SAFETY PERFORMANCE MEASUREMENT IN PROCESS INDUSTRIES

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Abstract

Performance assessment and measurements are important components in a continuous strive for improved efficiency. It is however not enough only to assess and measure performance, but these activities should be integrated in the management systems to ensure that actions are initiated whenever inferior performance is detected. The paper describes activities at VTT in which researchers through interactions with senior managers in companies, both in the nuclear and conventional industries, have established safety performance measurement systems for safety management.

Introduction

Prevention of accidents is the ultimate aim of striving for excellence in safe operation of process plants with potential to large hazards. This objective is achieved through the use of reliable structures, components, systems and procedures in a plant operated by personnel who are committed to a strong safety culture. As a consequence of disastrous accidents, like Bhopal, Chernobyl, and Seveso, an increasing attention has been paid to the management of safe plant operation. It is widely recognized by companies as well as by safety authorities that to work reliably and effectively necessitates a management attention at all organizational levels, and also efficient tools to be used by managers.

Technical Research Centre of Finland (VTT) has carried out business process analyses and performance studies for different businesses, such as manufacturing and process industry, as well conventional as nuclear energy. In the field of nuclear energy VTT[1] has followed up and analyzed operational performances achieved by nuclear power plants (NPPs) worldwide. Performance measures (PM) have provided a means both to monitor status and trends of various processes in power companies and to predict and compare goodness of alternative investment options.

Performance measurement systems (PMSs) have historically developed as means to maintain organizational control, where organizational control is the process of ensuring that an organization pursues strategies that lead to the achievement of overall goals. PMS's are today one important R&D areas of VTT Industrial Systems. VTT Automation (since the beginning of 2002 VTT Industrial Systems) has developed a concept of the safety indicator system for the use of both NPP licensees (utility companies) and safety authorities (Lehtinen, 1995). The concept is based on the well-known safety principle of defense in depth developed by the International Atomic Energy Agency (IAEA) for NPPs. As a continuation of these R&D projects VTT Automation has participated in establishing a comprehensive PMS for a Finnish power company (Lehtinen & al, 1996), (Lehtinen & al, 1998) as well as consulted the Finnish NPP authorities and the IAEA (IAEA, 2000) in development of safety related PMSs.

Since the beginning of 2000, an ”integrated” PMS (IPMS) concept that could be utilized by the Finnish enterprises representing a wide variety of process industry, like paper, metallurgy, and chemistry, is under

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[1] VTT played an important role in the introduction of nuclear power in Finland. Presently the involvement of VTT in nuclear research is about 150 person years per year. VTT has oriented its nuclear research by technologies to make it possible to have an efficient cross-fertilization between the nuclear and more conventional areas.

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development at VTT Industrial Systems. An IPMS, built for an organization, could be used by the management both as a rational control and decision tool to evaluate decision alternatives under several, possibly conflicting, decision criteria at different stages of plant life cycle.

Risk management – a part of strategic management

Strategic management is essential for ensuring future success of companies. Process industry worldwide have developed strategies to cope with economical production, environmental requirements and occupational safety targets. Industrial process plants should be operated effectively both from the economic and technical point of view, and undisturbed production should be ensured with long-term minimum cost. At same time, the risks for the owners, plant workers, customers, and environment[2] should be kept as low as reasonably possible (Figure 1).

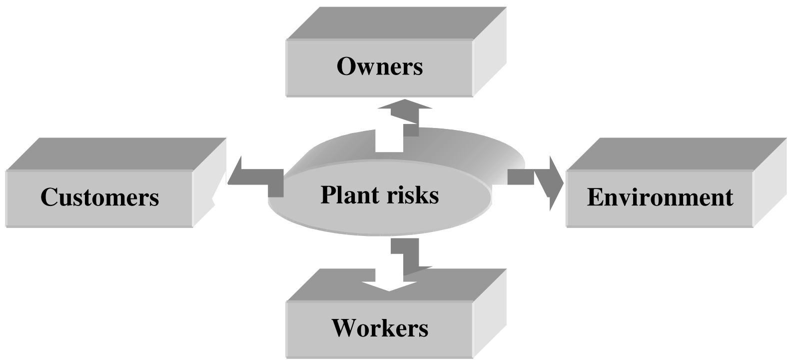

Figure 1. Plant risks directed towards company's interest group

Traditionally, risk management has referred to a process for preventing potential hazards for the company or minimizing the losses caused by these. The present definition extends risk management to cover the protection of a company against all possible risks. In addition to risks of injuries and damage on the environment and assets, the company must also consider its business risks. In large corporations this development can be directed by adopting risk management as a part of normal management processes. The company cannot make strategic decisions without comprehensive knowledge of its business risks and, on the other hand, strategic decision-making also requires know-how of methods for risk management. Risk management should be systematic and comprehensive to be efficient and it should function as an integral part of the business management system of the company. In order for risk management to benefit the company, the issues within its scope must be continuously monitored and evaluated.

”What is not measured is not managed”

Effective management is based on setting clear objectives. Essential objectives can be reached only if objectives are linked to operations in a natural way. However, this is not always simple due to the complexity of the objectives. It is relatively easy to break down quantitative financial objectives but linking various qualitative objectives together may turn out to be more difficult. This is why the determination of the key tasks of the various functions should focus on the results*, what kind of* results should be achieved, and *how*.

The concept of performance of a company has traditionally been limited to economic performance. Similarly the setting of objectives has usually concentrated on financial objectives as well. The argument for this has been that in business these are the final objectives and everything else constitutes means to reach them.

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[2] Surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans, and their interrelation (ISO, 1999)

However, financial objectives and their measurement alone are not enough to guide people to *do the right things in the right way*. Work is also done in chains of various activities, which involve many persons and it is often difficult for them to see how their performance link to the overall economic performance of the company. It is therefore advantageous to broaden the perspective from financial issues to be more comprehensive. The lower the organizational level, the higher is the need to use other than financial performance measurements. Problems frequently arising in a company and its operations are of a kind that cannot be directly measured in money and thus be monitored with money-based PMs. Another basic problem in performance measurement derives from the fact many important PM[3] is qualitative whereas many of the quantitative PMs is less important. Sometimes this has lead to measuring less important issues only because they are easy to measure.

Despite their evident significance the usability of other than financial PMs in control and decision-making is not obvious. The main difficulties are perhaps to identify the cause-effect relationships between the non-financial and financial factors, and to show how an improvement in non-financial performance affects the financial performance. Maybe one reason for this is that non-financial PMs are still relatively new, so the company directors and other persons influencing the decision making have not gained much personal experience or general knowledge from the outside on them. This complicates the identification of PMs supporting decision making and a development of them into an efficient and practical set.

Safety assessments – a prerequisite for safety management

The link to upper level objectives and ultimately to the result of the company as a whole can be viewed by repeating the question "why is this important" several times. The answers form a hierarchical chain leading to objectives at the company level. This hierarchy of objectives should be related to the line organization in a natural way. This is important since every major objective, or parts thereof, should have a responsible person; collective responsibility slips easily into being the responsibility of nobody. The responsibility for operating the plant safely is emphasized in organizations requiring high reliability in their operations. Responsibility is always returned to the top management of the plant even though the starting point is that each person is responsible for the quality and safety of his/her work.

The management of safety is an issue that is receiving an increasing attention in process industries. Many companies have developed and are implementing safety management systems. This is also reflected in recent regulatory development. In 1996, the so-called Seveso Directive of 1982, which was strongly focused on the technical side of safety, was replaced by the Seveso II Directive, which puts more emphasis on safety management. The new directive contains requirements for a major accident prevention policy and specific aspects of safety management systems. Similar developments in the USA led to similar requirements in the US Occupational Safety and Health Administration (OSHA) Regulation on process safety management (EPSC, 1996).

Within safety management, the attention is expanding from implementation to include measurement: from safety management systems to safety performance. The measuring of safety performance is a prerequisite for successful safety control. The management of the company needs the measurement results to support their decisions: matters that cannot be measured or priced have often less influence on the decision making. The information on safety and its trend is needed for assessing the efficiency of the *safety management system*, for selecting the improvement measures and for targeting them correctly, for verifying the trend and for assessing cost efficiency. The ultimate goal is to obtain early signals of changes in the safety performance of the plant and thereby to predict and prevent undesirable incidents from occurring.

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[3] In addition to *Performance Measure*, there are terms such as *Performance Indicator, Metric* and *Index*, but the terms are not always used in a consistent way. Performance indicator, for example, is used by International Organization for Standardization in Standard ISO 14031: Environmental performance indicator is defined as specific expression about an organization's environmental performance (ISO, 1999). - Performance indicator and both safety performance indicator and safety indicator seem to be used by NPP community very customary (IAEA, 2000).

What are safety performance measures

Safety is a concept that is not easy to define. It is even more difficult to define what constitutes an adequate level of safety. Safety is difficult to assess directly, because its appearance is indicated by an absence of incidents or dangers from which harm or loss or even a major accident could result. Then the only direct measure of achieved performance is in terms of absence of harm or loss, and reducing the cost of losses provides direct evidence of performance improvements.

Safety performance measures (see footnote 3) are generally intended to help in identifying early signals of deteriorating performance and thereby to provide means for warning of impending problems before an actual incident or accident occurs. Early warnings from safety performance measures should initiate a further investigation of the causes of the symptoms to ensure that corrective actions will be timely initiated and rightly directed (Lehtinen, 1995).

From reactive to proactive measurement

Measuring outputs is characterized by two important limitations (EPSC, 1996):
1. When safety is good and injury and loss rates low, then those measurements are not sufficient to provide adequate feedback for managing safety.
2. For operations where there may be potential for severe accidents, the likelihood of such events must be extremely low. This means that the absence of very unlikely events is not, of itself, a sufficient indicator of good management.

That is, the management will typically not have enough feedback to react on and the possible benefit provided by the direct, event-based outcome indicators can be limited. Therefore it has become necessary to find such measurable features in plant performance that should provide an advance warning of deteriorating performance before the direct outcome indicators are affected. There is need to be indicators that give assurance that the absence or reduction of harm or loss is due to a systematic management approach that is aimed at preventing of occurrence of incidents.

"Accentuate the positive to eliminate the negative"

In the model given by (EPSC, 1996) the framework for performance measurement consists of two dimensions: areas of safety management inputs and monitoring activities. Three areas of safety management inputs are distinguished:
- PLANT AND EQUIPMENT which is "fit for the purpose" of reducing the risks from identified hazards as fare as is reasonable practicable;
- SYSTEMS AND PROCEDURES to operate and maintain that equipment in satisfactory manner and manage all associates activities;
- PEOPLE who are competent, though knowledge, skills, and attitudes, to operate the plant and equipment and to implement the systems and procedures.

These are the *positive inputs* of safety management that are put in place to prevent the *negative outputs* (the failures). Within each of these three areas, various kinds of monitoring activities can be distinguished, ranging from regular, and often frequent, inspections through periodic, "in-depth" assessments to overall management audits. Continued improvement in safety management is about proactively expanding the positive inputs to reduce the negative outputs – that is, to reduce the total of incidents which create harm and loss to people, environment and assets (Figure 2).

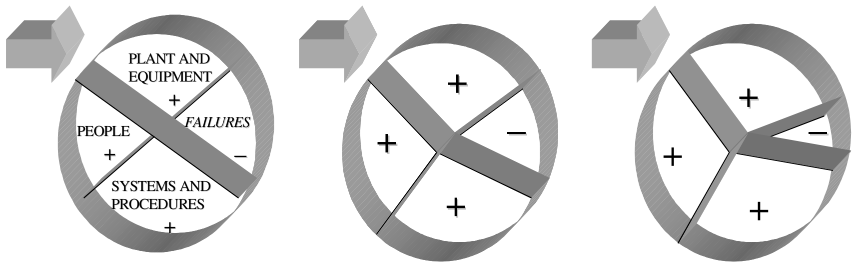

Figure 2.Safety performance areas – continual improvement

In a search for predictive indicators

Another way to approach accident prevention is to find and develop, in addition to event-based direct indicators, "indirect indicators" that can measure the performance of the functional units within the plant organization, such as operations and maintenance, training, and engineering support. The theoretical basis of such indicators implies that certain characteristics of management and organizational behavior is associated with changes in the likelihood of plant accidents and incidents (Marcus *& al*, 1990). If such organizational behavior is identified, and also judged to be strong by the indicators used, these constitute the need for correcting actions to be taken. The value in identifying indirect indicators is the possibility for them to be anticipatory indicators of potential problems. Indirect indicators of this type are often called leading or predictive.

In a study commissioned by the Swedish Nuclear Power Inspectorate (SKI) (Sewell *& al*, 1999) the leading relationship between different types of indicators was applied to seeking for predictive indicators of potential "forerunners" of more serious events. The approach of the study is based on the assumption that the forerunner-events represented by predictive indicators correlate with a change in a failure rate (of a safety component, train, system, or function) or an initiating event frequency. The aim was to identify the most promising organizational and operational-based safety-related performance indicators, and develop quantitative relationships between values of performance indicators and changes in PSA (probabilistic safety assessment) inputs (i.e., reliability measures consisting of component failure rates and initiating event frequencies).

An expert elicitation process was designed to consist of a combination of multiple-phase questionnaire and workshop. A total of 21 experts, representing Swedish licensees/plant staff, SKI, vendors, among the others, participated in the study. VTT was called as one of the non-Swedish experts to participate. The study gave in the first phase eleven key performance indicators, and after an evaluation process five high-worth performance indicators as summarized in Table 1:

Predictive indicators for nuclear power plants
1. Annual rate of safety-significant errors (i.e., reportable violations of technical specifications) by plant personnel, contractors, and others
2. Annual rate of maintenance problems (defined as maintenance rework or overdue maintenance)
3. Ratio of corrective versus preventative maintenance work requests (MWRs) on safety equipment
4. Annual rate of problems (deviations/failures) with repeated root cause (i.e., a cause previously identified by a vendor, the plant, another plant, the regulator, etc., for a similar plant or group of plants, or for similar components
5. Annual rate of plant changes that are not incorporated into design-basis documents by the time of the next outage following the change.

Table 1. List of high-worth performance indicators (Sewell & al, 1999).

Learning organizations

VTT is presently the coordinator of a project "Learning Organizations for Nuclear Safety, LearnSafe" (cf. http://www.vtt.fi/virtual/learnsafe/), which addresses organizational learning in NPPs. The project has a focus on senior managers at the NPPs and the corporate headquarters and aims at creating methods and tools for self-assessments. This project is another example of projects where the multiple interfaces of VTT serves a function of a transfer of generic insights between different industrial areas.

In the development of a *proactive model* of performance it is necessary to understand that a pure feedback approach is not enough (Figure 3). It has to be amended with a world model encompassing a description of the environment in which the company is operating, the company itself and all its work processes. This model should be used to tune company values and norms, strategies and practices, as well as the work processes by which performance is generated. The feedback path should take care of analyzing performance and make necessary changes when a mismatch between actual and expected performance is detected. Similarly the feed-forward path represents a proactive approach of a simultaneous adjustment of work processes, practices and strategies. The analysis activity in the feedback path is therefore supposed to introduce changes also in norms and values. In rare occasions a re-evaluation of experience may even induce changes in how the outside world is interpreted. This model actually gives a description of one kind of a double-loop organizational learning.

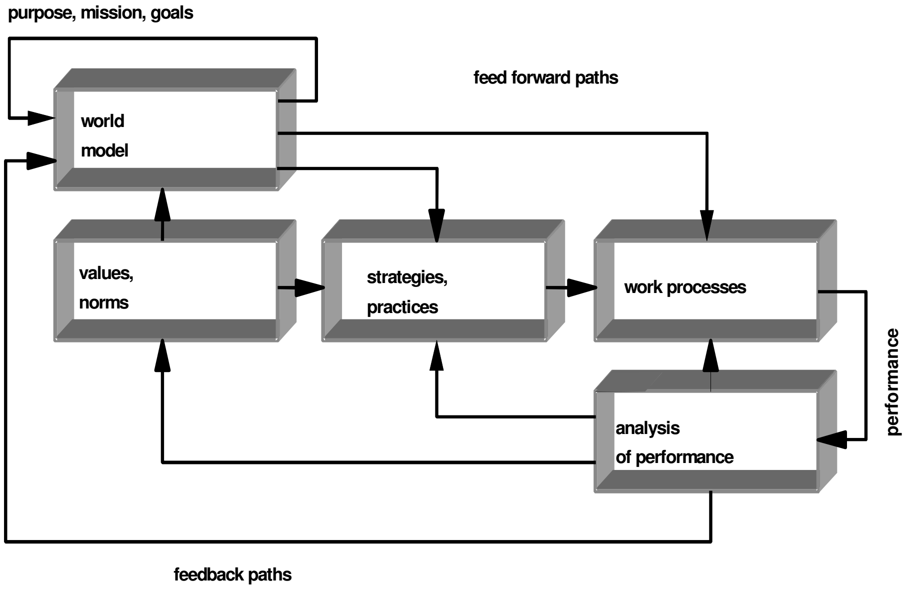

Figure 3. Feed forward feedback – a proactive model of performance

The crucial thing in this proactive approach is to build the world model of how work processes, strategies and practices, and norms and values influence actual performance. It is not enough to have an understanding of these relationships at a single instant of time, but it is necessary also to extend it to account for dynamics both in the company itself and its environment. For the company it implies an understanding of basic state variables on which strengths and competitiveness is built. These have then to be reflected in their interactions with environmental factors that are characterized with a reasonable forecast into the future. This is not to say that a company that is using sophisticated modeling and forecasting tools automatically would do better than another company, but it is concerned with an ability to understand crucial variables and their dynamic interactions. To simplify one may say that the crucial thing is to have a good understanding of factors influencing own performance and to have a proactive approach to variables within the own span of control.

In creating this understanding it is not enough to model the direct influencing factors, but it is also necessary to create an understanding of more intangible factors such as for instance how institutional knowledge and organizational culture are influencing performance. This also means that there should be methods by which the state of such intangible factors could be assessed to judge a possible need for investments. Investments in this connection do not cover only equipment and training, but may also include organizational restructuring and change. Finally, at some point it is necessary to have some kind of quantification of all the factors that are influencing performance, because otherwise it is not possible to ask the question, whether an investment of *x* units in improving factor *y* would be more profitable than the same investment in improving a factor *z*. In principle, the resource allocation of investments in a company should be Pareto-optimal, which may be difficult to judge especially when a large amount of the performance influencing factors are intangible.

A concept of safety indicator system for nuclear power plants

In 1990ies VTT participated in a research program where operational aspects of NPPs were considered. At same time a Nordic research project was carried out, where VTT was involved. The main objective of both projects was to define and demonstrate a practical use of living probabilistic safety assessment and safety indicators for safety evaluation of NPP operation and identification of possible improvement in operational safety (Holmberg *& al*, 1994).

Because safety is of paramount importance for the nuclear industry it is natural to consider the possibility to build safety performance measurement systems. To be useful a safety indicator system has to fulfil two requirements. Firstly it should be based on an understanding safety as an emergent property of work processes and activities. Secondly it should provide a proper combination of historical information and signals that can be used as early warnings of a deteriorating safety. Safety in the nuclear industry is built on the defense in depth and therefore it is natural to use this principle also in a safety indicator system.

All safety analyses for NPPs, both deterministic and probabilistic, revolve around the evaluation of the performance of the plant subject to different protection functions within the concept of defense in depth, and the reliability of the functions. Defense in depth aims at the establishment of three basic safety functions (controlling reactor power, cooling the fuel, confining radioactive material) to be preserved to ensure that radioactive materials do not reach people or the environment. The defense in depth-principle can be further extended to various technical and administrative barriers that ensure safety continuously. Indicators can thus also be assigned to these barriers. Four basic safety performance areas to be monitored by the safety performance indicator system were defined (Lehtinen, 1995):

1. SAFETY MANAGEMENT: performance in managing the plant day to day operations, works and other performance promoting activities;
2. NORMAL OPERATION UNDER CONTROL: performance in operating the plant under control for generation of electricity and detecting as well as responding to anomalous conditions and incidents;
3. SAFETY FUNCTIONS: performance in maintaining the availability of safety systems;
4. PHYSICAL BARRIERS: performance in maintaining the continued integrity of physical barriers.

The high level objective of Safety Management is to foster a good safety culture. This means striving for excellence of plant performance and strengthening the three other performance areas. The safety systems are intended to prevent incidents from developing to accidents. Physical barriers provide a confinement of radioactive material at successive locations, such as the fuel matrix, fuel rod cladding, primary coolant boundary and containment.

About 100 safety-related performance indicators used by utilities, authorities and international organizations were collected and refined in the form of a specification. The indicators were related to four performance areas (Lehtinen, 1995). The suggested division and the more accurate definitions enable utilities and authorities to check the coverage of their indicator sets from an operational safety point of view.

Development of a performance indicator system for a nuclear power company

After the completion of some R&D projects in 1990ies, a Finnish power company commissioned a new study from VTT. The task was to develop a PMS to be used as a tool for operational management of NPPs at the company. The project was decided to complete in a number of consecutive phases. In the second phase the objective was to build a computerized PMS. The building of the PMS was more experimental than based on some formal approach. Any PMS is depending on available data as needed by PMs. Four types of performance indicators were decided to be developed (Lehtinen *& al*, 1998):

A. *General performance indicators*, that include the PMs of the company's business economy and WANO[4] indicators. It is common for both the subgroups of PMs and indicators that they are very common or standardized PMs and indicators, in general, and they also are used to publish regularly, e.g. annually and/or quarterly.
B. *Basic condition indicators* to be developed in the use as a support in managing operations at the plants. These indicators are intended particularly for monitoring production function and for controlling those functions that are essential in their contribution to plant production. The performance indicators of this group are also more plant specific than the general performance indicators and will have the role of key indicators. These indicators will make up the largest part of the PMS.
C. *Goal specific indicators* have been designed to use for monitoring the attainment of goals and targets that are set by the management of the company and are connected to the strategic plans. These indicators will always have a less customary status.
D. *Cooperation indicators* are to be related to operational goals and workings within the organization. These can be divided in two groups, the one of which will be developed for assessment of efficiency of the plant organization, while the other one is intended for measurement of orientation and commitment of individuals.

A PMS is not usually implemented as such. Typically many performance indicators are monitored, but their integration to provide a comprehensive assessment of performance is more rare. In spite of this the nuclear industry has a policy to openly report the PMs of their business as well as their performance according to the international WANO indicators.

Conclusions

Performance measurement is a crucial part of achieving efficiency in continuous improvements. Performance measurements only are, however, not enough, but they should be integrated in some kind of a formal analysis on several levels to identify needs for improvements. In that formal analysis a necessary part is a model of precursors of performance. Experience has shown that it is sometimes difficult to implement sustainable improvements, which suggests that it is the execution part, which is difficult to get functional. With an efficient analysis that is brought to improved models of precursors of performance it should, at least in principle, be possible for organizations to enter a spiral of increasing performance.

The construction of a PMS for assessing the plant's technical and organizational performance is a demanding task. The PMS 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 PMS 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 PMS is, so to say, to be adapted to the local culture of the plant.

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[4] World Association of Nuclear Operators was established after the Chernobyl accident in 1986. The set of ten performance indicators as defined by WANO has been using by NPPs worldwide since 1990.

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