19.0 CREATING A PROCEDURES CULTURE TO MINIMISE RISKS USING CARMAN

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INTRODUCTION

The purpose of this paper is to describe the aircraft maintenance applications of a comprehensive methodology for reducing procedures violations that has been applied in the petrochemical and other high risk industries. The methodology is called CARMAN (Consensus based Approach to Risk Management), because it involves the explicit identification of sources of risk, and the development, using a consensus process, of work practices which will control these risks. CARMAN is primarily directed towards the reduction of human errors and violations in proceduralised activities such as maintenance. It also can also produce improvements in areas such as learning from operational experience, and raising the awareness of risks. A particular focus of the approach is the development of a participative culture which provides a basis for the sharing of information from all sources in the organization, including informal, normally undocumented knowledge possessed at the operational level. This information is used to develop Best Practices to control risks, such as maintenance errors, which could lead to catastrophic losses. This participative culture is developed by allowing technicians to play a significant role in the development of operational procedures and job aids that reflect the practicalities of the working environment.

Another aspect of the methodology is the provision of a process for evaluating, in a rational manner, the relative contribution of training, competency and job aids to support Best Practices that minimise risk. CARMAN provides a process for setting up a database of Best Practices which can be used both to develop training programmes and also to assess competency.

We will first describe a survey which addressed the factors influencing the use of procedures in a high risk industry. This will be followed by a discussion of the individual and system causes of procedural violations and a description of how the CARMAN process addresses these causes. The paper concludes with a detailed description of how CARMAN is applied in practice.

THE ROLE OF PROCEDURES IN HIGH RISK INDUSTRIES

Over the past few years the author has been involved in projects concerned with predicting and improving human reliability in high risk systems in industries such chemical processing, aerospace systems and transportation (Embrey et al[1]). One of the main characteristics of such systems is that risks are controlled by means of operational procedures which are designed to control any hazards that have not been eliminated by design, or which cannot be economically controlled by means of some form of automatic protective systems. In industries such as nuclear power, for example, there has been considerable emphasis on developing sophisticated Emergency Operating Procedures, even though the role of the control room operator has mainly been as a back up for the operation of the automatic safety systems. In fact, reviews of incident data from the nuclear industry have shown that maintenance errors probably constitute a far greater source of risk than errors during the handling of severe emergencies. This is partly because nuclear power safety systems have typically focused on major emergencies, despite the fact that they can be vulnerable to other sources of risk, particularly maintenance errors during the shut down state. Another factor is that maintenance is typically highly labour intensive, and therefore the opportunity to make errors is considerably higher during maintenance compared to the rare but high profile scenarios such as loss of coolant accidents (e.g. Three Mile Island). In addition, far less attention has been paid to the issue of human error in maintenance, because this issue does not normally feature prominently in the safety cases that must be produced for the regulatory authorities in high-risk systems such as nuclear and chemical plants.

The procedures in such systems are typically subject to considerable scrutiny, since they are intended to represent the way in which the system is operated, and, at least implicitly, how risks arising from these operations are controlled. For this reason, technical specialists usually write procedures when the system is first set up. If an incident occurs which leads to significant safety or environmental consequences, the operator of the system will be required to demonstrate that a safe system of operation (as represented in the procedures) existed. Then, if the incident can be shown to have arisen because the procedures were not followed, (a so-called procedural violation), the organization can assign a significant portion of the blame to the hapless operator. Another reason for the proliferation of written procedures is the need to satisfy the documentation requirements of quality management systems such as ISO 9000. These systems typically require that all working practices which can impact on quality be fully documented in the form of comprehensive written procedures.

Results of Survey of Procedures Usage in High Risk Industries

As part of our work in a number of high risk industries, we have conducted surveys regarding the attitudes of the workforce to procedures, and the extent to which written procedures are actually used to support technicians when they are performing their day to day tasks. The insights from these surveys, together with our experience in providing training and consultancy in procedures systems for a number of organizations, have provided the basis of the CARMAN approach. We will first describe the results of one of these survey activities, and then the general conclusions that emerged.

A procedures culture questionnaire was developed and distributed to nearly 400 operators and managers in the petrochemical industry. The first set of questions related to the extent that procedures were actually used for different categories of task. The results indicated that for tasks perceived to be safety or quality critical, the use of procedures was high (75% and 80% respectively) but by no means universal. Perhaps even more interesting was the finding that for problem diagnosis (regardless of whether a system was safety critical or not) only 30% of the respondents used procedures. In the case of routine tasks (which would include routine maintenance operations), only 10% of the respondents said they used procedures.

When a task is described as ‘proceduralised’ there is an implicit assumption that the procedures will actually be referred to when performing a task. However, the results of the survey indicated that even in tasks where procedures were said to be used, only 58% of the respondents actually had them open in front of them when carrying out the task. This indicates that the earlier findings regarding procedures use are probably an over estimate if ‘use’ is defined as actually working from the procedure while performing the task. These figures imply that the actual average ‘on-line’ usage for safety critical, problem solving and routine tasks is 43%, 17% and 6% respectively. If these findings translate to the aviation domain, the assumption that maintenance and testing errors will be minimised because of the availability of procedures would appear to be misplaced. Certainly the results indicate that the level of on-line usage of procedures is low, particularly in tasks not perceived to be safety critical.

Use of standardised working methods

One of the important functions of procedures is that they can provide the basis for standardised working practices, which ensure that the objectives of the task are achieved. One of the items in the survey concerned the use of ‘black books’ i.e. personal sets of notes held by individuals as informal job aids. The results indicated a very high usage of black books by both operators and managers (56% and 51% respectively). Although there is no reason in principle why such informal job aids should not be compiled by individuals, their existence suggests that there may be considerable variation in the way that tasks are actually performed. There are obvious implications for safety critical maintenance operations if some of these variations in performance do not achieve the required objectives.

Another dimension assessed by the study was the extent to which procedures should be regarded as being guidelines, or needed to be followed ‘to the letter.’ Although there was considerable agreement that safety and quality instructions should be followed to the letter (90% and 75% respectively) for most other categories of task about 50% of respondents believed that they were primarily guidelines. This came as a considerable surprise to the management of the companies included in the survey.

Strategies for improvements

The final part of the survey considered the question of why procedures were not used. Following prior discussions with technicians, seven factors were investigated with regard to their impact on procedure usage. These are set out in Figure 19.1.

It can be seen from this table that there was a high level of agreement with most of the suggested reasons for lack of usage of procedures. Another part of the survey asked people to indicate the five main reasons that procedures were not used, and the five changes that would be most effective in improving the quality of procedures and their use. The most highly ranked reasons for procedures not being used were as follows:

- If followed to the letter the job wouldn't get done
- People are not aware that a procedure exists
- People prefer to rely on their skills and experience
- People assume they know what is in the procedure

The most highly ranked strategies for improvements were:

- Involving users in the design of procedures
- Writing procedures in plain English
- Updating procedures when plant and working practices change
- Ensuring that procedures always reflect current working practices

There were no significant differences between the reasons for lack of procedure usage, but 'involving users in the design of procedures' was rated significantly higher than any of the other approaches to improvements.

Conclusions from the Survey

The conclusions that emerge from this study are that in the safety critical industry surveyed, the majority of maintenance and testing operations were performed without the on-line use of step by step written procedures. There were also significant variations in the ways in which a task was performed, which sometimes differed significantly from the 'official' procedures. People will not follow procedures if they feel they are impractical, and they will not routinely use written procedures if they believe they have sufficient skill and experience to get the job done on the basis of their skill or experience alone. However, the existence of 'Black Books' indicates that there is a significant need for some form of on line support, which is not provided by the existing procedures systems. Also, there appears to be significant variations in the way in which tasks are performed, between shifts or individuals.

An obvious question is the extent to which these findings are specific to the industries surveyed, or whether they could reasonably be expected to apply to the aviation sector. Although we have not yet performed a survey of this type in the aviation sector, over the past few years we have worked in many high-risk industries. These include petrochemicals, offshore oil production, manned space flight, and nuclear power generation, marine operations, medical and rail transport systems. In every case we have observed similar practices, and it seems unlikely that the aviation industry, is significantly different in this respect. This assertion is supported by several specific incident investigations that have shown non-compliance with procedures as a specific cause. For example, ICAO2 listed 'failure to comply with procedures' as one of the organizational causes common to accidents involving maintenance error. In a recent project concerned with military aircraft maintenance, where one would expect a strong culture of procedure compliance to exist, we have also observed similar practices, even for highly safety critical equipment such as ejection seats.

UNDERLYING CAUSES OF NON-COMPLIANCE WITH PROCEDURES

In this section, we shall examine the various causes for procedural non-conformance that can arise, primarily from the basis of our industrial experience, but also from the perspective of research findings on violations. The reasons for procedural non-compliance can be divided into two broad groups: individually based and system based. Because there has been extensive work in the area of the individual causes of non-compliance (usually referred to as violations because there is often an implied value judgement that they arise from blameworthy negative intentions), we will only provide a summary of this area in this paper. More detail will be provided on the system causes of non-compliance, which has received less attention in the literature. However, it should be emphasised that there is some degree of overlap between these two groups of causes.

'Procedures are not used because…' (percent agreeing)	
Accuracy	…they are inaccurate (21) …they are out-of-date (45)

Practicality	…they are unworkable in practice (40) …they make it more difficult to do the work (42) …they are too restrictive (48) …too time consuming (44) …if they were followed 'to the letter' the job couldn't get done in time (62)
Optimisation	…people usually find a better way of doing the job (42) …they do not describe the best way to carry out the work (48)
Presentation	…it is difficult to know which is the right procedure (32) …they are too complex and difficult to use (42) …it is difficult to find the information you need within the procedure (48)
Accessibility	…it is difficult to locate the right procedure (50) …people are not aware that a procedure exists for the job they are doing (57)
Policy	…people do not understand why they are necessary (40) … no clear policy on when they should be used (37)
Usage	…experienced people don't need them (19) …people resent being told how to do their job (34) …people prefer to rely on their own skills and experience (72) …people assume they know what is in the procedure (70)

Figure 19.1: Reasons for Non-Usage of Procedures

Individual Causes of Non-Compliance

Violations can be broadly defined as intentended actions which deviate from the specified rules or procedures of a system, even though the rules are known to the actor. Hence an individual who is unaware of the correct rules is not technically committing a violation if they are transgressed, even though the consequences may be serious. Free[3] has developed a classification of four types of violations: routine, situational, exceptional and optimising.

Routine violations are often activities which have become the unofficial working practices in an organization, even though they do not comply with the official rules or procedures. Routine violations may become so common that they come to be performed unconsciously, but will normally be recognised as violations if a person is questioned. Routine violations are said to arise when the costs of compliance seem to be greater than the benefits of violating the rules. Benefits in this sense could simply be the convenience of doing a job in a simple way that appears to save time compared with an apparently time consuming and cumbersome method set out in an official procedure. If an individual’s perception of the costs and benefits is correct, then the chosen strategy may actually be the optimal one for the system. This conclusion emphasises the dangers of making value judgements about violators. Unless a process exists for ensuring that the official rules are actually the optimal rules, then routine violations are likely to flourish, and not always for negative reasons. Routine violations often arise because of group pressures to conform to a particular working practice adopted by a group, or individuals with ‘expert power’ such as supervisors or experienced technicians.

The concept of a violation as arising from an incorrect perception of the balance between risks and benefits is a general principle which also applies to other forms of non-compliance. From this perspective, a general strategy for reducing violations is to ensure that an individual has an accurate perception of the risks associated with tasks, which is communicated either by training or by the procedures themselves (e.g. via warnings and comments).

Situational violations arise from procedures that are either impractical or are applied generally when they are only relevant within a limited domain. Impractical rules are often violated simply to get the job done. A situational violation may become routinised if the causes of the violation persist over a long period of time. This category of violations can also be seen as partly caused by procedures which are not optimal in that they do not recognise the practicalities of performing the task in the prescribed manner.

Exceptional violations are usually associated with rare or unusual situations where people are trying to solve problems in the knowledge based mode (Reason[4]). In these situations, people may assume that the normal rules do not apply, and therefore they may attempt to develop an ad hoc procedure without a full evaluation of its potential risks. The Chernobyl accident was a classic case of an exceptional violation of the reactor safety rules.

The final class of violations arises from the desire to optimise a work situation, from the point of view of exploring its boundaries or to make a repetitive or unchallenging job more interesting. Optimising violations can be seen as part of a process of learning by a person investigating the dynamics of a system by means of possibly risky 'experiments'. Normally, optimising violations are associated with more complex tasks than those encountered in aviation maintenance, where it is difficult for a technician to fully understand a system.

System causes of Non-Compliance

Although most violations are ascribed to individual causes, in fact there are usually specific system problems that create the preconditions for violations. In this section we will explore some of these causes, from the point of view of how they are addressed in CARMAN.

The primary system causes of procedural non-compliance can be summarised under the following headings:

- Absence of an auditable process for systematically developing optimised working practices ('Best Practice') which control risks and which are acceptable to the workforce.
- 'Official procedures' which are out of date and impractical and therefore lack credibility with the workforce
- Lack of a culture which develops ownership of procedures by a process of active participation in their development, thus giving rise to 'buy-in' and compliance without the need for repeated motivational campaigns.
- Lack of communication channels in an organization to allow procedures to be frequently updated in line with organizational learning.
- Absence of a process for capturing formal and informal knowledge which may be distributed widely both within and between levels in an organization.
- Lack of the detailed knowledge of how to perform complex or infrequently encountered tasks, due to a failure to integrate training, competency and procedures development
- Failure to recognise that different types of procedural support are required depending upon familiarity, task complexity and other factors.
- Absence of a method for identifying the critical information needed to perform a task

Requirements for an Auditable, Risk-Based Approach to Procedure Development

In most organizations, many of the formal written procedures do not document current Best Practice. ‘Best Practice’ is defined as the performance of a task in the manner which achieves the required objectives whilst minimising the safety, economic and quality risks. This is due to two main reasons. Firstly, procedures are often written by technical specialists or engineers who do not necessarily have a high level of hands –on experience with the environment and the practical constraints of performing a task in the field. A second reason is that there is rarely a system in place for ensuring that procedures are modified to take into account organizational learning and gradual changes in working practices. In the military aircraft maintenance context for example, it may take months for recommended changes in working practices to actually be fed back to the equipment vendor so that they can be approved and appropriate changes made in the procedures themselves. In the light of these delays, it is not surprising that technicians frequently make informal changes to working practices without bothering to put these changes through the formal review system. This process gradually erodes the credibility of the official procedures, and can give rise to a considerable body of informal undocumented methods which may or may not be effective.

In CARMAN, the working practices which are actually used by the technicians are examined using a participative process which documents the variations that exist, and then attempts to evaluate them from the point of view of whether they are practical and whether they control all the risks associated with critical tasks. Best Practices are then developed and documented, which take into account the preferences and insights of the workforce, whilst ensuring that all risks are adequately controlled.

Developing a Participative Culture

In any system of procedures there are three elements: the database of procedures held by the organization, the Best Practices which control risks in the most efficient manner and the preferred working practices of the technicians who actually perform the maintenance tasks. The key to eliminating non-compliance with procedures lies in ensuring that these elements converge. In order to achieve this, a process is required which harmonises working practices to achieve agreement about the best methods for performing maintenance tasks. It should be emphasised that such a process must not only include the maintenance technicians, but also technical specialists who may have insights into why a task should be performed in a particular way. This process seeks to provide a neutral forum for the exchange of information about differing working practices (e.g. between shift teams) and also to allow insights to be gained into the risks associated with different ways of carrying out tasks. Technical specialists contribute to this information exchange process, but do not dominate it. This is because it is essential to ensure that the developers of the revised procedures have a shared sense of ownership. This is a major factor in encouraging compliance, once a compromise has been established amongst the different stakeholders (i.e. technicians, maintenance teams and technical specialists) concerning the working practices that will be adopted.

Integration Between Training, Competency Assessment and Procedures

One of the major reasons for lack of compliance with procedures is simply that the person making an error is unaware of the Best Practice for performing a task. This often arises from the absence of a system for generating Best Practice, which provides a baseline against which to develop training programmes and assess competency. Obviously, unless standardised methods have been agreed with regard to how risks are to be controlled in safety critical tasks, then assessing competency will be extremely difficult. Unfortunately many industries have adopted an approach which essentially relies on providing training in generic skills, with the assumption that task specific skills will be acquired through working with an experienced technician. Unfortunately, without the existence of a database of Best Practices, there will be no standardisation in the methods transmitted from the trainer to the trainee. The absence of the database also means that competency will probably be assessed against the standards of the trainer, rather than those defined by the Best Practices.

In CARMAN, the procedures, training programmes and competency assessments are all based upon the same Best Practices.

Matching the Type of Procedural Support to the Needs of the End User

In most high risk industries it is common to find voluminous manuals containing detailed step by step instructions for performing tasks, in control rooms and maintenance technician's office. However, a close examination of these documents generally shows that they are either in pristine condition, or are very dusty, both of which indicate that detailed step by step instructions are rarely consulted by experienced technicians. The insistence that a large volume of procedures is the best form of job aid is based upon a misunderstanding of the role of procedures. The Best Practice database generated by CARMAN is essentially for reference purposes, in that it provides the basis for training and competency assessment, and also documents the risks associated with tasks. Only a limited subset of the information in the database needs to be transmitted to the technician in the form of on-line job aids, to supplement the competencies acquired through training.

Essentially, most tasks will be performed primarily on the basis of skill and experience. Experienced technicians will usually be operating in the skill based mode defined by Rasmussen's[5] classification. In some cases, some form of on-line job aid will be required, particularly if a task is complex and / or infrequently performed, and where the technician is likely to be operating in a rule-based mode. The format for such job aids is often best left to the discretion of the technician, since it needs to be tailored to his or her specific needs. Obviously, a trainee will require a more comprehensive set of job aids than an experienced technician. Many of the best job aids are found in technician's Black Books and it is often a useful exercise to encourage the sharing of this information during the development and documentation of Best Practice. One of the functions of job aids is to provide the critical reference information such as dimensions and tolerances in an easily accessible form. One of the commonest forms of job aids in maintenance tasks are job cards. These should contain all the reference information required by the technician. However, unless the content of the job cards is based upon the Best Practice for the task, it is unlikely that all the relevant information will be available. The CARMAN process provides some decision aids for selecting the appropriate level of support.

THE CARMAN PROCESS

CARMAN comprises two stages: the development and documentation of Best Practice, and the development of job aids, competency standards and training programmes based upon the Best Practices.

Prior to commencing the steps of the first stages of CARMAN, it is first essential to appoint a facilitator, and to provide training in the tools and philosophy of CARMAN. His or her role is to collect information from the various technicians about their working practices, and to assist in the development of consensus regarding Best Practice. It is essential that the facilitator is respected by the technicians, and that he or she has good communication skills. It is also desirable to provide some awareness training for the technicians, and also basic training in task analysis.

The first step of stage 1 is to list the tasks that exist in the system. This list is called a Task Inventory, and is intended to ensure that no important tasks are omitted. Following the development of the Task Inventory, a screening analysis may be conducted to identify all tasks which are considered to be critical. The current practices for the tasks of interest are then documented using Hierarchical task Analysis (HTA). This method of task analysis is used because we have found it to be particularly flexible in allowing tasks to be analysed at whatever level of detail is required to identify risks. Usually there will be discrepancies and differences between shift teams regarding how tasks should be performed. These are compiled by the facilitator, and then resolved by convening consensus groups, which examine the similarities and differences between methods. These groups also evaluate the consequences associated with various types of error, and on the basis of these risk assessments and the discussions, consensus is reached on the Best Practice. At this stage, technical specialists are invited to the consensus sessions to comment on the draft Best Practices. Unless the specialists provide specific reasons for modifying the Best Practice, this is then appended to the database in the form of an HTA Reference Procedure together with information concerning the possible hazards and consequences.

In Stage 2 of CARMAN, the Reference Procedures in the Best Practice database are used to develop competency specifications, training programmes and supporting job aids, based upon the level of on-line support required for each task. The primary factors that are considered when determining the level of on-line support are the severity of consequences if the task fails, the frequency with which the task is performed and its complexity. The more severe the consequences, the lower the frequency of task performance, and the greater the complexity, the more elaborate the level of support that is provided.

An example of a decision rule for a set of operators is shown in Figure 19.2. In this figure, it can be seen that the majority of tasks will be performed without written instructions. As the tasks become more critical, complex and infrequent, the level of support increases. However, overall, less than ten percent of the tasks require step by step instructions.

Task Critically	High	Medium	Low

Task Familiarity	Freq	Infreq	Rare	Freq	Infreq	Rare	Freq	Infreq	Rare
Task Complexity									
Low	NWI	NWI	JA	NWI	NWI	JA	NWI	NWI	NWI
Medium	NWI	JA	SBS	NWI	NWI	JA	NWI	NWI	NWI
High	JA	JA	SBS	NWI	JA	SBS	NWI	NWI	JA
		No Written Instruction required (NWI) Job Aid required e.g. checklist/memory aid (JA) Step by Step instruction required (SBS)							

Figure 19.2: Decision Aid for Choosing Level of Job Aid Support

CONCLUSIONS

This paper has described a systematic approach to the management of risk arising from human error and violations that has been applied to high-risk industries over the past five years. The intention of the paper has been to indicate the potential of the approach to achieving similar objectives in the aviation maintenance sector. Although we are only at the preliminary stages of applying CARMAN to this area, we believe that it has considerable potential.

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