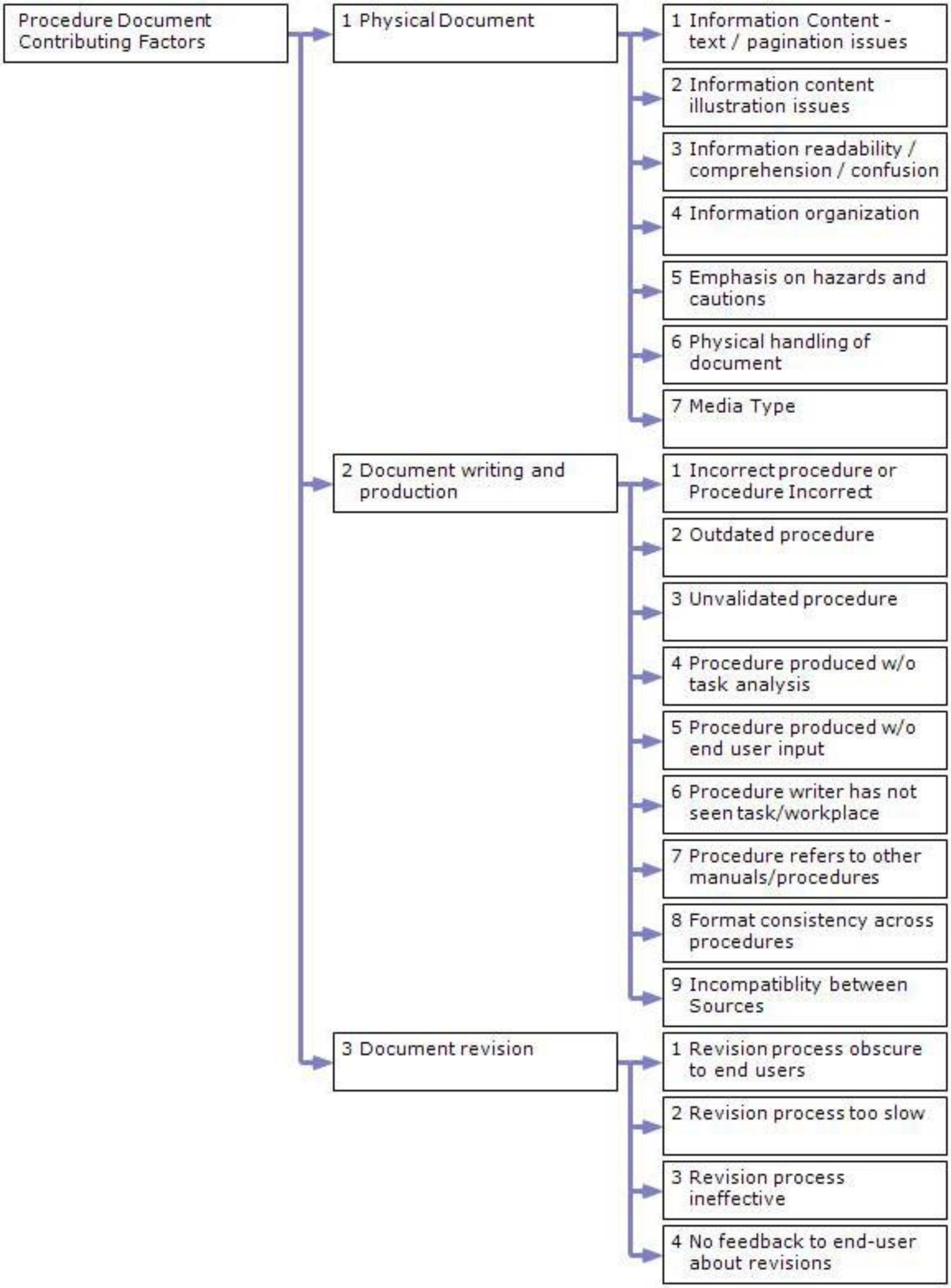

Figure B4. Hierarchical structure for Procedure Document Contributing Factors

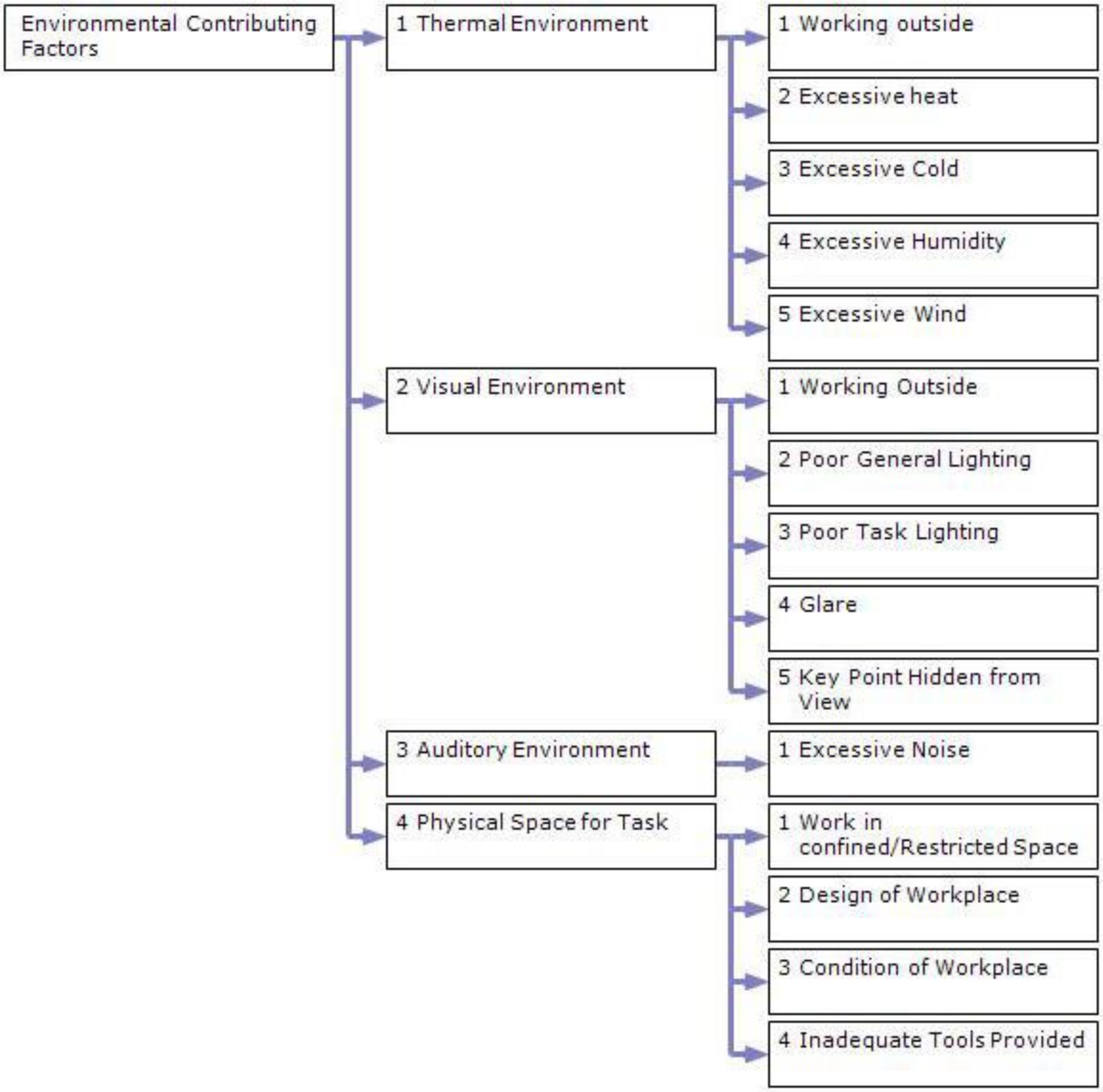

Figure B5. Hierarchical structure for Environment Contributing Factors.

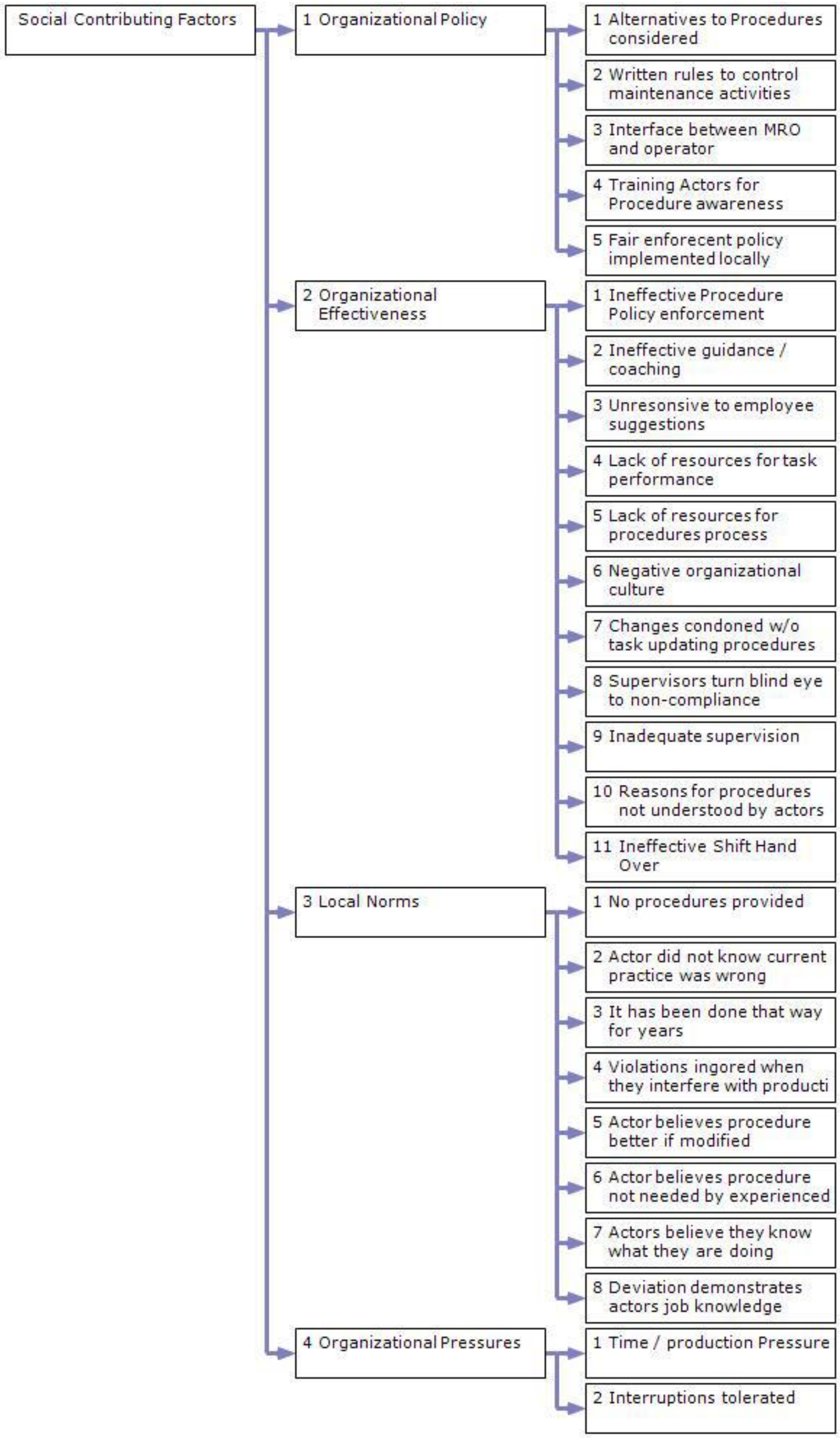

Figure B6. Hierarchical structure for Social Contributing Factors.

APPENDIX C

Summarized Sources for Event Patterns/Contributing Factors,
Best Practices, Challenges, and Good Questions[2]

Table C1. Example from Event Patterns/Contributing Factors Table

Source	**Event Patterns / Contributing Factors**
Revitalizing Procedures (HSE, 2009)	Procedures are not correct or out-of-date
	Procedures are difficult to use or follow
	Procedures are not readily available/portable
	There are easier ways of performing the task
	Pressure from peers
	A failure to understand the risks

Table C2. Example from Best Practices Table

Source	**Best Practices**
Revitalizing Procedures (HSE, 2009)	be accurate and complete
	be clear and concise with an appropriate level of detail
	be current and up to date
	state necessary precautions for hazards
	use familiar language
	use consistent terminology
	reflect how tasks are actually carried out
	promote ownership by users
	be in a suitable format; and be accessible
	Design the job or task so that the correct procedure is hard to avoid (e.g., by engineering-out short cuts through equipment design or programmable logic controllers)
	Base the procedure on how the task is actually performed. The operators may have devised an informal procedure that is quicker/easier and these methods should be incorporated into the formal procedure (as long as safety/quality issues are not compromised)
	Identify incentives to take short cuts (such as work pressures) and address these directly
	Adopt a control and review process to keep procedures relevant and up-to-date
	Workcard Best Practices detail

[2] Note that each table runs to several pages and only a few examples are presented here.

Table C3. Example from Challenges Table

Source	**Challenges**
Improving Maintenance (HSE,2000)	Procedures that are needlessly too detailed or complicated
	Procedures that contain technical errors
	Clarity of instructions in procedures/manuals
	Speed with which information can be found in procedures/manuals
	Procedures that are needlessly too detailed or complicated
Johnson (2014)	Need process to identify difficult tasks
	Need process to report issues to OEM
	Need process to improve response time for operator issues
	Need process to clarify information requirements to promote change

Table C4. Example from Good Questions Table

Source	**Good Questions**
Revitalizing Procedures (HSE, 2004)	Are your procedures accessible?
	Are they actually followed by staff?
	Do they always use the procedures? - Why not?
	Are they written so that they can be understood and followed easily?
	Do they reflect the tasks as they are actually carried out?
	Do the procedures include key safety information?
	Are they kept up to date and reviewed occasionally?
	Are they of the right level of detail?
	Do they include safety critical tasks?
	Do they identify all the necessary warnings?
	Are they easy to use?
	Do operators use 'black books'? - Why?
	Ask them to explain how to do a specific task - Do they always do it that way? - How do they remember how to do it?
	Were they involved in developing procedures?
Procedures audit tool (HSE, 2009)	Make good use of open space; avoid clutter; remove unnecessary information.
	Use margins; justify text to the left.
	Ensure font size is appropriate for all users and conditions (e.g., users with impaired eyesight; poor lighting; PPE with restricted visibility).
	Check that the use of colour is appropriate (availability & reliability of suitable printers; colour-blind personnel; contrast of text under artificial lighting etc.).

Source	Good Questions
	Use consistent type-face and spacing.
	Use page-breaks to ensure steps are not split across pages.
	Number all steps (e.g., 1.1, 1.2, 1.2.1 …).
	Differentiate clearly between steps (e.g., use a different tabular cell for each step).
	Have one action per procedural step.
	State who does what and when.

APPENDIX D

Classifying Contributing Factors Noted by Sources

Table D1. Mid-Level Contributing Factors with Frequencies from the Literature

Mid-Level Code	**Title**	**Count**
100	Task Contributing Factors	0
110	Problems with the task as found	5
120	Errors made during task performance	21
200	Actors Contributing Factors	0
210	Actor Background	24
220	Actor Current State	39
300	Procedure Document Contributing Factors	3
310	Physical Document	88
320	Document writing and production	55
330	Document revision	17
400	Environmental Contributing Factors	4
410	Thermal Environment	1
420	Visual Environment	3
430	Auditory Environment	1
440	Physical Space for Task	10
500	Social Contributing Factors	0
510	Organizational Policy	16
520	Organizational Effectiveness	37
530	Local Norms	39
540	Organizational Pressures	21

Table D2. Original Task Contributing Factors with Frequencies from the Literature

Code	Title	Count
100	Task Contributing Factors	
110	Problems with the task as found	1
111	Existing parts installed incorrectly	2
112	Prior tasks incorrectly performed	
113	Prior tasks incorrectly signed off	1
114	Miscommunication at hand-off	
115	A/C configuration not as specified in procedure	
116	Equipment / tools not available	1
120	Errors made during task performance	
121	Uses wrong procedure	3
122	Task performed from memory	10
123	Document not carried to work site	2
124	Task steps not performed in specified order	3
125	Missed task step	
126	Parts installed incorrectly	
127	Fails to inspect / sign off task	1
128	Fails to replace tools / equipment after use	
129	Forgets to perform task	2

Table D3. Original Actor Contributing Factors with Frequencies from the Literature

Code	Title	Count
200	Actors Contributing Factors	
210	Actor Background	
211	Training	9
212	Experience	7
213	Knowledge	5
214	Qualification	2
215	Native Language vs. Documentation Language	1
216	Motivation/commitment to Follow Procedures	
220	Actor Current State	1
221	Fatigued	5
222	Cutting Corners	10
223	Sees Procedure as too restrictive	6
224	Believes rules do not apply	3
225	Needs to explore boundaries	1
226	needs to make task more interesting	4
227	Task Familiarity	4
228	Workload	5

Table D4. Original Procedure Contributing Factors with Frequencies from the Literature

Code	Title	Count
300	Procedure Document Contributing Factors	3
310	Physical Document	15
311	Information Content - text / pagination issues	20
312	Information content illustration issues	4
313	Information readability / comprehension	27
314	Information organization	11
315	Emphasis on hazards and cautions	5
316	Physical handling of document	3
317	Media Type	3
320	Document writing and production	5
321	Incorrect procedure	18
322	Outdated procedure	7
323	Un-validated procedure	8
324	Procedure produced w/o task analysis	7
325	Procedure produced w/o end user input	1
326	Procedure writer has not seen task/workplace	
327	Procedure refers to other manuals/procedures	1
328	Format consistency across procedures	5
329	Incompatibility between resources	3
330	Document revision	10
331	Revision process obscure to end users	1
332	Revision process too slow	2
333	Revision process ineffective	3
334	No feedback to end-user about revisions	1
335	Revision not validated	

Table D5. Original Environment Contributing Factors with Frequencies from the Literature

Code	Title	Count
400	Environmental Contributing Factors	4
410	Thermal Environment	
411	Working outside	1
412	Excessive heat	
413	Excessive Cold	
414	Excessive Humidity	
415	Excessive Wind	
420	Visual Environment	1
421	Working Outside	1
422	Poor General Lighting	
423	Poor Task Lighting	
424	Glare	
425	Key point hidden from view	1
430	Auditory Environment	1
431	Excessive Noise	
440	Physical Space for Task	1
441	Work in confined/Restricted Space	2
442	Design of Workplace	3
443	Condition of Workplace	1
444	Inadequate / Missing tools /equipment	3

Table D6. Original Social Contributing Factors with Frequencies from the Literature

Code	Title	Count
500	Social Contributing Factors	
510	Organizational Policy	1
511	Alternatives to Procedures considered	6
512	Written rules to control maintenance activities	
513	Interface between MRO and operator	1
514	Training Actors for Procedure awareness	7
515	Fair enforcement policy implemented locally	1
520	Organizational Effectiveness	2
521	Ineffective Procedure Policy enforcement	10
522	Ineffective guidance / coaching	3
523	Unresponsive to employee suggestions	1
524	Lack of resources for task performance	3
525	Lack of resources for procedures process	2
526	Negative organizational culture	4
527	Changes condoned w/o task updating procedures	
528	Supervisors turn blind eye to non-compliance	3
529	Inadequate supervision	4
591	Reasons for procedures not understood by actors	3
592	Shift Handover ineffective	2
530	Local Norms	8
531	No procedures provided	19
532	Actor did not know current practice was wrong	1
533	It has been done that way for years	4
534	Violations ignored when they interfere with production	1
535	Actor believes procedure better if modified	2
536	Actor believes procedure not needed by experienced people	3
537	Actors believe they know what they are doing	
538	Deviation demonstrates actors job knowledge	1
540	Organizational Pressures	2
541	Time / production Pressure	15
542	Interruptions tolerated	4
543	Distractions tolerated	