MANAGEMENT OF SAFETY THROUGH PERFORMANCE INDICATORS FOR OPERATIONAL MAINTENANCE

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Abstract: Management and organizational issues have shown to have an important influence on safety of nuclear power plants. Maintenance activities provide support for a continued safe operation and should therefore get the necessary attention both within and outside the maintenance department. A continuous assessment of organizational performance is one important management tool by which possible deficiencies can be identified and corrected before incidents reveal their existence. The use of performance indicators is one important part of such an assessment. The paper presents a system of indicators proposed to be used for a continuous assessment of the safety influence of a maintenance organization at a nuclear power plant, The proposed system of indicators include both objective and subjective measures.

1 INTRODUCTION

Safe and economic operation is the goal of nuclear power operation. Safety is achieved by preventing incidents of any nature and economy by avoiding their consequences in outages and equipment damage. There are many preconditions for a successful avoidance of incidents of which some are technical and some personnel related. Technical preconditions relate to the use of reliable structures, components, systems and procedures and personnel preconditions to well trained people who are committed to a strong safety culture.

A consequence of the nuclear accidents at Three Mile Island and Chernobyl is that an increasing attention is paid to issues related to organization and management in achieving a safe and reliable operation. It is widely recognized, that ensuring a high quality performance of operations and maintenance requires an allocation of management attention to the concrete work at all organizational levels. To support this attention and to help in selecting priorities more comprehensive tools are needed for the management.

Maintenance has in the PSA studies and, more importantly, by its involvement in safety significant events, shown to be an important factor in the operational safety of nuclear power plants. Maintenance activities encompasses a large span of activities of which some are executed under large time pressure. High quality training and retraining for maintenance personnel is perhaps more difficult to give than for control room operators for whom training simulators usually are available.

Presented at the IAEA Specialist Meeting on Methodology for Nuclear Power Plant Performance and Statistical Analysis, 30.9-2.10.1996, Vienna, Austria.

High quality maintenance can be characterized as doing all the small things right all the time. Maintenance tasks rely on a proper coordination with many other ongoing activities. This means that maintenance people have to communicate with many other people such as control room operators, radiation protection and safety people. They have also to record the actions they carry out and they should be alert to detect any anomalies in the equipment they work with. Maintenance activities require a special managerial attention directed towards a possible insidious accumulation of latent organizational deficiencies. The definition of a system of performance indicators can provide an efficient tool to be used both by the managers and the maintenance people themselves. Such a performance indicator system should include both technical and organizational dimensions.

2 THE ART OF MANAGEMENT

Hundreds of bestselling books have been written on the art of management.[1] Still it as difficult as before, to give concrete prescriptions on successful management. The special traits required of managers at nuclear power plant are to some extent the same as for business organizations and to some extent very distinct. Is it possible to give any general guidance on what qualities managers at a nuclear power plant should possess? This question can be answered with a daring yes and the qualification that all nuclear power plants are unique and prescriptions have to be related to the culture prevailing at the plant.

The most important managerial skill that is required on a nuclear power plant relate to understanding the plant and its people in the broadest way.[2] A nuclear power plant is a very complex piece of equipment and it is operated by highly trained technical people. Managing these people in such a way that they are able to respond to all both scheduled and unscheduled demands sets a challenge for managers. This cannot be done without responding to needs both from unforeseen technical difficulties and needs to maintain and develop the technical skills of the personnel Typical managerial skills such as communication with people, resolving conflicts, defining goals, etc. are important, but these skills are often reflected through the technical systems at the plant.

A prerequisite for a high performance is a systematic planning process which is both efficient and well covering. The planning process itself can take different forms, but the definition of long-term goals which are converted into yearly plans and actions is on a general level very similar on all plants. The collection of operational experience for a comparison with the plans to establish a database for supporting later planning activities closes the loop. The task of the managers are to build and maintain such a system.

Long-term goals are typically defined in a process of strategic planning. This process identifies *strengths*, *weaknesses*, *opportunities* and *threats* to characterize the *present* situation which combined with *visions* for the future helps in defining a *target* state and the means for reaching these ends. The assessment of required resources and indicators that demonstrate that goals have been reached provides the final part of the strategic plan. A strategic planning process should be specially alert for conflicting goals, because they should be approached and resolved with a proper balance.[3] The main short-term conflict at a nuclear power plant is the conflict between economy and safety, which can be resolved only with a proper long-term perspective. Similar smaller conflicts should also be approached and resolved in a similar way are given in Table 1.

One important part of a successful management within any organization is the degree of commitment to organizational goals which are expressed by the personnel. An important task of the management is to assess attitudes and when necessary try to change them.[4] On a nuclear power plant these are to a large extent safety related with the understanding that high quality work provides both to safety and economy of the plant.

Table 1. Conflicting goals of an organization operating a nuclear power plant

A healthy self-esteem - accept outside advice
Formal - informal rules for assuring safety
Accept errors - require errorless performance
Centralized - distributed decision making
Managing details - maintaining the overview
Search for information - avoid information overload
High specialization - generality of roles
Cooperation - competition for resources and power
Monitoring and reporting - confidence and trust
Move from past strategies - enforcement of roots

The commitment to organizational goals are fostered both in the day to day routines and in the handling of exceptional circumstances. Managers have to be extremely cautious to avoid sending messages with double meanings. If decisions are made, which can be interpreted as putting economy above safety, these can induce people to only pay lip-services to safety. A necessary quality assurance for a difficult decision can be obtained only through a careful evaluation of conflicting goals. When a decision has been made the reasoning behind it should also be clearly displayed.

Management also involves providing feedback on achieved results. This implies that outcomes have to be assessed in the light of existing plans and used resources. The performance has then to be judged and the responsible persons should be given feedback on their achievements. In the case a negative feedback has to be given, it is extremely important that this is not directed towards the person and that the deviation is placed in relationship with its influence on the overall goals of the organization. Only then it is possible use the full learning value of the experience without an impairment of the persons commitment.

The perhaps most important task of a manager on a nuclear power plant is to convey an understanding and a concern for all the small things that can go wrong. Any deviation from accepted safety norms should be reported and reacted on. People should not be content with only knowing how, but should always actively engage themselves in asking why.

3 INFLUENCE OF MAINTENANCE ON SAFETY

Maintenance is a mean to ensure safe and economic operation. The effect of good maintenance is seldom seen, but inferior work quality will reveal itself very soon. The work load on the maintenance department is determined not only by their own efforts, but also by the technical quality of the plant and the quality of operation. All this means that it can be difficult to define a concrete and operational goal for the maintenance activities. Still it is necessary to make an effort in defining such goals also for maintenance activities and indicators by which the fulfillment of the goals can be monitored.

Maintenance activities can be divided into corrective and preventive maintenance. A high performance of a plant is typically characterized by a higher share of preventive than corrective maintenance. An emphasis of correcting problems before they emerge also stresses

the importance of preventive maintenance.

Some plants do at least a part of their regular test and maintenance during power operation. This has the benefit of to gain time during the annual outages and therefore reach a higher load factor. There are however other drawbacks of doing test and maintenance during power operation such as an increased vulnerability for disturbances and the possibility of radiation exposure.

The annual refueling outages typically include a large amount of test and maintenance activities. The outages are also used for major revisions of the plant making the short time rather hectic. A very careful planning of the outage can help both in minimizing the outage time and the quality of the maintenance work during the outage.

Test and maintenance activities can introduce hidden failures modes of the components. An error in selecting the component to do maintenance on can cause the disappearance of redundant safety functions. Maintenance activities usually require a different line-up of process components than normal operation. If the maintenance line up is not changed correctly back to power operation there is a possibility that important components are inoperable on demand. There is also a possibility of introducing common cause failures when several components are maintained in a sequence.

Reasons for human errors have been pondered in many occasions. Similar models can be assumed to work for maintenance errors as for other human errors. According to one model human errors can be seen as a misfit between task demands and available resources. This stresses the systemic cause behind human errors, but is not detailed enough to provide guidance for the planning of maintenance tasks. Several mechanisms contributing to maintenance errors have been proposed. One of them is connected to the availability and correctness of maintenance instructions and another to interruptions and possible interference between parallel activities.

4 PERFORMANCE INDICATORS

Measurement is a precondition for control. When performance can be measured directly the only remaining problem is to select the most efficient controls to achieve wanted performance. Unfortunately it is not always possible to measure performance by direct means. Safety for example is difficult to assess directly, because its appearance is indicated by an absence of incidents and accidents. Similarly organizational efficiency is something very difficult to measure by direct means.

When direct measurements of some component of performance are not possible, indirect measurements can be used. The use of indirect measurements relies on the selection of measurable variables which has some correlation with the actual dimension of performance to be controlled. The problem with indirect measurements is that perhaps several measurements have to be collected which have some, but not always well known, relationship with the actual variable. The measurements may also be correlated with each other making it even more difficult to make a correct assessment of actual performance. A practical approach to these problems is to define a performance indicator system and to use it with necessary care.

An ideal performance indicator system should for a nuclear power plant make an assessment of operational efficiency in which components of economy and safety have been included. The performance indicator system should at least to some extent be hierarchical to make it possible to identify necessary control actions in the case of a deteriored performance. Both technical and organizational indicators should be combined in the same system. In selecting performance indicators one aim is that they should be anticipatory and sensitive.

The information obtained from events and failures occured at the plant are one important component of operational experience and should therefore be reflected in the performance indicator system. The problem is that these indicators may not be sensitive enough when a very high plant performance has been reached. The approach to this problem is to collect and analyze performance of functions and organizational units within the plant. Changes in the performance of functions and organizational units can be assumed to be good predictors of changes in the plant safety performance.

The use of performance indicators in the control of safety of nuclear power plants have been proposed in various connections. IAEA has defined the characteristics of an ideal performance indicator system (Table 2). WANO has defined a system of performance indicators which are used for the exchange of operational experience.

Precursor models of the interdependence between selected indicators are helpful for an assessment of the statistical relevance for observed changes in the indicators. It is therefore important for data to be collected is stored in a manner that facilitates analysis to help determine what future actions, if any, should be taken. A performance indicator involves information in a compact form, which means that crucial information can be lost outside the boundaries of the indicator or that other essential information is hidden. Instead of single indicators a larger set of performance indicators should therefore be used.

Table 2. Ideal characteristics of a set of performance indicators.

Close relationships to risks and/or safety,
Data readily available,
Quantitative (show range of performance),
Unambiguous,
Unlikely to cause undesirable actions,
Significance should be understood (objective, fair),
Industry wide applicability,
Not susceptible to manipulation,
Physical results,
Independent indicators essential,
Manageable set,
Worthy goal.

A performance indicator system is most efficiently used during periods of good performance. If incidents indicate a deterioration in performance the remedies are most easily found not through the performance indicator system, but through a root cause analysis of the incidents. A performance indicator system also requires a commitment to it which can be achieved only if it is understood and accepted. This indicates the importance of a systematic approach in bringing the selected system into practice.

5 INDIVIDUAL AND ORGANIZATIONAL PERFORMANCE

The assessment of both individual and organizational performance is crucial at any nuclear power plant. Efforts have been made to create various assessment methods.[5] The assessment

of individual performance should always be connected to the identification of needs for additional training. The assessment of individual performance is typically done as a part of the regular development discussions used also in many business organizations. The discussions have similar contents regardless of the organization and the hierarchical level within the organization. In the discussions earlier outcomes are gone through and compared with commitments made at earlier discussions. The discussion should also jointly define the goals for the next period.

Many organizations have developed various bonus systems. A special care should be used when a bonus system for a nuclear power plant is implemented. It is fair that a good availability and thereby a good economic result is reflected in the payments to the personnel, but the incentives should however not be that strong that it will override safety concerns in the operation. TVO is using a bonus system with the components given in Table 3.

Table 3. Components of the bonus system used at TVO with their respective weights.

Power availability - 50%
etc.

The assessment of individual and organizational performance is not as straightforward as the assessment of technical performance for some system, because ratings will always be subjective. Various rating methods have been developed within behavioral sciences which rely on the construction measuring scales. The most simple scale is only a categorization of behavior into certain classes. On the next level an order relationship between the classes define for instance the relationship *better* between the classes. Only seldomly a ratio scale can be defined where it is possibly to define the ratio between two values on the scale. A Likert-scale is a ratio scale which is measuring individual agreement with some statement between being of completely same to completely different opinion. In the creation of the scales an assessment of their reliability and validity should always be done.

Behavioral scales rely on people to make the assessments. The reliability of the scoring can be increased by using multiple persons which can discuss and modify their scores after an initial round. The data to be scored can be collected in various ways, such as discussions, structured interviews and questionnaires. The data can be collected and scored by people inside or outside the organization to be assessed. The development discussions provide one possibility for data collection where superiors and subordinates meet regularly with discussions on performance. The use of typed behavior classes can support such discussions with some kind of scoring mechanism.

The use of structured interviews performed by outside people perhaps gives the most reliable data. The problem is however that both data collection and assessment can be very resource consuming. It may also be difficult to obtain a good reliability in the data handling if the same persons cannot do all the interviews. A questionnaire is easier to administer and to treat, but the results may be more difficult to interpret.

6 CONSTRUCTING AN INDICATOR SYSTEM

The construction of a performance indicator system for assessing technical and organizational performance of a nuclear power plant is a demanding task. The performance indicator system

should evidently be well in line with strategic and operational goals. It should be practical enough to motivate the effort as compared with the expected benefits. A performance indicator system has to be accepted which does not only mean that the whole personnel sees it as valid, but also to the extent that it is in line with the views people have of how to promote performance. The indicator system has, so to say, to be adapted to the local culture of the plant.

The performance indicators should be in line with other information collected which means that additional checks of key factors can be obtained by other means to calibrate for possible biases in the judgements. The performance indicators should be control oriented which means that relatively clear views should be available for how various indicators can be influenced. Finally the performance indicator system should be adaptable to specific needs which may emerge over time.

For the technical part of the performance indicators system the strategy of defence in depth completed with PSA logic model and structure provide an appropriate framework. The influence of the maintenance on the operational safety can then accordingly be modelled through the influence on risk functions and systems have. The assignment of organizational units to various tasks provide the link between the technical and the organizational indicators.

The individual and organizational performance indicators are similarly as the technical indicators connected to the precursor paths for human errors and organizational deficiencies. There are many possibilities for selecting dimensions of individual and organizational performance. Still it is necessary also to obtain some assessment of commitment, attitudes, and beliefs, ie. the orientation of individuals towards their work.[6] Regardless of the selected dimensions some grouping of the indicators is always necessary. Depending on the resources available for collection and scoring of data, more or fewer dimensions could be assessed separately. If data is to be collected and assessed regularly as a part of the development discussions the dimensions have to be restricted to the absolute minimum. If data can be collected in a separate project involving also outsiders more dimensions can be used. The final selection should be based on a trial data collection.

A candidate performance indicators system for the maintenance organization can include the items of Table 4. The considerations behind this proposal are the following:

- the indicator system should not be entirely new, but an extension to present systems,
- the technical maintenance indicators are reflected through the importance of certain functions and systems on safety and economy,
- an active problem seeking and correcting maintenance is reflected in a large share of preventive maintenance,
- an active reporting of minor deficiencies should be specially fostered,
- only the most important individual and organizational performance indicators should be included to make them practical.

Table 4. A candidate set of performance indicators for the maintenance department at TVO.

General indicators
an adaption of WANO indicators
modifications and improvements
Technical indicators
initiatives and suggestions
number of faults and work orders
repair times
maintenance backlogs
share of preventive maintenance
cleaniness
corrected minor deficiencies
Organizational indicators
communication
systematic planning
organizational support
Individual indicators
orientation
commitment
cooperation

The scoring of the individual and the organizational indicators are suggested to be facilitated through the use of behaviorally anchored rating scales (BARS). These scales provide a suitable categorization of the selected dimensions together with a characterization of typical behavior rated with that score. The scales used are typically ordinal scales providing a goodness rating for the more deliberated and well established behavior.

7 TAKING AN INDICATOR SYSTEM INTO OPERATION

The perhaps most important task in taking a performance indicator system into use is to anchor it in the organization concerned. This means that people should be informed about and they should agree with the system. This means that those concerned should have a possibility to influence the system or, even better, participate in its design. It is important to remember that already the implementation of an indicator system, ie. a system for measuring, exercises control both for good and bad within the organization.

When a candidate performance indicator system has been proposed, it should be discussed broadly within the organization. The internal structure of the technical indicators and the possibilities for influencing them by various groups should be one item for the discussion. It may be helpful to have another division of the indicators depending on the organizational groups concerned which stress the controllability of the indicators in separating between of primary, secondary and perhaps even tertiary indicators from the point of view of the group concerned. This means for example that performance indicators associated to maintenance activities should be especially brought forward in connection with the maintenance department.

In the discussions it is still important to stress that everyone is concerned. It is not only the shop floor, but also the managers who are concerned. For the organizational and individual

indicators it is important to stress that everyone is assessed using the same dimensions.

It is not likely that the performance indicator system will be ready immediately. It is therefore wise to have a trial period where experience is collected and fine tuning of the indicators is exercised. During this period various systems for collection of opinions concerning the approprietness of various indicators and the scoring principles.

Presenting the results in an easily comprehensible form is also important. Several possibilities can be used such as numbers, characterization or color-coding (Table 5). It is also possible to weight the indicators together into some overall indicator.

The assessing of the results should in the trial period concentrate on the fine tuning of the indicator system. This does not however exclude an assessment also of the values of the indicators. Did the indicators vary in expected regions or were some unexpected values found.

Table 5. Broad categories of classification for performance indicators using numbers, words or colors.

5, excellent
4, very good
3, good, green
2, satisfactory
1, acceptable, yellow
0, not acceptable, red

When the performance indicator system has gone through the fine-tuning it can be taken into regular operation. That does not mean that it should remain unchanged ever since, because the performance indicators should actually be incorporated in the process of strategic planning. The performance indicators does not measure real performance and therefore it is always possible that organizational control will concentrate more on the indicators than actual long-term performance. A continuous reassessment of the performance indicators should therefore be exercised where the indicators, their definitions and their target values are reflected on a continuing basis to the long-term goals of the organization.

8 CONCLUSIONS

A well defined performance indicator system can provide an efficient management tool for organizational control. A performance indicator system should in addition to the technical indicators also contain individual and organizational indicators. The individual and organizational indicators requires the use of specially designed scales for scoring observed behavior.

The performance indicator system should be integrated to be a component of the process of strategic planning. When the performance indicators are re-evaluated continuously to reflect the long-term goals of the plant the dynamics of a continued learning can also be integrated into the system. A performance indicator system can be supported by other means for collecting information. This continuous change also helps in maintaining organizational vigilance for emerging problems.

Maintenance activities are truly important for a continued plant safety. A proactive strategy in trying to keep the plant "as good as new" all the time helps in the allocation of resources over time to avoid later costly refurbishments. This strategy will reflect itself through the maintenance indicators giving a fair amount of preventive maintenance.

The indicator stressing the reporting of minor deficiencies which have been corrected is deliberately chosen to foster an atmosphere of reporting also minor problems. It is believed that such an atmosphere is an important part of a continuous learning from which operational excellence is obtained.

The performance indicator system is still in its planning phase for TVO which means that it is too early to report on findings from the system. The initial considerations however indicate that correctly defined this may have an important influence on the day to day operation of the maintenance activities.

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