# 7 Human Factors in Power Plant Maintenance

## 7.1 INTRODUCTION

Human factors play an important role in power plant maintenance because improving the maintainability design of power plant facilities, systems, and equipment with respect to human factors helps to increase, directly or indirectly, plant productivity, availability, and safety. For example, past experiences indicate that many plant outages have been either caused or prolonged by human factors problems associated with maintenance. It is estimated that the loss of plant power generation costs at least $500,000 to $750,000 per day [1].

Interest in human factors issues in the power industry is relatively new in comparison to the aerospace industry. In fact, it may be traced back to the middle of the 1970s when the WASH-1400 Reactor Safety Study criticized the deviation of the design of controls and displays and their arrangement in nuclear power plants from the human factors engineering standards [2]. The Electric Power Research Institute (EPRI) took note of this criticism and sponsored a study concerning the review of human factors in nuclear power plant control rooms in the United States [3]. This study highlighted various minor and major human factors–related deficiencies that can result in the poor effectiveness of the man-machine interface [1, 3]. Subsequently, over the years, the occurrence of many human factors–deficiency-related events, including the Three Mile Island nuclear power plant accident, has resulted in an increased attention to human factors in various areas of power generation including maintenance.

This chapter presents various important aspects of human factors in power plant maintenance.

## 7.2 HUMAN FACTORS ENGINEERING MAINTENANCE–RELATED DEFICIENCIES IN POWER PLANT SYSTEMS

Over the years, many studies have identified various human factors–engineering deficiencies, directly or indirectly maintenance related, in power plant systems. One survey-based study has classified such deficiencies under six categories [4]. In descending order, these categories are as follows [4]:

**Limited access or inadequate clearance to perform maintenance.** It means that there is inadequate clearance for inspection, no room for the right tool, etc.

**Equipment poorly designed to facilitate the maintenance activity effectively.** It means that the required work is too detailed to perform with mask and gloves on, design is complicated (i.e., too difficult to repair), it is impossible to open cabinet doors all the way, etc.

**Equipment/systems inherently unreliable.** It means items such as cheap and dirty design of the rod position indicators, flatbed fitter is under-designed and requires constant maintenance, overly sensitive controllers, and the system drifts and is unstable.

**Personnel safety hazard.** It means items such as no safety rail where is, say, a 35-foot drop, oil on the floor from the main feed pumps, hydrogen unloading facility is rather dangerous, and poorly designed equipment in high-radiation areas.

**Impaired mobility for both personnel and equipment.** It means items such as no elevator access to the turbine deck, lack of work platforms with ladders, one way access to hatch into containment, no cargo elevators where needed, and lack of pad eyes for lifting.

**Miscellaneous.** It means items such as lack of standardization, high-temperature environment, and poor air conditioning.

## 7.3 DESIRABLE HUMAN FACTORS ENGINEERING MAINTENANCE–RELATED ATTRIBUTES OF WELL-DESIGNED SYSTEMS IN POWER GENERATION

The survey-based study of Ref. [4] reported many desirable human factors–, engineering maintenance–related attributes of well-designed systems used in power generation. In descending order, these attributes are as follows [4]:

- **Effective accessibility.** It means items such as good accessibility around the diesels, easy access to air compressors, and good access to rod controls for repair.
- **Ease of disassembly, removal, and repair.** It means items such as modular design of rod controls, easy removal of circuit breakers, and modules on rollout rails.
- **Ease of system troubleshooting testing, and monitoring.** It means items such as engineered guards easy to test, built-in calibration system, good test jacks and easy to input signals, and control cabinet for boiler control easy to troubleshoot.
- **Effective lifting and movement capability.** It means items such as built-in hoist always in place, easy removal through roof, and access for vehicles.
- **Highly reliable equipment.** It means items such as reliable relays, air compressor easy to operate and rarely breaks down, and highly reliable engineered safeguards actuation system.
- **Ease of inspection and servicing.** It means items such as good access for preventive maintenance, easy to spot problems, and ease of oil changes.
- **Good quality prints and manuals.** It means items such as readable prints, understandable procedures, and detailed operating instructions.

- **Avoidance of contaminated areas.** It basically means, for example, equipment placed in an accessible location well outside the "hot" areas.
- **Good laydown area.** It means, for example, excellent laydown area for turbine-generator.
- **Availability of required tools.** It means the availability of all necessary tools, for example, all the essential special tools provided for a complicated assembly.
- **Miscellaneous.** It includes items such as fail-safe design and frequent use of mock-ups for training.

## 7.4 POWER GENERATION PLANT PERFORMANCE GOALS THAT DRIVE DECISIONS ABOUT HUMAN FACTORS

There are many power generation plant performance goals that drive, directly or indirectly, maintenance-related decisions about human factors. These goals may be grouped under three classifications as shown in Figure 7.1 [5]. The classifications are plant safety, plant productivity, and plant availability. The plant safety goals include minimizing injury to personnel, damage to equipment, and, in the case of nuclear power plants, eliminating the potential for release of radioactivity to the environment and reducing the radiation exposure to humans.

The plant availability goals include increasing the amount of time the plant can operate at full power generation capacity by minimizing the occurrence of human errors that, directly or indirectly, contribute to system/equipment failures or increase system/equipment corrective maintenance time.

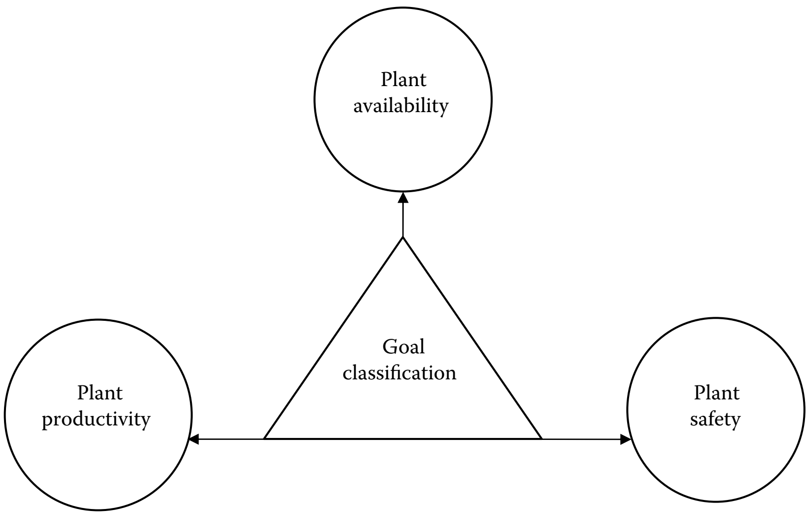


**FIGURE 7.1** Classifications of power generation plant performance goals that drive decisions about human factors.

Finally, the plant productivity goals include improving the reliability, efficiency, and motivation of all involved personnel.

## 7.5 STUDY OF HUMAN FACTORS IN POWER PLANTS

A survey of the maintenance of five nuclear and four fossil-fuel power generation plants with respect to human factors revealed various types of, directly or indirectly, human factors–related problems. This study was wide ranging in scope, extending to an examination of items such as facilities, environmental factors, designs, organizational factors, procedures, spares, and tools.

The study findings were grouped under the following 16 classifications [1, 4]:

- Facility design factors
- Environmental factors
- Equipment maintainability
- Anthropometrics and human strength
- Movement of humans and machines
- Labeling and coding
- Maintenance stores, supplies, and tools
- Maintenance information, procedures, and manuals
- Personnel safety
- Communications
- Equipment protection
- Productivity and organizational interfaces
- Preventive maintenance and malfunction diagnosis
- Job practices
- Selection and training
- Maintenance errors and accidents

Some of the above classifications are described below [1, 4].

The facility design factors classification is concerned with, directly or indirectly, human factors–related problems pertaining to facility design. Some of these problems are high noise levels, poor temperature-ventilation control, inadequate facility to store contaminated equipment, and insufficient storage space to satisfy maintenance needs effectively. The environmental factors classification is concerned with human factors problems pertaining to the environment. Two examples of these problems are heat stress and a high variability of illumination.

An example of the problems belonging to the anthrometrics and human strength classification is the lack of easy access to equipment requiring maintenance. Some of the problems belonging to the labeling and coding classification are poorly descriptive label tags, under-estimation of the need for identifying information by designers, unsystematic replacement of labels lost or obscured over time, high likelihood of the occurrence of maintenance errors in multi-unit plants in which both units are identical or highly similar in appearance.

Some of the problems belonging to the personnel safety classification are radiation exposure, steam burns, chemical burns, and heat prostration. The communications classification includes problems such as inadequate capacity of the existing communications system to satisfy the volume of communications traffic required throughout the plant, particularly during outages, the protective clothing worn by maintenance personnel while working in radioactive environment causes serious impediments to effective communications and insufficient communication coverage throughout the plant.

The most common problem belonging to the equipment maintainability classification is the placement of equipment parts in locations that are inaccessible from a normal work position. The main problem belonging to the maintenance information, procedures, and manuals classification is poorly written procedures and inadequate manuals. Two problems belonging to the selection and training classification are the informality of the training process, with no clearly defined selection criteria and lacking validated screening tools or techniques and the overall inadequacy of the training efforts in nuclear power plants.

## 7.6 HUMAN FACTORS APPROACHES FOR ASSESSING AND IMPROVING POWER PLANT MAINTAINABILITY

Many human factors methods can be used to assess and improve power plant maintainability. Six of these methods are shown in Figure 7.2 [1, 6]. Each of these methods is described below, separately.

### 7.6.1 Task Analysis

This is a systematic approach used to assess the equipment maintainer's needs for successfully working with hardware to accomplish a given task. The analyst records and oversees each task element and start and completion times, in addition to making observations concerning impediments to effective maintainability. The observations

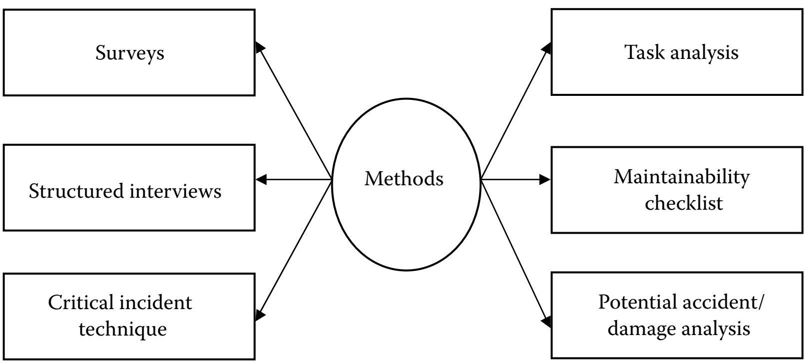


**FIGURE 7.2** Human factors methods for assessing and improving power plant maintainability.

are categorized under sixteen classifications: equipment maintainability design features, availability of appropriate maintenance information (e.g., schematics, procedures, and manuals), tools and job aids, maintenance crew interactions, equipment damage potential, decision-making factors, personnel hazards, lifting or movement aids, communication, training needs, spare-parts retrieval, workshop adequacy, supervisor-subordinate relationships, environmental factors, access factors, and facility design features [1].

Additional information on the method is available in Refs. [1, 6].

### 7.6.2 Maintainability Checklist

This checklist is based primarily on the survey study reported in Ref. [4] and is divided into 14 distinct topical areas. These areas are personnel safety, radiation protection, communications, facilities, maintenance information, equipment maintainability, labeling and coding, preventive maintenance, anthropometrics and human strength, selection and training, environmental factors, job and organizational factors, equipment protection, and stores, spares, and tools.

Additional information on the method is available in Ref. [4].

### 7.6.3 Potential Accident/Damage Analyses

This is a structured approach used to assess the accident, damage, or potential error inherent in a specified task. To determine the potential for the occurrence of mishaps in the performance of a maintenance job, the starting point is to establish a mechanism that describes the job under consideration in detail. Subsequently for each task element the following question is asked by the interviewer of the interviewee (e.g., repair person): Is there a low, medium, or high potential for the occurrence of an error/an accident/damage to equipment /system in performing, say, step xyz?

After a careful analysis of all the collected data, changes to items such as equipment, facility, and procedures are recommended. Additional information on the method is available in Refs. [1, 6].

### 7.6.4 Structured Interviews

This is one of the most effective methods to collect valuable maintainability-related data in the shortest possible time. The method assumes that people such as repair persons, technicians, and their supervisors close to maintainability problems usually provide the most meaningful insights into the problems involved in doing their job the best possible way.

In a structured interview, a fixed set of questions such as presented in Table 7.1, are asked [1, 6]. After a careful analysis of all the collected data, appropriate recommendations for improvements are made.

Additional information on the method is available in Refs. [1, 6].

**TABLE 7.1**
**A Sample of Questions Asked during a Structured Interview**

| No. | Questions |
|---|---|
| 1. | Is your workshop facility arranged properly so that it allows efficient and safe performance of maintenance activities? |
| 2. | How well is your workshop facility integrated into the total plant design? |
| 3. | How would you describe the environment in your workshop facility with respect to factors such as ventilation, illumination, and noise? |
| 4. | Are proper laydown areas and workbenches provided? |
| 5. | Is our workshop facility sized appropriately to accommodate effectively all the personnel in your organization? |

### 7.6.5 Critical Incident Technique

Past experiences indicate that the history of maintenance errors, accidents, or near-mishaps can provide information concerning required maintainability improvements. The critical incident technique is an effective tool to examine such case histories from the human-factors standpoint. The application of the critical incident technique calls for making arrangements to meet individually with members of the maintenance organization. The following three questions are asked of each individual:

- Give one example of a maintenance error, accident, or near mishap with serious or potentially serious consequences, based on your personal experience. In addition, describe the specifics of the case involved and indicate the ways the situation could have been averted.
- Give one example of a plant system or unit of equipment that is not "human engineered" or is poorly designed from the maintenance person's perspective and which has resulted in, or could result in a safety hazard, damage to equipment, or an error.
- Give one example of a plant system or unit of equipment that is well–"human–engineered" or quite straightforward to maintain, and describe the system/unit by emphasizing the features that make it good from the maintainer's perspective.

After the analysis of all the collected data, appropriate changes for improvements are recommended.

Additional information on the method is available in Refs. [1, 6].

### 7.6.6 Surveys

When the results obtained through the application of methods such as task analysis, structured interviews, and maintainability checklist, indicate a need for more detailed examination of certain maintainability-related factors; the surveys method is used. Two examples of such scenario are as follows:

- Poor illumination is proving to be a problem in the course of analyzing one or more specific tasks. Under such condition, it might be useful to conduct a plant-wide illumination survey of all maintenance work-related sites.
- The majority of maintenance manpower has expressed concerns in the area of communications. Under such conditions, it might be useful to conduct a survey or test of message intelligibility between important communication links within the plant.

Additional information on conducting such surveys is available in Ref. [6].

## 7.7 BENEFITS OF HUMAN FACTORS ENGINEERING APPLICATIONS IN POWER GENERATION

Past experiences indicate that there are many benefits of human factors–engineering applications in power plant maintenance. Nonetheless, benefits of human factors engineering applications in power generation in general that directly or indirectly concern maintenance may be grouped under two main categories: increments and reductions [5, 7–9]. The increments category includes increases in safety, productivity, and availability, reliability and efficiency of personnel performance, adequacy of communications, cost-effectiveness of training, and job satisfaction of personnel (i.e., motivation, confidence, and commitment to achieving plant goals).

The reductions category includes reduction in needless costs, occurrence of human error, consequences of error (i.e., number and severity of injuries and damage to equipment), wasted time and motion, number and qualifications of personnel required, training requirements and attrition, and job dissatisfaction of personnel (i.e., turnover and absenteeism).

## 7.8 PROBLEMS

1. Write an essay on human factors in power plant maintenance.
2. List and discuss at least five types of human factors engineering maintenance–related deficiencies in power plant systems.
3. List and discuss at least eight desirable human factors engineering maintenance–related attributes of well-designed systems in power generation.
4. What are the power generation plant performance goals that drive, directly or indirectly, maintenance-related decisions about human factors?
5. What are the important benefits of human factors–engineering application in power generation with respect to the maintenance activity?
6. What were the classifications of the findings in a survey of maintenance of nuclear and fossil-fuel power generation plants with respect to human factors?
7. List at least five human factors methods that can be used to assess and improve power plant maintainability.

8. Discuss the following two human factors approaches that can be used to assess and improve power plant maintainability:
   - Task analysis
   - Maintainability checklist
9. Describe the structured interviews method that can be used to evaluate and enhance power plant maintainability and give a sample of questions asked during a structured interview.
10. Compare the critical incident technique with the potential accident/damage analyses method.

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