DEPARTMENT of NUCLEAR TECHNOLOGY
CHULALONGKORN UNIVERSITY, BANGKOK , THAILAND

CIDA COURSE ON QUALITY MANAGEMENT

" HUMAN FACTORS in DESIGN, OPERATIONS and MAINTENANCE "

Presentation 9 - NOV. 1996,
by G. WIECKOWSKI, Operations Quality Corp. Canada

1. Objective of Presentation :

This presentation deals with human factor considerations as they apply to minimization of human error in design, operations and maintenance. These considerations and preventive actions find application in many diverse industries, ranging from control room operations, to flying an airplane, to hospital operating rooms and to banking and trading operations.
Specifically, the following will be discussed :

- general guidelines
- error-reduction considerations in :
  - design
  - operations and maintenance
- human performance evaluation system (HPES)

2. Introduction .

The success of human activities depends on numerous factors, some of which can be controlled by the individuals performing the tasks. However, in to-days complex technology and organizational structures, some factors cannot be controlled directly by the individuals. Accordingly, human error can be due to many factors external to the individual.

In this context, human error often is not a cause of an event, but more often a symptom of underlying causes. The various systems used to minimize human errors encourage their identification, investigation, dissemination of "lessons learned" and correction of identified causes.

The objective is to improve quality of operations by reducing human error thorough correcting the conditions, situations and management attitudes which contribute to errors.

This objective is approached through a series of activities (program) based on the following premises :

- human error can be reduced and minimized
- causes of minor events are often the same as those of major events

- the management environment is of key importance
  - people want to perform well
  - punitive action often does not correct underlying event causes and can discourage reporting of errors
- accurate identification and correction of causes can preclude repeat events and reduce opportunities for similar events
- sharing of "lessons learned" from human error events promotes better understanding and correction of human error causes.

Adherence to these premises fosters a management climate that advocates non-punitive reporting of human error events. This includes **near-miss events** that are too minor to meet other reporting requirements, but are often pre-cursors of more serious events .

The following program framework supports adherence to these premises :

- a method for identification of minor as well as major human error situations
- coordinators trained in the program's root-cause -analysis methodology
- a feedback system for sharing actual human performance experience and solutions with others

3. General guidelines .

It is no more likely that human error will ever be completely eliminated than it is that electronic or mechanical machine failure will ever be completely eliminated. Since it is not practical or realistic to believe that all human error can be eliminated it is better to assume that human error will occur and take rational steps to reduce it.

The importance of adopting attitudes and developing error-reduction programs that accept human error as an inevitable result of human variability cannot be over stressed. Human error can be reduced by analyzing the errors and addressing conditions under which they occur. The key is to **attack the cause not the symptoms.**

The following are a number of general guidelines to be applied when attempting to reduce human errors :

- adopt attitudes and develop programs which accept human error as natural and inevitable part of human variability, but which can be minimized by analyzing errors and conditions under which they occur
- assigning blame certainly has a place in any organization, but it should be used with discretion. It is an easy way out compared to identifying and correcting the cause. Causes are more often due to situational factors than individual factors. Assigning

blame could also be counter-productive by lowering employee motivation.

- attack the cause of errors, not the symptoms. Use a methodical, systematic approach to error investigation.
- ensure that situational factors are compatible with the capabilities and limitations of humans. Reduce the number of opportunities for error by designing-out error likely situations in operations and maintenance.

The two basic approaches to human error evaluation and reduction are:

- the **causal factor approach,** which assumes that most human errors can be prevented by eliminating the factors that cause errors to occur
- **error-analysis approach** which concentrates on discovering "situation caused" errors

4. Error -reduction considerations.

Efforts to minimize potential for errors should begin in the design stage and also be applied during major back-fits. At that time it is possible to consider interaction between man and machine and to incorporate design features which cater to human capabilities and requirements, are "user friendly" and thus contribute to elimination of errors.

Subsequently, during the operational stage steps should be implemented to capitalize on the design and develop programs intended to minimize occurrence of errors. This applies equally to operating activities as well as to maintenance.

Design.

It is no more acceptable for the human factors characteristics to be specified without consideration of the design intent , than it is for the design to be completed without consideration of the human operator.

Traditional human factors concerns within the design process include strategies to optimize the following :

- instrumentation design appropriate for its specific purpose
- instrumentation and equipment layout to facilitate task completion
- elimination of undesirable environmental conditions which adversely affect human performance, including :
  - conditions which promote discomfort and fatigue
  - working environment - illumination
    - noise and disturbance
    - thermal environment
  - visual display and clarity of information

- room and furniture arrangement
- access to equipment and instrumentation

In the past, decisions have been made by the designer as to the equipment and instrumentation requirements of a system, and the finished product passed to the users to operate.

This philosophy did not consider how the system will be operated. Such approach could lead to difficulties with an operating system which is :

- not compatible with the user's mental model of the system
- is incompatible with the physical or mental capabilities of the operators
- prone to human error and as such will be subject to down-time and possibly result in accidents

It is essential that an effective process be implemented which considers human capabilities and limitations, and through which the users have an input to the design. This will ensure that the above deficiencies are not created and result in a safer, more cost effective operating facility.

The underlying principles of human factors which should be considered throughout the design process are :

- designers should bear in mind both the physical and mental capabilities of the users so not to impose excessive demands upon the worker
- interfaces between system and the operator should be simple and provide the information that the operator needs to know, but should not include any redundant information. They should be robust against user error.
- designs should consider the demands of the tasks that the operator is required to carry out
- the operators should be provided with feedback on the success or lack of it arising from their action.
- information about the status of the system should be provided at all times.
- standardization should be employed as far as design and operational philosophies are concerned in order to create consistency and compatibility

The following are the important activities of human factors specialists in design :

- function and system analysis
- task analysis
- interface design
- maintainability analysis
- communications analysis

- organizational analysis
- workplace layout
- physical demand analysis
- workload analysis
- human reliability assessment
- emergency planning

Results of these analyses should be fed back to the designers for consideration and inclusion in the design.

With the introduction of highly automated systems a decision has to be made regarding **allocation of function,** interface design and training. How much should be automated to achieve the optimum balance between overloading the operator and creating boredom, which causes inattention and potentially leads to decline of performance.

How can it be ensured that in the event of a system failure or malfunction, the operator will have the knowledge and the experience to detect the problem and restore/maintain the system in a safe state ?

In order for the operator to be able to restore the system to a safe state , the following must exist :

- an understanding of the current equipment and system status
- clear indication of the problem
- understanding of the appropriate actions to take to restore the system
- accurate expectation of the results of chosen operator actions

To enable the operator to respond correctly, the design must optimize the presentation of information and feedback to the operator, the training program must ensure that the operator is familiar with possible abnormal situations and their remedies, the appropriate procedures must be developed , and the alarm information must ensure accurate diagnosis of the problem.

Good "human factors" design is achieved when all these parameters are coordinated and optimized.

The financial costs of not including human factors in the design process may be considerable and include costs of the following :

- necessity of re-designing part of the system and implementing the new design later in the process, or of repair if equipment damage results from poor operation
- complications arising from impact a new piece of equipment has upon the rest of the system, e. g. new procedures, additions to training program

- loss of production during the time of implementation of modifications, repair or system shutdown, arising from poor operation
- the need to replace and rehabilitate a member of staff, incapacitated as a result of injury

Operations and maintenance .

Results over the last decade or so, especially in the aviation industry have shown that :

- incidence if human error can be reduced, i. e. quality of work can be improved
- sustained improvement cannot be obtained by motivation alone, no matter how well motivated the work force
- for sustained improvement, a long term program is required, supported by :
  - management commitment
  - specialist resources
  - identification and analysis of human errors
  - data base, feedback and learning from experience

This program must address the following areas, which have key influence on quality of performance :

- procedures
- qualification and training
- supervision
- verification
- internal interfaces within organization (communication)
- working conditions
- personal factors
- feedback to groups and individuals (performance assessment)

Several developments have combined to underline the importance of addressing human factors. Some of these are :

- the focus of design has shifted from direct operator control to automated systems requiring **supervision** from the operator. Operator tasks are increasingly more cognitive in nature.
- the effects of performance shaping factors such as management policy, company expectations and the effects of maintenance activities, has been recognized as contributing significantly to quality of operations
- the source of human error is shifting from operator based to maintainer based as systems become more automated.

Diagnosis and maintenance is becoming more technical and complicated

The effect of human error on system performance can be reduced by employing the same principles that reduce the effects of machine failure on system performance : **redundancy and independence.**

Redundancy means that more than one incorrect action is required to cause system problems. Failure will occur only if two independent events happen in sequence. The system is robust in its tolerance of error.

Independence means that work should be planned so that it can be confirmed through testing or inspected and verified by an independent, qualified inspector.

Procedures.

Procedures are a key pre-requisite for consistently satisfactory performance. It is therefore essential that high standard of procedure preparation and upkeep be specified and maintained.

Good procedures are :

- technically correct and complete
- clear, free of ambiguity and user-friendly - easy to understand and to follow
- supported by warning of hazards and supplementary information
- direct and to the point, specifying only those activities which must be done to accomplish the objective
- supported by adequate operating/maintenance aids

Additionally :

- there are no awkward actions required,
- sequences of events agree with smooth operation of equipment,
- the procedure is consistent with the plant's operation or maintenance philosophy

Procedures have to be kept up to ensure that they stay in step with the way work is done. This is accomplished by :

- a mechanism by which staff doing the work can provide feedback whenever procedures are found to be inadequate
- a process for speedy revision of procedures, including speedy review and approval of revisions.

Additionally, there has to be a periodic, thorough review of procedures. This must be a cooperative effort involving the users of a procedure. People who use a procedure must have an input into its preparation.

One striking feature of the aviation industry is the standardization of maintenance procedures and instructions which are perfected over time.

One striking feature of the nuclear industry is the high frequency of non-standard maintenance. Although preventive maintenance is scheduled and predictable, much of the remaining maintenance is unpredictable, because of unexpected or unforeseen failures.

Thus a lot of time and effort is spent in preparing one-off procedures, and comparatively less time is available on refining and clarifying existing standard procedures.

Qualification and training.

Quality of work can be compromised if the worker has inadequate training or experience to do the job. This can occur either because qualified personnel are not available, or because qualified people are not properly selected for specific jobs.

This problem can be overcome if :

- only the staff who are trained, qualified and experienced for the work they are asked to do are assigned the work
- the record of individual's qualification and experience is readily available to the person who assigns the work
- qualifications are periodically and formally confirmed through demonstration of a specific skill
- work requiring specific qualification is clearly identified
- staff are sufficiently knowledgeable to be able to recognize an out-of-normal situation, get into a safe configuration and ask for assistance

Supervision and organization of work.

Supervision plays a key role in determining the way work is done.

A good supervisor must :

- know his people, recognize their abilities and shortcomings,
- be often seen at the work site inspecting the work and offering on-the job support and on-the-job instruction
- ensuring that procedures are adhered to
- ensuring that work can be done safely and that all safety regulations are observed
- provide clear and definite assignments with clear indication of expectations
- provide prompt feedback to individuals with respect to their performance

Work should be organized to promote communication and cooperation between various groups and thus to optimize efficiency. Crew briefings, clear understanding of tasks, team building and teamwork are some of the skills a modern supervisor must have.

Verification.

Human failure to meet ideal standard of performance is to be expected and unavoidable. In the case of operation or maintenance , there is probability greater than zero that an error will be made at any step in a complex procedure.

The above stresses the importance of redundant technical verification to reduce the risk of error. Personnel should perceive these inspections for what they are - the recognition of risk potential - and not as doubts about personal competence.

"Independent inspection and verification of safety related work" is widely practiced in the nuclear and aviation industries. It means that safety-related work is always inspected by someone with appropriate qualifications who did not do or directly supervise the work.

Inspection means an evaluation as the job progresses, so that critical steps are inspected while they are visible and before they are concealed by re-assembly or subsequent work. Inspection does not mean disassembly and reassembly of already completed work, a superfluous activity which can add error rather than reduce it.

This implies that for every safety-related job there must be a job procedure which specifies check-points, and a check list which records the verification by an outside inspector.

There are two sides to all independent verification procedures. The positive side is their potential to reduce errors by direct observation. The negative side is the increase in labor and time requirements. It follows, that the need for independent verification should be carefully considered against consequences of a possible error and specified only when the consequences exceed the additional cost.

An independent verification procedure which is followed only on paper because of workload will not necessarily improve safety or efficiency. Before mandating independent verification, the practical constraints must be considered. Otherwise it is pointless to require it.

In addition to the above, reliability of relatively simple jobs can be improved through an individual self-checking technique known as STAR -"stop, think, act, review".

Internal interfaces within organization.

A good interface between management and the workers requires effective management practices and policies addressing communications, which are implemented, monitored for effectiveness and continually improved. Certain organizational mechanisms need to be created to permit free and unrestricted communications.

Suitably designed interfaces must encourage effective transfer of information between various crews, shift groups, technical specialists, supervisors and managers.

Reporting requirements must be defined and enforced. Particular attention must be paid to activities which were found the most prone to deficient communication :

- shift turn-over : loss of information at shift turn-over
- communication between work groups on the same shift crew
- work reports : insufficient information on a maintainers work report
- communication between technical and production staff

Also of importance is the adoption of good operating practices in the area of operating communications. One of these consists of both parties repeating verbal instructions and confirming correct understanding of what was said.

Working conditions.

Working conditions are perhaps the easiest of performance shaping factors to control. Good working conditions by themselves will certainly not result in work of good quality, but poor conditions will almost certainly result in poor work.

Following are the considerations which define working conditions :

- plant layout and facility access
- maintainability and access to equipment
- signs, labels and coding
- illumination
- thermal environment
- noise and vibration
- control room design
- design of information displays
- human-computer interface

A special consideration is freedom from interference and disruption, such as might occur if people are allowed to enter the control room without any limitations, or in other ways interrupt work in progress.

Environmental requirements are task specific and so should be considered within their particular content.

Personal factors.

This item deals with psychological and physiological requirements of the job and addresses

- physical demands of the job, including
  - effects of fatigue,
  - work posture
  - physical exertion necessary
- level of stress experienced as the result of
  - job or supervisory demands
  - level of extended concentration required
  - conflicts with co-workers on the job
- industrial hygiene considerations
  - industrial safety
  - frequency of breaks
  - cafeteria and food
  - showers and toilets

Also, there are responsibilities to the workers and the public in terms of maintenance of occupational health and safety.

Performance appraisal

Humans are adaptable and their performance can be improved. To recognize variability in human performance is to recognize the need to reward superior performance and to improve inferior performance. Mere assessment of performance without a follow-up to determine the source of any problems observed is not sufficient.

Data obtained from performance assessment programs must be fed back to workers and provide the input for individual goal setting, which is an effective tool for improving quality of performance.

The performance assessment program must be fully integrated into the corporate culture so that it is taken seriously by employees at all levels, and that it becomes an effective tool for improvement and change.

Communication is essential : both employee and the manager must agree on what performance standards are being sought and what criteria are being used to evaluate performance.

Combination of "knowledge of results" and specific performance goals which are set sufficiently high so as to be difficult to achieve, yet still possible given the individual's level of skill, lead to improved quality .

The expected performance standard should be :

- clearly stated
- performance related rather than trait-related
- measurable

Human performance evaluation system (HPES).

This program is applied at many nuclear power plants. An equivalent program called "Aviation Safety Reporting system " (ASRS) is used by the aviation industry.

The program's primary implementation elements are :

- reporting of human factor events
- analysis
- corrective action
- feedback

HPES system has three objectives:

- to determine the causes of poor human performance
- to specify and implement corrective action
- to monitor the success of corrections made and to modify them as necessary

The following plant personnel are involved in program implementation :

- line management - uses program results to resolve the underlying causes of human performance problems
- "reporters" - all workers and managers who report human error events to program coordinator
- program coordinator - a specially trained worker who analyzes reported events, determines their causes, recommends corrective actions to line management and provides feedback to reporters
- evaluators - individuals specially trained to assist the program coordinator, normally on a part-time basis, in the evaluation of human performance problems. These individuals have detailed

knowledge of the plant as well as skill in conducting root cause and other types of analysis.

The program operates in the following manner :

- plant personnel voluntarily report to the coordinator human error events.
- the coordinator or evaluator determines event cause, using the program techniques, and develops corrective action recommendations. Both evaluation and recommendations are recorded on standard forms.
- the line management selects, implements and tracks the effectiveness of corrective actions

Produced by :
Operations Quality Corp.

A:\CIDA\TEXT\BK-09.DOC