A HUMAN FACTORS APPROACH TO EFFECTIVE MAINTENANCE

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Abstract

Traditionally in the field of Human Factors within the nuclear industry, the focus has been to identify the potential for human errors in operating tasks, and develop strategies to prevent their occurrence, provide recovery mechanisms, and mitigate the consequences of error as appropriate. Past experience has demonstrated however a significant number of human errors within the nuclear industry occur during maintenance tasks. It is for this reason, and the fact that our nuclear power plants are ageing and increasingly in need of maintenance, that the industry must pay more attention to maintenance tasks.

The purpose of this paper is to present a framework for effective maintenance programs, and based upon this framework discuss an approach (an audit tool) that can be used to both design such a program, and to assess existing programs. In addition, this tool can form the basis of cost benefit decisions relating to priorities for improvements to existing programs.

Introduction

Traditionally in the field of human factors within the nuclear industry, the focus has been to identify the potential for human errors in operating tasks, and develop strategies to prevent their occurrence, provide recovery mechanisms, and mitigate the consequences of error as appropriate. Since the Three Mile Island accident in 1979, more than 35% of abnormal occurrences can be attributed to maintenance errors, according to NUREG-0933, “A Prioritisation of Generic Safety Issues – TEM-HF8: Maintenance and Surveillance Program”. In addition, a special study discussed in the same NUREG report, which examined licensee event reports from 1981 to 1983, discovered that 19 out of the 27 events resulted from human errors during maintenance and testing.

This provides evidence that maintenance errors are at least as prevalent as human errors during operations tasks. It is for this reason, and the fact that our nuclear power plants are ageing and increasingly in need of maintenance, that the industry must pay more attention to maintenance tasks. Typically maintenance activities are carried out under time constraints, yet are pivotal to the achievement of productivity targets. This leads to situations where maintenance personnel work long hours, and so error precursors are created. It is therefore important that maintenance activities are provided with support in a number of areas to comply with the principle of defence in depth.

It can be considered that there are a number of elements relating to human performance that contribute to a successful maintenance program:

- Design for maintainability – if a plant was not designed with maintenance in mind then this is a challenge during the operating life of the plant, and during plant refurbishment
- Provision of appropriately trained and experienced maintenance staff
- Provision of usable, accurate and up to date maintenance procedures
- Good planning
- Human performance program, including error prevention tools, and performance measures
- Strategies to learn from past performance

The purpose of this paper is to present a framework for effective maintenance programs from a human performance perspective, and to discuss an audit approach or tool, based upon this framework, that can be used to both design such a program, and to assess existing programs. In addition, this tool can form the basis of cost benefit decisions relating to priorities for improvements to existing programs. The development of this tool is a work in progress. Further research is required to provide the level of detail that will allow an audit to be conducted of how effectively Human Factors issues are addressed within maintenance.

Human Factors Framework for Effective Human Performance within Maintenance

The framework itself is based upon the realisation that there are many factors that comprise an effective maintenance program from a human performance perspective (see figure1). The way in which a program is developed, planned, and implemented may be constrained by a number of internal and external influences, such as the way the plant was designed, the age and type of equipment to be maintained, the frequency and duration of outages, staffing levels and schedules, regulatory issues, and a number of other factors that may be historical in nature. It is not practical therefore, for an existing facility to start from scratch and develop an effective maintenance program that complies with all elements of best practice. It is desirable though to define the elements of best practice, ascertain where the organisation sits on a continuum from poor maintenance practices to excellence in this field, and define ways of moving further towards the excellence end of the scale.

Figure 1 shows the main overall components that can be considered to contribute to an effective maintenance program from a Human Factors perspective. Within the audit tool or methodology described in this paper, each of these elements identified in figure 1 is then divided into a number of sub-elements, or conditions, that must exist for the goal of the element to be achieved (see figures 2 to 7). The intent is that each of the sub-elements will be further decomposed in future iterations of the tool, to provide specific questions that can be answered in an audit situation. Each of the elements is discussed briefly below.

First of all the system or plant ideally should have been designed with maintenance in mind (see figure 2). This means that appropriate guidelines and standards are identified, and applied during the design process to ensure the following:

- physical access is available to maintain all pieces of equipment that are likely to require maintenance throughout the lifetime of the plant
- visual access is provided for all equipment to be maintained
- the physical demands associated with maintenance activities are within human capabilities and are not likely to cause injury or discomfort
- equipment and instrumentation is designed for ease of maintenance from a cognitive perspective, so that errors are unlikely
- maintenance is planned effectively to ensure that workload is acceptable whilst meeting the required frequency of maintenance

Some examples of useful standards and guidelines are included in the references [1-6]. It is intended that future development of this audit tool will lead to the identification of a suitable set of criteria for the acceptability of standards and guidelines. The effective implementation of the standards and guidelines is dependent upon the personnel possessing the appropriate level of experience in Human Factors, and upon Human Factors being addressed as an integral part of the design. This means that Human Factors issues will be identified and addressed from the start of the project (whether it is a new build or refurbishment project), and that decision making mechanisms are provided to address situations where Human Factors proposals may be in conflict with other design and project considerations.

When Canadian nuclear generating stations were designed and built, design for maintainability was not a common practice, and it is difficult to backfit a design to comply with such principles and guidelines. Design for maintainability should however be considered within modification and refurbishment projects, and be implemented as far as practical. This is a major challenge for today’s designers working within the constraints of yesterday’s design.

Although the expectation is that the maintainers will have the necessary skills, there will be a need for procedural documentation relating to complex tasks, tasks that have a large number of steps and/or the steps must be carried out in sequence, tasks that are carried out infrequently, and specialised tasks. These procedures must be based upon task analysis of the maintenance tasks, they must be written with usability in mind, and they must be up to date and accurate. The procedures must also be updated as part of the engineering change control process when modifications or additions take place within the plant (see figure 3).

For all maintenance activities, staff with the appropriate qualifications and experience must be available to carry out the maintenance activities. Maintenance task analysis and training needs analysis should form the basis of the identification of skills, knowledge and experience required to carry out maintenance tasks. Decisions must be made, based upon the educational and industrial environment in the country at that time, and internal economic factors, to determine whether the necessary skills will be subject to training internally or whether they will be recruitment requirements. Training programs should be designed to address the maintenance requirements of the plant, and to be compatible with the recruitment requirements. Refresher and retraining needs should be identified and implemented at frequencies that will ensure that the maintainers will remain proficient at tasks that are complex and perhaps not carried out very often. In addition, there must be methods of assessing post maintenance performance to validate the effectiveness of the recruitment and training processes (see figure 4).

For maintenance to be effective it must be well planned so that the best use is made of the available time. This is important to an operating facility relating to maintenance that can only be completed while the reactor is shut down, as the goal is to maximise the maintenance activities, while minimising the outage time, in order to meet productivity targets. This challenge has led to the need for risk based maintenance planning. Maintenance that is inappropriately rushed, or subject to cutting corners, has the potential to lead to unsafe conditions and the requirement for rework. This makes maintenance planning particularly important and requires that sufficient time and resources are allocated to the planning activity itself. In addition, adequate resources must be available for the completion of the maintenance tasks.

The impact of maintenance on operations must be clearly identified and addressed in situations where the reactor does not need to be shutdown. In addition, the impact of maintenance activities upon other maintenance activities in all situations must be considered. The scheduling, sequence and duration must be carefully planned. Skills, tools and equipment must be identified, available, purchased, and suitably located in time for the maintenance activities. Even with the best plan, the unexpected is still destined to occur. The facility must learn from unexpected occurrences and feed back their experiences into the next planning phase, through the use of the station's abnormal event reporting system (see figure 5).

Designing for maintainability, planning for maintenance, providing knowledgeable and experienced maintainers, and providing procedures are all proactive measures for ensuring effective maintenance from a Human Factors perspective. In essence they are all preparing for maintenance. There are ways in which we can implement best practices in the performance of maintenance activities, through the use of a human performance program and error free tools. Error free tools may include the following:

- procedural compliance – the requirement to follow procedures as they are written at all times, and to stop work if the procedure cannot be followed, in order to investigate the issue
- correct component verification– the practice of ensuring that the piece of equipment that is about to be manipulated is correct by comparing the equipment label against that contained in the procedure or the checklist. The maintenance activity may be completed by two people; one person to read out the component identifier from the procedure, and the other person to confirm that they have located the correct component
- correct unit verification – it is important in multi-unit operating stations to ensure that the maintainer is about to work on the correct unit

- use of work permits – the process of authorising work, ensuring that the system is in safe state for maintenance to be completed, and communicating the nature and duration of the work to others who may be impacted

These are just a few examples of practices that can be implemented to reduce the likelihood of human error. There should be ways of measuring maintenance performance, both relating to the human performance in maintenance activities and the resulting impact upon the equipment. The success of maintenance activities may be measured by recording such data as the number of rework activities that are carried out, and other performance data relating to the equipment itself. Lessons learnt should be fed back into the human performance program for maintenance tasks (as described in figure 6). This feedback should encompass "good" practices as well as poor practices.

Even if the plant is designed for maintainability, trained and experienced maintainers are provided, good procedures exist, and maintenance work is carefully planned, there are still likely to be unplanned events and occurrences associated with maintenance activities. The facility should learn from their experiences by investigating the causes and root causes of the events and take actions to ensure that the event does not recur (see figure 7).

Audit Tool for Assessing Human Performance within Maintenance Activities
This tool is based upon the framework described above, and follows the principles of the systems approach to effective performance. The systems approach requires that an organisation develops and implements policies, procedures and practices, evaluates the effectiveness of the policies, procedures and practices, and then uses the lessons learnt to make improvements to the policies, procedures, and practices. This systems approach is part of a program of continuous improvement. In this approach, the assessment of human performance within maintenance comprises 3 main steps:

Step 1 of the Assessment Tool– Baseline Assessment of Human Performance within Maintenance Activities
An audit will be completed at the plant using this assessment tool to ascertain a score for each of the elements of the framework. Any deficiencies and areas for improvement are identified, and presented to the plant. The extent to which the plant has met the objective of each sub-element will be rated on a scale of 1 to 5, with 1 representing a situation where significant deficiencies exist, and 5 represents a situation where excellence has been achieved. A percentage score for each of the elements is then calculated, and an overall percentage is determined.

Step 2 of the Assessment Tool – Document Action Plan
The plant will be asked to prepare an action plan to address the issues identified in the audit. This action plan will define the owner of the actions, the method of implementation and a timeframe for completion. The auditor will review the action plan for applicability to the issues identified in the audit, any modifications will be made to the plan, and a final version will be developed. A date and time will be discussed for the reassessment audit at this point.

Step 3 - Reassessment of Human Performance within Maintenance Activities
The audit will be conducted again to measure the improvements that have been effected since the baseline audit.

This process should be iterative. This means that the plant can commit to a series of ongoing audits to suit their plan for improvements. The audits may be carried out on an annual, or biannual basis, or at any other suitable frequency requested the plant. The frequency may be guided by the audit results and the action plan, and may not follow a prescribed frequency, depending upon the needs and priorities of the organisation at that time. The percentage scores may be compared against that of other facilities within the industry, if agreed by all parties concerned.

The intent of this paper has been to raise the awareness of the need for an approach for the assessment and improvement of human performance in maintenance, which addresses the many different facets of maintenance performance in a strategic manner. In improving the areas of design, training, procedures, planning, human performance, and learning from experience, the nuclear facility will be utilising an integrated approach to performance assurance which will facilitate identification, prioritisation, and planning for maintenance improvements, based upon existing successes and challenges.

References

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2. EPRI, NP-4350, 1985, “Human Engineering Design Guidelines for Maintainability.”

3. MIL-STD-1472F, 1999, “Human Engineering Design Criteria for Military Systems, Equipment, and Facilities”, US Military.

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5. Sanders, M.S., and McCormick, E.J., 1983, “Human Factors in Engineering and Design”, McGraw-Hill Inc.

6. Van Cott, H., and Kincade, R., 1972, “Human Engineering Guide to Equipment Design”, New York: McGraw-Hill.

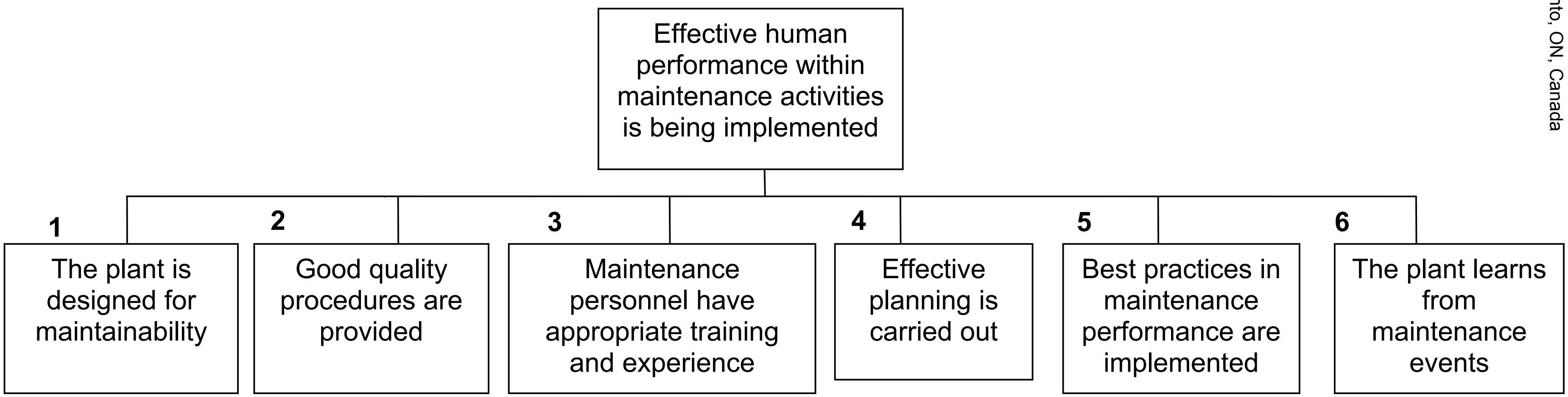

Figure 1: Framework for Effective Human Performance within Maintenance

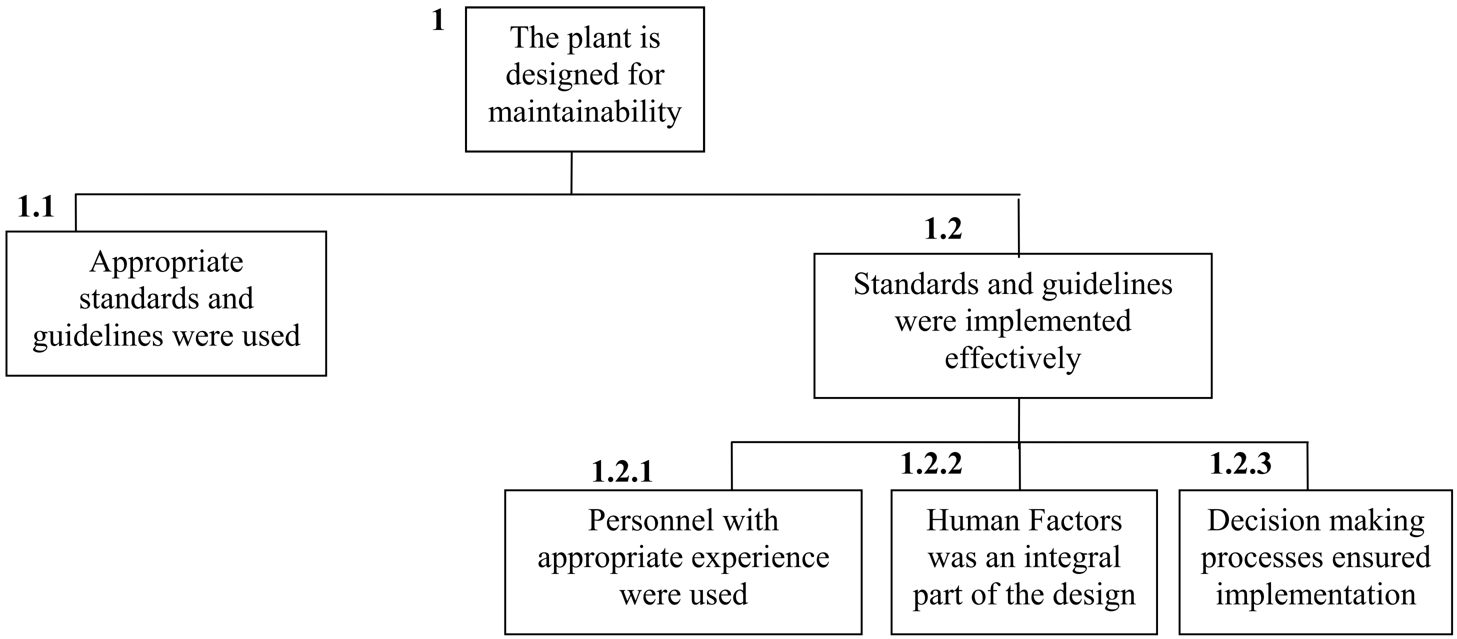

Figure 2: Design for Maintainability Issues

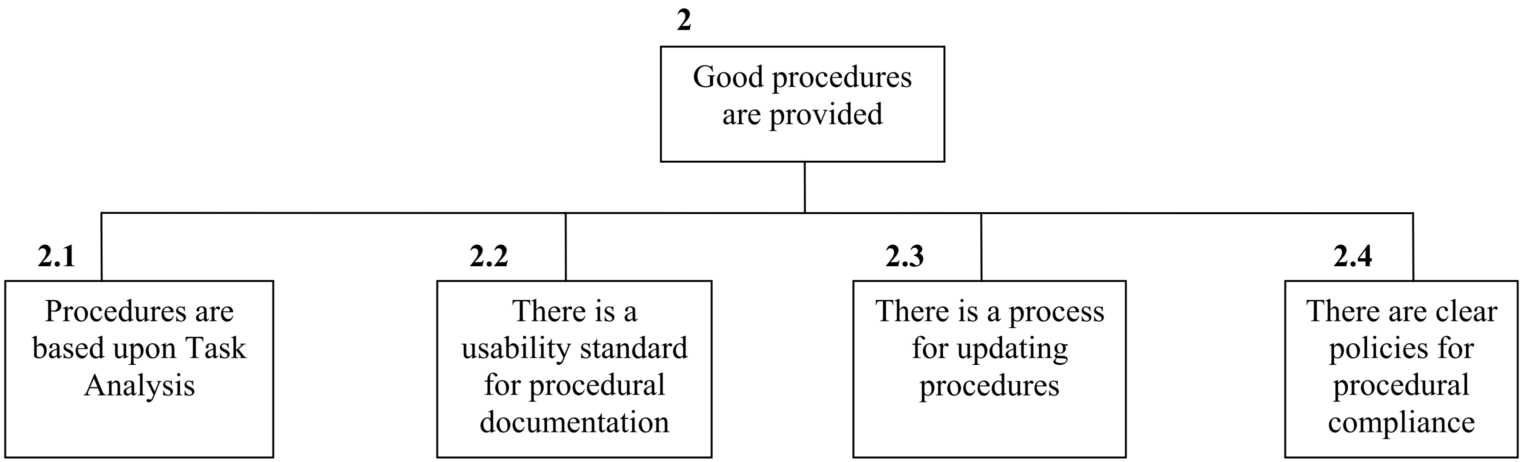

Figure 3: Procedural Issues Associated with Effective Maintenance

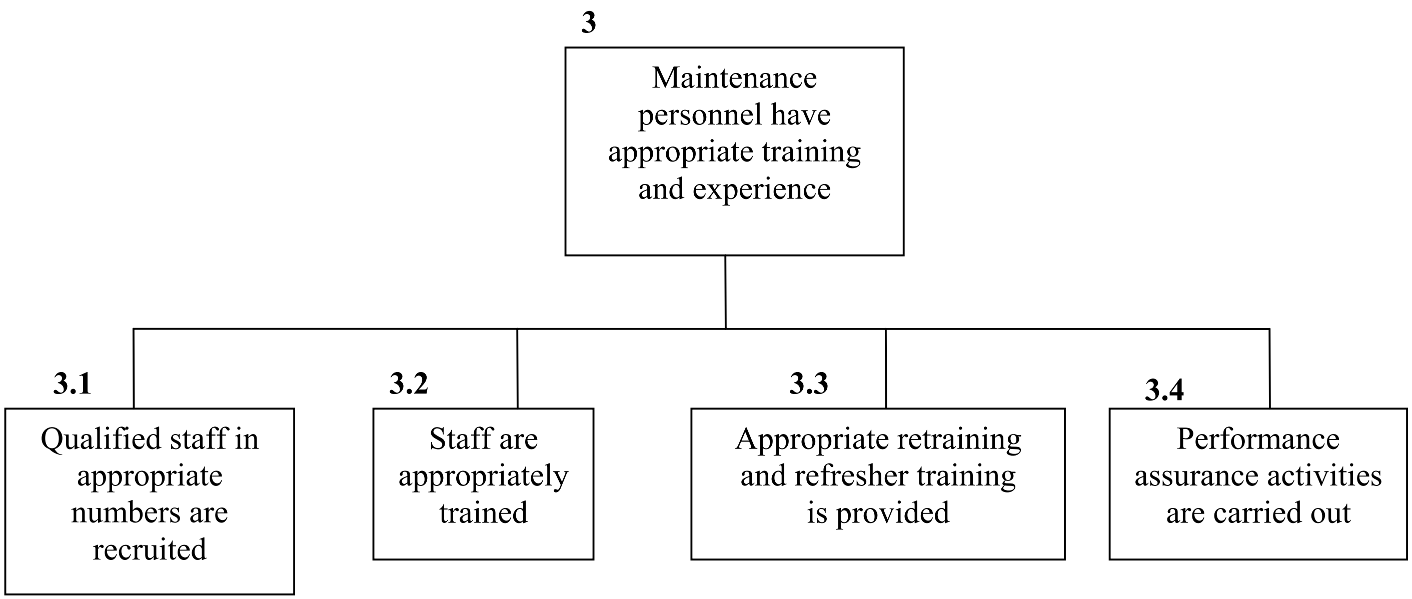

Figure 4: Training Issues Associated with Effective Maintenance

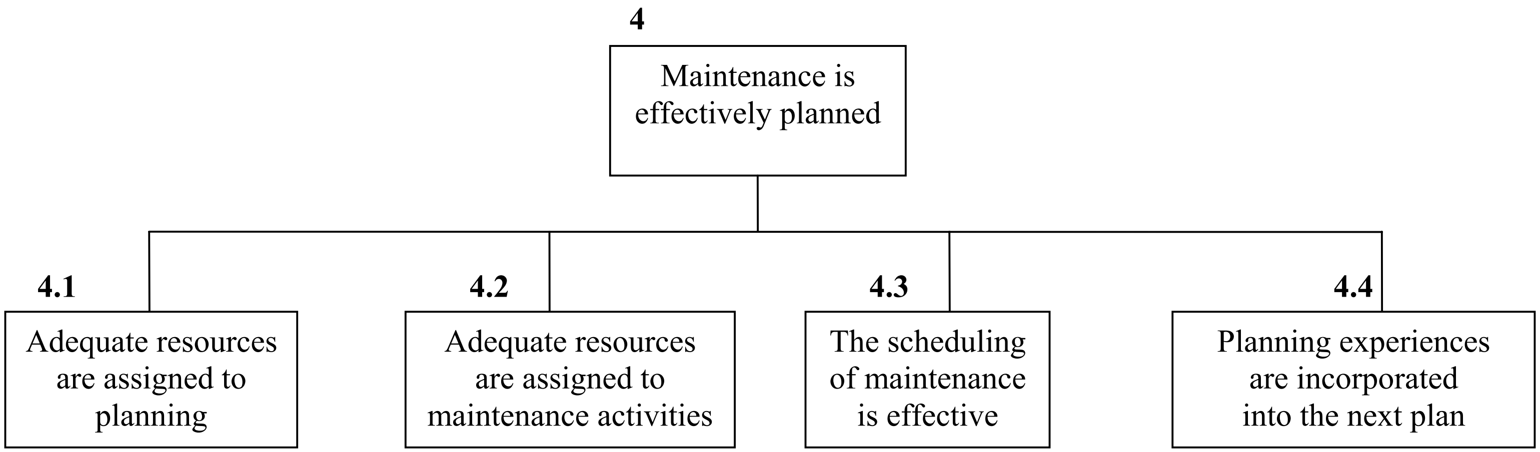

Figure 5: Planning Issues Associated with Effective Maintenance

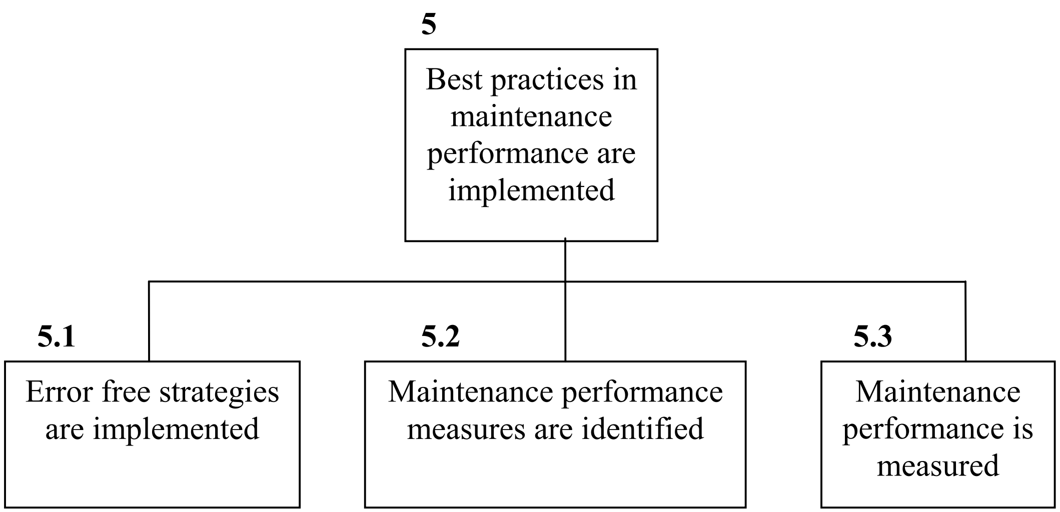

Figure 6: Human Performance Issues Associated with Effective Maintenance

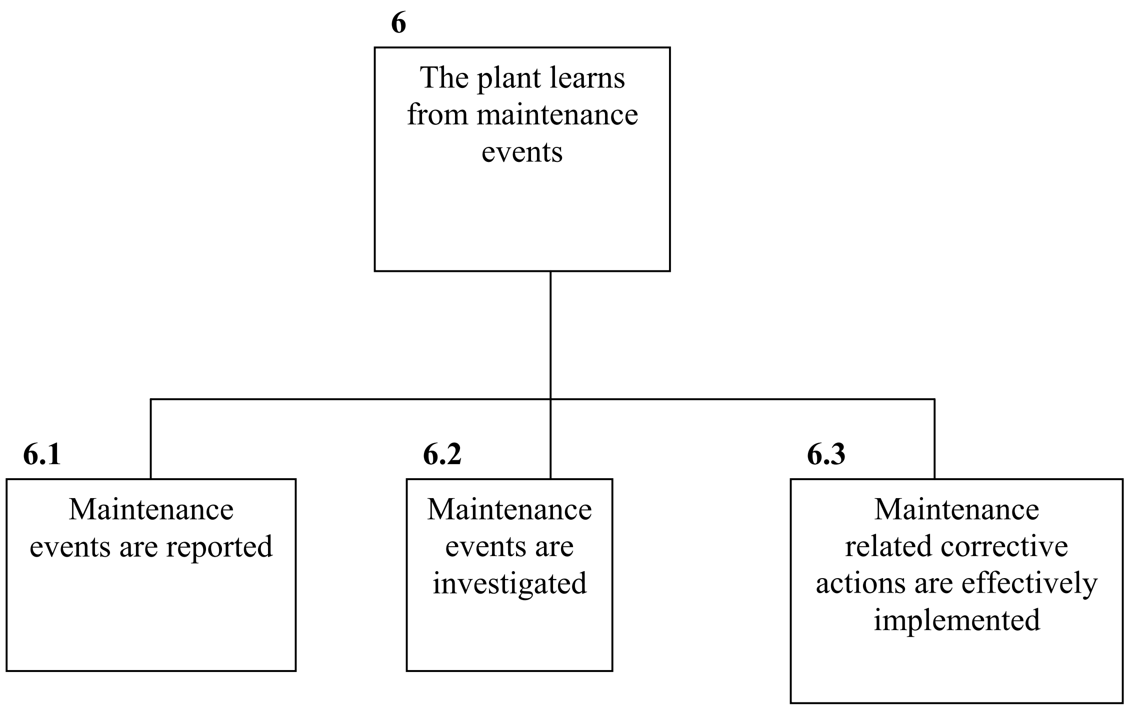

Figure 7: Feedback Issues Relating To Effective Maintenance