

CARMAN: A SYSTEMATIC APPROACH TO RISK REDUCTION BY IMPROVING COMPLIANCE TO PROCEDURES

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The first section of the paper discusses the role of procedures in high-risk systems such as chemical processing, aerospace and transportation. The results of a survey, which addressed the factors influencing the use of procedures in the petrochemical industry, are described. This and other evidence shows that there is often a wide disparity between the formal written procedures in an organisation and the ways in which the work is actually carried out. This has major implications for the control of risks and the maintenance of quality. The paper discusses reasons for this problem, and describes a systematic process called CARMAN, (Consensus based Approach to Risk MANagement) to prevent this situation.

Keywords: procedures, training, participation, task analysis, organisational culture

THE ROLE OF PROCEDURES IN ORGANISATIONS

In high risk industries, written procedures are typically subject to considerable scrutiny, since they are intended to represent the way in which the system should be 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, quality or environmental consequences, the organisation will be required to demonstrate that a safe system of operation (as represented in the procedures) existed. Another reason for the existence of written procedures is the need to satisfy the documentation requirements of quality management systems such as ISO 9001. These systems typically require that all working practices that can impact on quality be fully documented in the form of comprehensive written procedures.

It is clear that without procedures and therefore standardised ways of doing things, our complex, interdependent society would rapidly collapse. Heroic interventions have their place in unusual or unique situations which cannot be anticipated and where rapid action is necessary. However, when sitting in an aircraft over Heathrow during the rush hour, most of us would prefer to place our faith in the procedures rather than relying on the creative skills of an individual flight controller who may or may not have developed an improved way to do his job. However in some situations, complying with the 'official' procedure may not be the best or even the safest strategy. A process is needed to ensure that the 'Best Practices' which most effectively control risks are also the preferred practices of the people

at the sharp end who actually do the job. In other words, 'Best Practice' and 'preferred practice' need to become identical.

Procedures are the codification of working practices that are seen by an organisation as the best way to get things done. From the perspective of risk analysis, procedures can be seen as the means for achieving the commercial and other objectives of an organisation in the most efficient and cost effective manner, whilst minimising the risks arising from human or hardware failures.

Procedures are not only relevant to safety critical situations. They have a central role to play in quality systems. Without defined working practices it is impossible to achieve adherence to quality standards. Indeed, non-compliance with procedures is probably the most commonly cited causes of product variability in situations where there is significant human involvement in the manufacturing process.

THE PROCEDURES CULTURE SURVEY

As part of our work in a number of 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 operators when they are performing their day to day tasks. In one project, a procedures culture questionnaire was developed and distributed to nearly 400 operators and managers in a particular industry. In this section we summarise the results of that survey.

Extent of Usage of Procedures

The first set of questions related to the extent that procedures were actually used for different categories of task. For tasks perceived to be safety or quality critical, the use of procedures was high (75% and 80% respectively) but by no means universal. 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, 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 work. These figures imply that the actual average 'on-line' usage of procedures for safety/quality critical, problem diagnosis and routine tasks is quite low, i.e. 43%, 17% and 6% respectively. Later, we shall consider the issue of whether quality or safety will necessarily be compromised if a person does not always use step by step written procedures.

Use of Standardised Working Methods

One of the important functions of procedures is that they can provide the basis for standardised working practices, which should 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 individual variation in the way that tasks are actually performed. There are obvious implications for safety or quality critical 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 1.

'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 1: Reasons for Non-Usage of Procedures

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.

One definition of Best Practice is the performance of a task in a manner which achieves its required objectives whilst minimising any SHE (Safety, Health and Environment), economic and quality risks. As indicated by the survey discussed above, in many cases the formal written procedures do not document Best Practice and also may not correspond to the way in which the work is actually done. The disparity between the formal procedures and Best Practice is due to two main reasons. Procedures are often written by technical specialists or engineers who do not have a high level of hands-on experience with the work environment and may also be unaware of 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 organisational learning and gradual changes in working practices. These problems gradually erode the credibility of the official procedures, and can give rise to the use of informal undocumented methods that may or may not be effective in controlling risks.

Conclusions from the Survey

The conclusions that emerge from this study are that in the industry surveyed, the majority of tasks were performed without the on-line use of step by step written procedures. There were also variations in the ways in which tasks were performed, between both shifts and individuals, 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. However, the existence of 'Black Books' indicates that there is a definite need for some form of on-line support, which is not provided by the existing procedures systems.

Human Reliability Associates have developed a methodology, called the Consensus based Approach to Risk Management (CARMAN), to address some of these problems. The original impetus for CARMAN came from a number of procedures improvement projects where the main focus was on improving the usability of procedures by applying ergonomics design standards to issues such as readability, layout and formatting. However, it was found that even when the usability of procedures was considerably improved, their level of usage was sometimes still low, and procedural violations still occurred. This led to work aimed at understanding the causes of procedural non-compliance, and the development of the CARMAN approach that combined insights from task and risk analysis, group processes, and work on organisational learning. This approach was gradually refined by being applied to a number of petrochemical plants.

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

DEVELOPING A CONSENSUS BASED PROCEDURES CULTURE

The key to maximising compliance to procedures lies in developing a culture where the preferred practices are identical to the best practices, which are then documented as the 'Reference Procedures'. The Reference Procedures provide the basis for training content and competency assessment criteria, and also guide the development of the most appropriate form of on-line support. In order to achieve these objectives, a consensus process is required which evaluates working practices to achieve agreement about the best methods for performing tasks. It should be emphasised that such a process must not only include shop floor personnel, but also technical specialists who may have insights into why a task should be performed in a particular way.

The process seeks to create 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 consensus has been established amongst the different stakeholders (i.e. shop floor personnel, technical specialists and managers) concerning the working practices that will be adopted. If a working practice has been developed via a consensus process, there are strong group pressures to adhere to the procedures produced by the process. These group pressures partly stem from a desire of a group, e.g. a particular shift that has participated in the consensus process, not be left behind in the implementation of the agreed working practices. Participation in the consensus process involves arguing one's corner and possibly relinquishing the current way of performing a task in favour of a demonstrably superior approach. Given that the consensus process usually involves give and take by the different stakeholders, it is likely that everybody will leave the process with the feeling that at least some of the time their view has prevailed and they have contributed to establishing

the best practice. In management theory terms, the objective is to create a 'Win-Win' situation.

Measures to overcome barriers to the acceptance of CARMAN in an organisation can be summarised as follows:

- All participants in the process should feel that they have made a significant contribution to the best practices that have been developed, in order to maximise the sense of ownership
- The process should be driven primarily by the end users of the procedures and job aids, with the assistance of the facilitator
- Sufficient resources must be made available by senior management to ensure that all interested parties have an opportunity to be involved in the development of the best practices via the consensus group
- If incidents still arise, there should be immunity from blame and disciplinary sanctions as long as the agreed best practices can be shown to have been in use at the time. In this case, responsibility is deemed to be shared by all the participants in the process, and there is a continuing role for the consensus group to find out why the practice failed and to develop a revised Best Practice to prevent a recurrence of the problem.

The Role of Task Analysis

One of the important requirements for reaching a consensus is the existence of a common method for describing tasks in a clear, unambiguous manner, such that there is a shared understanding of the alternative ways of performing a task. In order to achieve this, participants in the consensus groups are trained to document their tasks using a form of task analysis called Hierarchical Task Analysis (HTA). HTA was originally developed for use in training operators in the process industries. It has two major advantages: firstly it is easy to learn, and secondly, it allows tasks to be described at varying levels of detail. The level of detail of the description is based on two criteria:

- Can the risks associated with errors be identified at the current level of detail of the description?
- Is the task described in sufficient detail to allow training specifications, job aids and procedures to be developed which will control the risks?

Figure 2 shows first level of an HTA for a booster pump. It can be seen that the task is broken down into a series of subtasks, the text in the bottom left of the box specifying who performs the subtask (OT is the outside technician, and CR the Control Room operator). The preconditions box specifies the starting assumptions of the analysis, and the plan box the conditions governing the execution of the subtasks (e.g. timing, ordering). It should be emphasised that an HTA is not a flowchart, but closer to a functional decomposition into a series of hierarchical goal directed activities. If a line is drawn below a subtask, this means that the task does not need to be decomposed further, since both of the criteria set out above (i.e. risks identified and sufficient detail for training purposes) are satisfied. Figure 3 shows a further breakdown of one of the subtasks. It can be seen that at each level of the decomposition a separate plan is developed. The block diagram form of HTA can be

expressed in a more compact textual format, where each level of the analysis is represented by indented text. Our experience has shown that operators have no difficulty in learning HTA given appropriate guidance, and they can use it to represent all types of task. A further advantage of HTA is that it very readily translates into a format suitable for documenting procedures. Breaking complex tasks into a series of subtasks with clearly defined goals facilitates ease of understanding of the overall structure of a task. This is valuable both during training and for on-line use of the procedure.

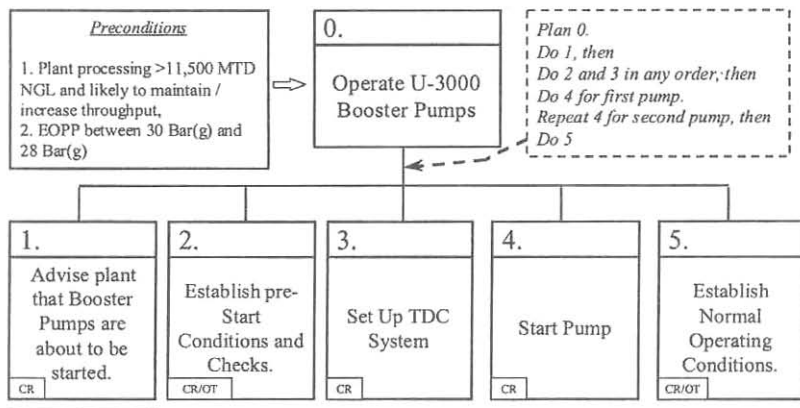


Figure 2: First level of Hierarchical Task Analysis for Booster pump

Integration between Training, Competency Assessment and Procedures

One of the major reasons for lack of compliance with procedures is often that people are simply unaware of the Best Practice for performing a task. This often arises from the absence of a system that provides baseline Best Practices 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. However, 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 documented as Reference Procedures.

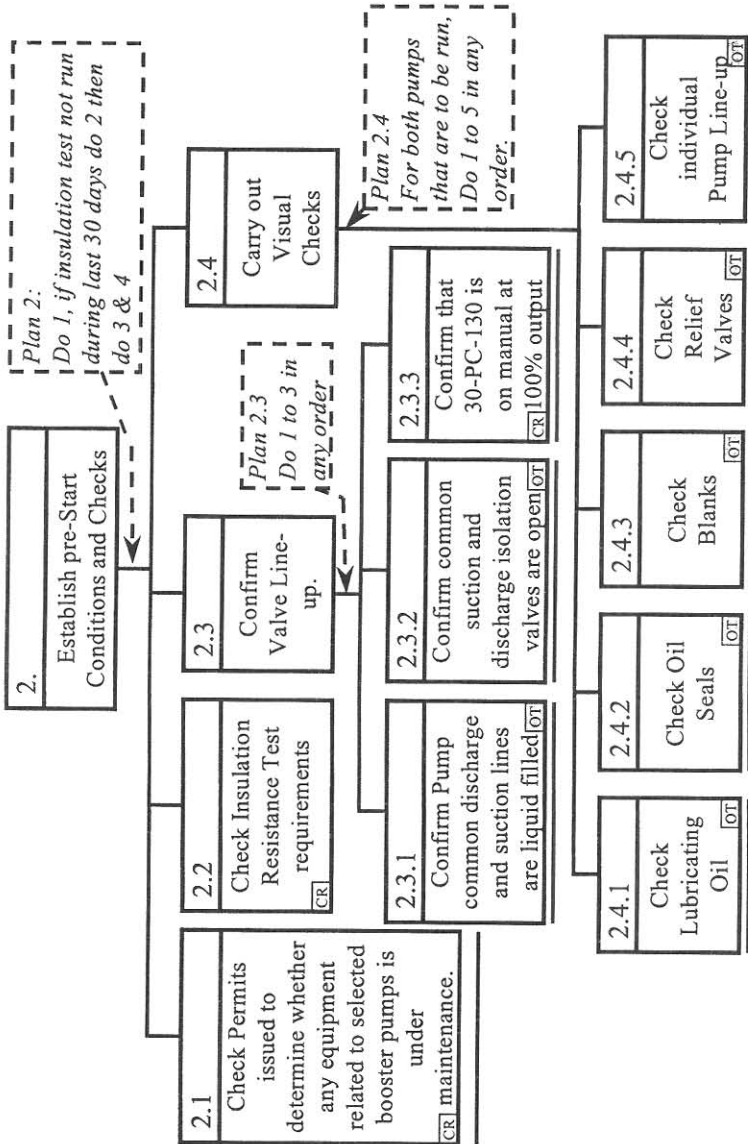


Figure 3: Break down of Subtask 2 in HTA format

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

In many industries, particularly those where formal quality management systems have been applied, it is common to find voluminous manuals containing detailed step by step instructions for performing tasks. However, a close examination of these documents often reveals that they are either in pristine condition, or else are very dusty. This tends to confirm the view that only a small subset of the information in detailed step by step instructions is actually consulted by experienced technicians. The assumption that a large volume of written step by step procedures is the best means for providing the information required to perform a task is based upon a misunderstanding of the role of procedures. They cannot simultaneously function both as formal statements of policy and also as documents to support a person who is performing a task. This is partly because the level of documentation that is needed to support best practice will depend on the level of experience and skill of the worker. However, in almost all cases, we find the documentation of standard practices to be much more detailed than that required for on-the-job support. 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. This information may include critical values for parameters such as flow rates or temperatures, sets of rules that will optimise quality or production, or short aide memoirs for handling infrequently occurring but critical disturbances. This information may be in the form of flow charts, checklists or graphics, depending upon how it is best represented for the needs of the end users.

Many tasks will be performed primarily on the basis of skill and experience. However, some form of on-line job aid will often be required, particularly if a task is complex and / or infrequently performed. This situation often arises in organisations where multi-skilling is employed, since this often means that workers only infrequently encounter certain jobs, and hence erosion of skills may arise. The format for such job aids needs to be tailored to technicians' 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 technicians' 'Black Books' and it is often a useful exercise to encourage the sharing of this information during the development and documentation of Best Practices. One of the functions of job aids is to provide critical reference information such as dimensions and tolerances in an easily accessible form. Also, written documentation may not be the best way of presenting information, especially for use in unusual situations when a rapid response may be required. Graphical or pictorial representations may sometimes be preferable in this case. The CARMAN process provides decision aids for selecting the appropriate level of support (see Figure 6). Obviously, job aids still need to be subjected to the same levels of change control as other documentation in a quality system.

THE CARMAN PROCESS

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

The overall structure of Stage 1 is shown in Figure 4. Prior to commencing the steps shown in Figure 4, 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 stakeholders, and to assist in the development of consensus regarding Best Practice. It is essential that personnel respect the facilitator, 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, which is an important technique in the process.

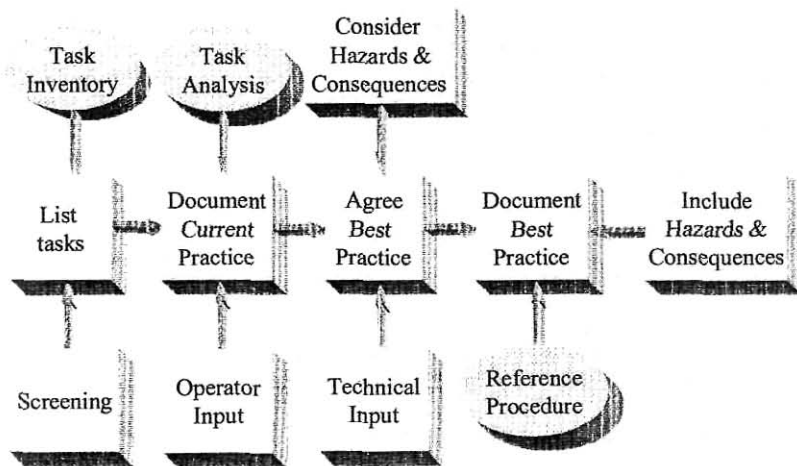


Figure 4: Stage 1 of CARMAN

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 that are considered to be critical. The current practices for the tasks of interest are then documented using HTA. Usually there will be differences between individuals and 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 a Reference Procedure together with information concerning the possible hazards and consequences.

In Stage 2 of CARMAN (Figure 5), 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.

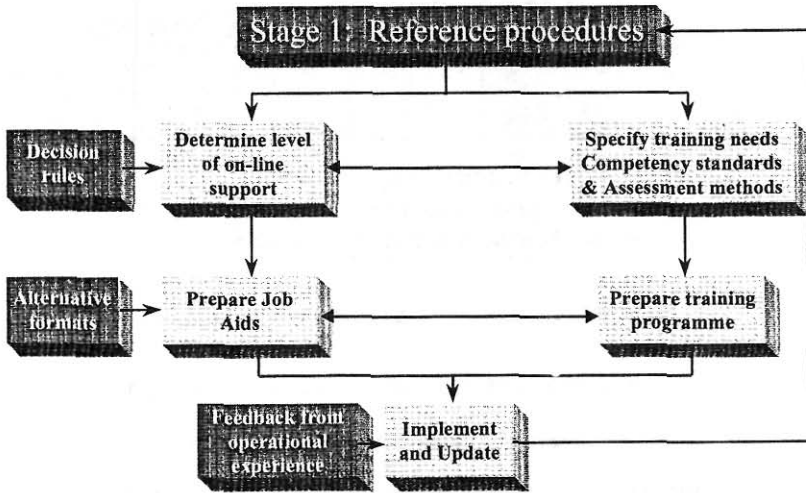


Figure 5: Stage 2 of CARMAN

An example of a decision rule for a particular set of experienced workers is shown in Figure 6. 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 for on-line support. This is in sharp contrast to many organisations, where nearly all cells in the matrix would specify the use of step by step instructions.

Task Criticality	High			Medium			Low		
	Freq	Infreq	Rare	Freq	Infreq	Rare	Freq	Infreq	Rare
Task Familiarity									
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 6: Decision Aid for choosing level of Job Aid Support

CASE STUDIES OF THE APPLICATION OF CARMAN

Application to Tasks in a Large Oil Refinery

So far, CARMAN has been most extensively applied in the petrochemical industry. In a project with a major oil refinery, the long-term objective was to apply the process to all operational tasks on the site in order to produce measurable benefits in terms of safety performance. The stages of the project were as follows:

- Pilot project to demonstrate proof of principle and benefits
- Development of task inventory and selection of initial departments within which to implement the process
- Selection of example tasks within departments
- Selection and training of facilitators in tools and techniques
- Developing reference procedures and associated job aids for selected tasks by the facilitators with guidance from the consultants
- Setting up consensus groups
- Initial facilitation of consensus groups by consultants in conjunction with facilitators
- Monitoring of consensus groups to ensure effectiveness of the CARMAN process
- Development of job aids and reference procedures by the consensus groups.
- Repeat of previous steps to develop reference procedures and job aids across the site
- Extension of the process to develop integrated training and procedures system

The pilot project was conducted over a period of six months and included the analysis of a complex process operation and also two non-process but safety critical tasks, i.e. excavations and vehicle entry on site. Both reference procedures and job aids were developed for these areas. The pilot study provided the opportunity to fine-tune the process and to demonstrate its applicability to simple but critical tasks as well as more complex production operations.

Once the pilot study was completed and the results analysed, the next stage involved developing an implementation plan for the site as a whole. The first stage of this plan was to develop an inventory of all the tasks on the site, and select the specific departments and tasks within which the process was to be initially applied. Training programmes were developed and personnel from the selected departments were selected and trained as facilitators. The personal qualities of facilitators are extremely important. They need to be trusted and respected by their peers, and have sufficient social skills to successfully manage the sometimes stormy discussions that can arise during the process of reaching a consensus. If possible, we recommend that facilitators also receive training in how to manage group dynamics. In order to ensure that the facilitators had a comprehensive grasp of the process, they applied it to example tasks from their departments, under the guidance of consultants.

Once the facilitators had demonstrated their competence, by producing acceptable reference procedures for the example tasks, they were involved in setting up consensus groups and facilitating these groups with the guidance of the consultants. Currently the process is now in production mode and is being extended to other units on the site. The next stage will be to extend the project to integrate the site training system into the procedures and job aids. So far the implementation process has taken approximately 18 months. During the second year of the process, the role of the consultants has changed from that of implementation to monitoring, consolidation and the extension of the process to new departments. The measurable benefits to date have included the following:

- Reduced emissions of effluent across the site
- Improved utilisation of steam
- Plant start-up times substantially reduced
- Fewer pump breakdowns arising from incorrect operations

A comprehensive before and after evaluation is currently being implemented, to evaluate key performance indicators in the area of safety and quality. However, it is clear that the project costs have already been recouped in terms of improved efficiency and reduced down time.

Management of plant disturbances

Another significant area of application for CARMAN has been the improved handling of plant disturbances. In a new polymer plant there were concerns regarding incidents which could lead to considerable financial losses as a result of product solidifying in the pipe work following the incorrect handling of disturbances. In the event of a disturbance, in which the heating system usually tripped out, operators were required to diagnose the problem and take appropriate corrective actions to restore the heating system, all within a very restricted time frame. Because of newness of the plant, no effective strategies had been developed for

handling the disturbances and for providing appropriate support in the form of training and job aids.

For the application of CARMAN, ten of the most significant disturbances, in terms of potential financial loss, were selected for analysis. The CARMAN process was applied to develop the most effective strategies, by pooling the knowledge that existed both across shifts and between technical specialities. Interestingly, the development of the optimal methods for handling disturbances involved facilitating communication between groups of individuals, e.g. chemical engineers and operators, who would not normally have a forum for discussion. Another result of the analysis was the finding that the process information display system, although very sophisticated in some ways, did not provide the critical information required to handle the disturbances in a way that supported the strategies required for effective response. The CARMAN process can therefore be seen as providing the additional benefit of allowing the process information needs of the operators in critical tasks to be defined in a systematic manner. Applying CARMAN to the polymer plant has led to significant improvements in safety performance as well as reduced losses arising from disturbances.

A similar application of CARMAN to disturbance handling in a refinery has focussed on preventative measures designed to reduce the likelihood of incidents. During a recent insurance evaluation of the plant, the assessors were sufficiently impressed by the results of the process that they retained some of the job aids and other documentation as a model to show other plants what could be achieved. CARMAN is now being applied to develop an improved emergency response system, by identifying the specific needs of the participants in the system by means of task analyses and consensus groups. It is also intended that a new Quality Assurance System being developed at the plant will be based on the principles of CARMAN. The main idea is that the system will provide a participative process so that the practices needed to ensure that quality standards are achieved and maintained are developed by the personnel who have day to day contact with the plant. The intention is that all of the stakeholders in the quality assurance process (managers, plant technicians and technical specialists) are included. In this way, the Quality Assurance system can become a true continuous improvement process rather than a paper driven bureaucracy.

CONCLUSIONS

This paper has described the findings from a study of the use of procedures in the petrochemical industry, and has shown that a major problem exists with regard to the differences that exist between informal working practices and those documented in formal procedures. In order to solve this problem, CARMAN, a consensus-driven approach to identifying risks, and developing Best Practices to control these risks, has been developed. This approach has been successfully applied to several organisations in the petrochemical sector over the last few years. It provides a framework to control safety, quality and other risks by the development of a participative culture, and the integration of training and procedures. It also provides a logical method for selecting the type and degree of on-line support required to complement the skills acquired through training and experience. The process can be seen as a means for achieving many of the objectives of both safety management and quality systems, in addition to providing measurable benefits in terms of improved efficiency.