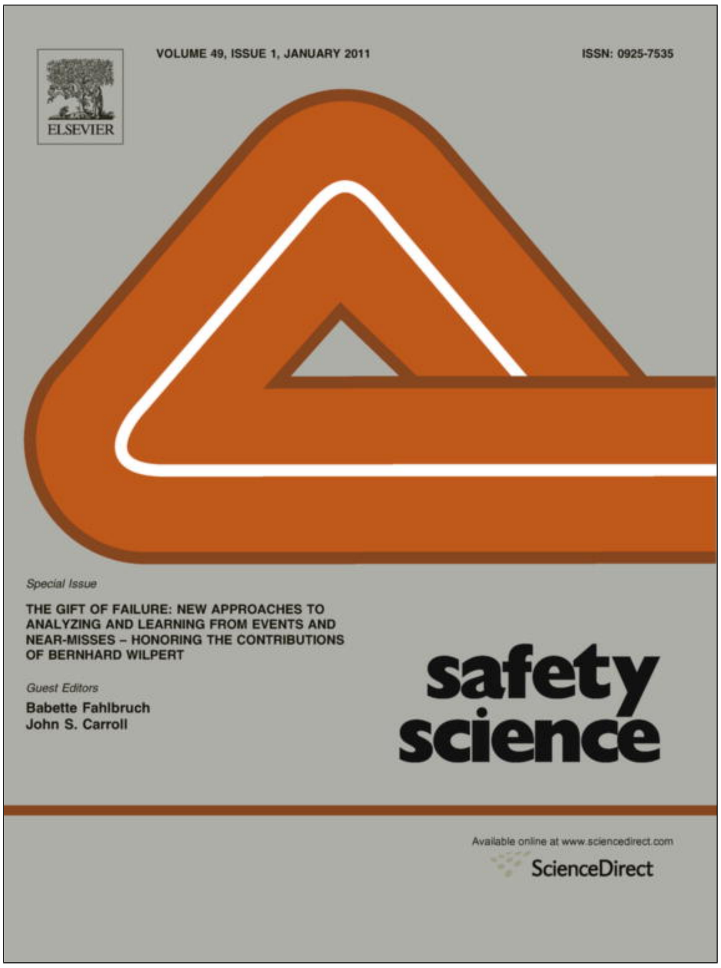
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Organisational learning – Reflections from the nuclear industry

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A B S T R A C T

Organisational learning has attracted scholarly interest for some time. In parallel a recommendation has been expressed to nuclear power plants to become learning organisations. I start from systems and practices of organisational learning that can be observed within the nuclear industry. After that I give a short description of the LearnSafe project and its main results. Next, I suggest a model that may provide help to nuclear organisations in structuring their discussions of organisational learning. Finally, in the last main section of the paper I discuss implications for the nuclear industry. At the end conclusions are drawn to give suggestions for future research.

1. Introduction

Organisational learning has attracted scholarly interest for some time (Easterby-Smith, 1997; Easterby-Smith et al., 1999, 2004). In parallel the recommendation to the nuclear industry has been that operators of nuclear power plants should become learning organisations (IAEA, 2002). Unfortunately however, this recommendation has been given without concrete guidance for how this could be achieved. The aim of this paper is to explore models that can provide help to the nuclear industry in structuring their own discussions on facilitators and hindrances of organisational learning.

Organisational learning has in the management literature been seen as adaptations to changed operational environments. The deregulation of the electricity market represented such a period of change for the nuclear industry, which during the years 1995–2005 due to low prices for electricity introduced many tensions in the operation of nuclear power plants. Increased prices during recent years have caused a revival of nuclear power and the plants are now seen as very profitable. Fulfilling the requirements for safe operation is however still the major challenge to managers and organisations at the nuclear power plants.

In the first major section of the paper I give a description of practices in the nuclear industry, which have an application to organisational learning. After that I describe briefly how data was collected in the LearnSafe project[1] and how it was analysed. From there I develop a model that may provide help to nuclear organisations in structuring their discussions of organisational learning. Implications for the nuclear industry form the last section of the paper. At the end I draw some conclusions and give suggestions for future research in the area.

2. Organisational learning in the nuclear industry

2.1. Organisational characteristics

Organisational structures in use at nuclear power plants are designed to meet the need to manage areas of deep technical skills and knowledge that are necessary to run the plants. Organisational innovations such as lean structures with few organisational levels, empowerment and process orientation have been tried, but requirements for accountability and repeatability have preserved structures with line organisations and formalised procedures for decision making and work control. Modifications of the plants are handled through a parallel use of project organisations.

Nuclear power plants have a very long operational life. Most nuclear power plants that are in operation were initially designed for 30–40 years of operational life, but today many plants are planned to run for at least 60 years. The long operational life places many challenges on the plants. One challenge is connected to technical development, which at some point in time will force the plants to modernise due to a combination of more stringent safety requirements, opportunities for power upgrades and difficulties to get spares. Another challenge is connected to maintaining skills and competence over two or more generations of staff.

Regulatory oversight implies that it is not enough that the plants are safe, but they are in addition forced to provide continuous proof to the regulator that they are safe. International practice

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[1] LearnSafe – Learning organisations for nuclear safety. This work was funded by 5th Euratom Framework Programme 1998–2002, Key Action: Nuclear Fission by the European Commission with the contract number FIKS-CT-2001-00162.

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places the sole responsibility for safety on the operator of a nuclear power plant. This is a straightforward requirement, but it also carries a subtle contradiction in the assumption that the regulator should not manage the plants, but still influence what they do (Wahlström, 2007a).

Nuclear power is a political technology, which stirs emotional reactions from politicians, media and the general public. This means that the nuclear industry's words and deeds are watched closely. Decision power also is exercised in political processes when power companies apply for building and operation permits. If something unexpected happens during plant construction or operation scrutiny is started immediately and efforts to restore public confidence and trust may be considerable.

2.2. Plant, people and processes

Since the first commercial plants were built in the 1960s, the nuclear industry has gone through several cycles of learning. Unfortunately, this learning has been partly reactive in response to incidents and accidents that brought earlier shortcomings in plant design and operation to the surface. Early safety concerns were focused mostly on technical matters and considerable efforts were spent on defining principles to be applied in developing requirements that would ensure safety of the plants. The deterministic safety principles that were created are still used today, but a few incidents in the early 1970s demonstrated the need for amending them with probabilistic safety criteria.

The Three Mile Island accident brought focus on the people who operate and maintain the plants. The accident brought many improvements into control room design, procedures and operator training to nuclear power plants all over the world. This development also triggered research in human behaviour and probabilistic safety assessments to provide estimates of the likelihood of human errors. Attempts in the early 1980s to elevate the influence of organisation and management on safety to the agenda did not at that time influence the thinking of the nuclear community.

The Chernobyl accident changed this situation. The post-accident meeting hosted by IAEA identified deficient safety culture as the root cause for the accident (IAEA, 1986) and a new cycle of learning was initiated. Today it is common practice to address the three systems of plant, its people and work processes or with a different set of terms man, technology and organisation. In hindsight it may be considered surprising that it took nearly half a century and two major accidents to create this insight.

2.3. Management systems

The management systems in use at nuclear power plants build on quality systems and organisational handbooks that were introduced in the late 1970s (Wahlström, 2004). At nuclear power plants today different concerns such as quality, safety, environmental protection, labour safety and security have been integrated into a single management system that also includes various non-safety related systems. The management systems of today typically have a hierarchical structure starting from the top with descriptions of mission, organisational values and vision and ending at the bottom with detailed instructions for carrying out specific activities and tasks.

Instructions that control daily activities form an important part of the management systems and they can on a general level be divided into three groups: operational, maintenance and administrative instructions. The operational instructions are further subdivided into instructions for start up and shut down as well as disturbance and emergency instructions. The operational instructions are usually validated at simulators and they are assumed to be followed literally. Maintenance instructions are also assumed to be followed literally, but administrative instructions are often seen more as ensuring repeatability in work activities.

The management of change at nuclear power plants goes through strictly controlled procedures, which are enforced by the regulator. Special administrative instructions are written and used to control this process. At nuclear power plants a separation is usually made between technical modifications and organisational changes. The formal procedures for the management of change are sometimes perceived as preventing even well motivated changes, but experience has clearly demonstrated the need for thorough reviews of all modifications and changes before they are introduced (OECD/NEA, 2005).

2.4. Organisational culture

Whereas the management system can be seen as the formal part of the organisation, the organisational culture can be seen as its informal part. Organisational culture has to do with shared values, attitudes and beliefs that members of the organisation have towards different things. One model of organisational culture separates between artefacts, espoused values and basic underlying assumptions and argues that organisational culture is difficult to assess and change (Schein, 1992).

A common view is that organisational culture is an emergent property that does not lend itself to conscious control. Organisational culture will however change over time in response to external events and to achieved and perceived performance. Good performance over extended periods of time has a tendency to enforce organisational beliefs in continued success, which may introduce more lax attitudes towards thorough safety precautions. Incidents and accidents have shown that gradual drift in organisational culture can create careless attitudes for example towards instructions. A common practice today is that nuclear power plants carry out organisational surveys that reflect prevailing organisational culture.

IAEA has since the Chernobyl accident actively been marketing the concept of safety culture to nuclear power plants (IAEA, 1991). Safety culture can be thought of as an organisational culture that safety oriented organisations should have (IAEA, 1998). IAEA has been active in developing guidance for activities that can support a good safety culture and the property of being a learning organisation has also been associated with a good safety culture (IAEA, 2002).

2.5. Systems facilitating organisational learning

The nuclear industry has a long tradition of sharing knowledge. These traditions have resulted in formalised systems for the exchange of information, which are operated by IAEA and WANO. One example is the feedback of operational experience that documents and shares lessons learned from incidents all over the world. These systems lay a dual responsibility on the nuclear power plants to report and analyse their own incidents and to extract and apply lessons from incidents at other nuclear power plants in the world.

IAEA and WANO also support organisational learning by peer reviews. A team of 10–20 persons from several plants visits a host plant for a period of 2–3 weeks to assess performance in several organisational areas. This practice gives a learning opportunity both for the host plant and for the people taking part in the review. The effect of learning is enhanced by revisiting the host plant some 18–36 months later after the peer review.

The management systems contain several functions that facilitate organisational learning. One example is the yearly planning in which plans are compared to performance outcomes to analyse deviations and to suggest improvements. Regular audits of work processes and organisational units are another function that provides similar opportunities for organisational learning. Most management systems of today include requirements for regular performance reviews by the senior management. A regulatory requirement is that all nuclear power plants go through periodic safety reviews with a time interval of approximately 10 years (IAEA, 2003).

3. Insights from the LearnSafe project

3.1. The LearnSafe project

The LearnSafe project was set up to address issues connected to organisation and management that have an influence on nuclear safety. The project was aimed at assessing consequences of a period of rapid change in the nuclear industry that took place after the deregulation of the electricity market at the end of 1990s (Wahlström et al., 2005). The LearnSafe project built on established channels of co-operation in an earlier project (Baumont et al., 2000). The project was set up with an empirical focus to give managers at the participating plants opportunities to freely express their ideas for and concerns about nuclear safety. This focus implied that no explicit model of organisational learning was applied in the data collection.

The LearnSafe project was divided into two major phases of which the first addressed *challenges* for the industry as seen by senior mangers (Kettunen et al., 2007) and the second collected and analysed views on *organisational learning*. The discussion below gives an account of results from the second phase of the LearnSafe project.

3.2. Data collection

In the second phase of the LearnSafe project data was collected in response to the following three research questions:

Q1: What kind of features and attributes characterise learning organisations?
Q2: What are the most common hindrances to organisational learning and b) how can they be removed?
Q3: How are various company cultures and sub-cultures influencing organisational learning?

Responses to the research question Q1 were generated in group discussions consisting of 2–4 managers (1st or 2nd line), who dealt with feedback experience, knowledge management, organisational development, training, evaluation of implementation of corrective actions, responsible persons for audits, etc. Fig. 1 was used in the discussions to illustrate the overall learning process and to stimulate discussions. Furthermore, factors impacting learning as well as formal and informal practices for learning were discussed and recorded. The results were collected as single sentence statements.

Data for the research questions Q2 and Q3 were collected in a combination of a Metaplan session and a group discussion with groups of 5–10 managers from different organisational positions. A Metaplan session (cf. http://www.moderationstechnik.de) is set up in two parts, where the first part is an individual and the second part a group exercise. In the first part of the Metaplan session 3–5 answers to the question Q2a were collected on separate cards. In the second part of the Metaplan session these cards were posted on the wall and moved around to form clusters that were given descriptive names. The resulting clusters and their content can be seen as a collective mind map of the participants in the session.

The group discussion was initiated by informing participants of the responses to the research question Q1. After that the research questions Q2b and Q3 were discussed with the groups. The resulting data sets consisted of the answers recorded at the cards and additional comments on the questions Q2b and Q3. There were some national variations in the data collection procedures as a result of the practical availability of people at the participating nuclear power plants. The collected data consists of nearly 1000 statements given by more than 100 managers from ten nuclear power plants in five countries.

The data collection was carried out in the native language of the plants. LearnSafe team members translated the statements into English, which means that some of their subtle meanings may have been lost. All statements together with their associated data were written into Excel tables for further analysis.

3.3. The method used for data analysis

The difficulty in analysing sentences in natural language is connected to a need for building metrics in the space of statements. We developed a metric in three stages of which the first stage was to select a descriptive model that would be as simple as possible, but still able to encode the richness of the data material. In the second stage this model was used to code the statements as members of fuzzy sets defined by the model. In the final stage hierarchical cluster analysis was used to group the statements into

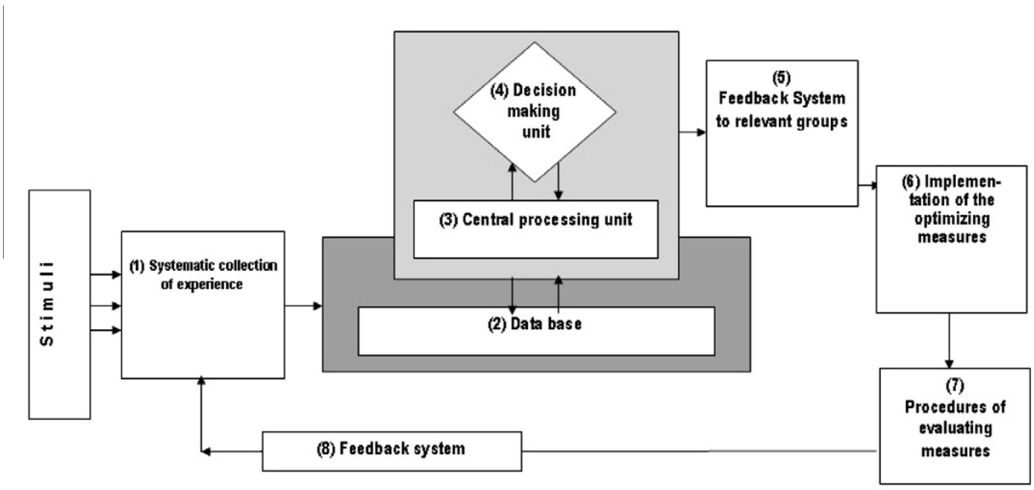

Fig. 1. The learning organisation metaphor that was created in the LearnSafe project to govern data collection.

clusters that were given descriptive names. A brief account of this method is given in the Appendix A.

This method has several advantages as compared with classical content analysis methods (c.f. Holsti, 1969) for analysing statement in natural language. Firstly the descriptive model can be selected to depend on the intent of the analysis, which means that the analysis can be carried out with different interpretations of the data. Secondly by associating each statement with one or several dimensions, where the strength of membership is given a specific value, it is possible to model the inherent ambiguities in natural language. Thirdly the solutions obtained by cluster analysis have a spectrum, where a larger number of clusters give a better fit and a lower number a simpler interpretation. Fourthly the cluster centres establish a metric in the space of statements that can be used to compare positions of single statements. Finally the possibility to start the cluster analysis from different initial points makes it possible to evaluate the robustness of the obtained solutions.

The model in Fig. 2 was used in the analysis. It defines four fuzzy sets, where the membership functions of the statements define points in a four-dimensional space. The model can also be interpreted to categorise statements on facilitators and hindrances of organisational learning on two axes. The first axis related is to a time dimension of present and future with systems and procedures in one end and objectives and priorities in the other. This axis can also be seen as characterising the span between actual and ideal. The second axis is related to an individual and organisational dimension. This axis also carries a reflection of the formal and the informal organisations. The coding of the statements was done by three different persons, one in Finland, one in Germany and one in the UK. The coders also coded the statement to be either facilitators or hindrances.

3.4. Clusters and their mutual relationship

The cluster analysis of the whole data set found feasible solutions with 11, 6 and 5 clusters. These cluster solutions were found to be distinct in the sense that a transfer from M to M-1 clusters gave comparably large increases in the sum of distances to cluster centres. The cluster centres were found to place themselves with loadings on all four dimensions. The cluster centres were quite stable with respect to the numerical solutions. The method proved to give a reasonable structure of the statements when they were ordered into the 11 clusters with respect to their distances from cluster centres. The 11 clusters were given the following names:

A. Objectives, priorities and resources.
B. Formal systems and practices.
C. People's attitudes and orientation.
D. Corporate culture and traditions.
E. Communication, guidance and appraisals.
F. Maintaining touch and focus.
G. Openness and trust.
H. Work community.
I. Encouragement and rewards.
J. Adequacy of means and methods.
K. Networking and co-operation.

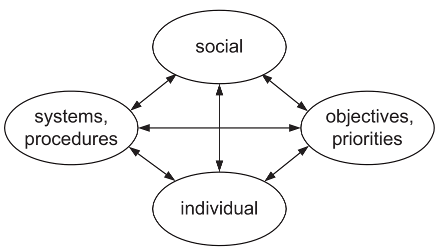

Fig. 2. Model used for the coding of statements.

Two additional cluster analyses were carried out, one restricting the data set to facilitators and the other restricting the data set to hindrances. From the facilitators and hindrances 6 and 7 cluster solutions were identified, respectively. This gives an indication that facilitators and hindrances are not symmetric in the sense that hindrances simply would be the negations of the facilitators.

An analysis of the distances between cluster centres in the different solutions revealed several similarities. For example 4 of the cluster centres (clusters A, B, C and D) were found to be almost identical in all solutions. Furthermore the fifth cluster centre of the five cluster solution was also found in the 11 cluster solution (cluster H) and similarly the two remaining clusters of the 6 cluster solution appeared as separate cluster centres in the 11 cluster solution (clusters F and K). Similar correspondences were found between the 6 cluster solution of facilitators (clusters H and I) and the 7 cluster solution of hindrances (clusters E, F and G) in the 11 cluster solution of the whole material.

A Euclidean distance model in a two dimensional plane of the cluster centres was calculated (cf. Fig. 3). A short distance between 2 clusters centres suggests similarities between the clusters and vice versa. The two dimensions of the plane do not necessarily have a meaning, because they are iterated to give a reasonable approximation of the distances between the cluster centres, which are situated in four-dimensional space. On the other hand they can be seen to reflect the major axes of the model used in coding the statements.

3.5. A discussion of results

The main result of the analysis is the cluster centres and the corresponding distance relation that provide various possibilities for further analysis. One such path of analysis is to compare countries and plants with each other as was done with the data from the first phase of the LearnSafe project (Kettunen et al., 2007). Such an analysis shows for this set of data that the number of statements in the clusters depends strongly on the country and the organisation they came from. This implies that facilitators and hindrances are seen differently in different organisations and countries.

The loadings of the four dimensions for the cluster centres provide another piece of information. The dimension individual has high loadings in the clusters C, F, G and H, the dimension social in the clusters D, G and I, the systems and procedures in clusters B, E and K and finally the dimension objectives and priorities high loadings in the clusters A, E, F and I.

Another path of analysis is to consider statements near cluster centres to get an understanding of issues referred to in statements belonging to the cluster. Leaving out the clusters J and K, which do not appear in the cluster solution restricted to facilitators and hindrances, the characterisations in Table 1 can be given for statements near to cluster centres.

In assessing results from a practical point of view two aspects seem to be important. The first one has to do with an identification of needs and opportunities for improvements and the second with an allocation of resources for organisational development to different activities.

3.6. How the results can be used

The clusters provide a set of issues that can be used as checklists to assess facilitators and hindrances to organisational learning. In that way they can provide a basis for the construction of assess-

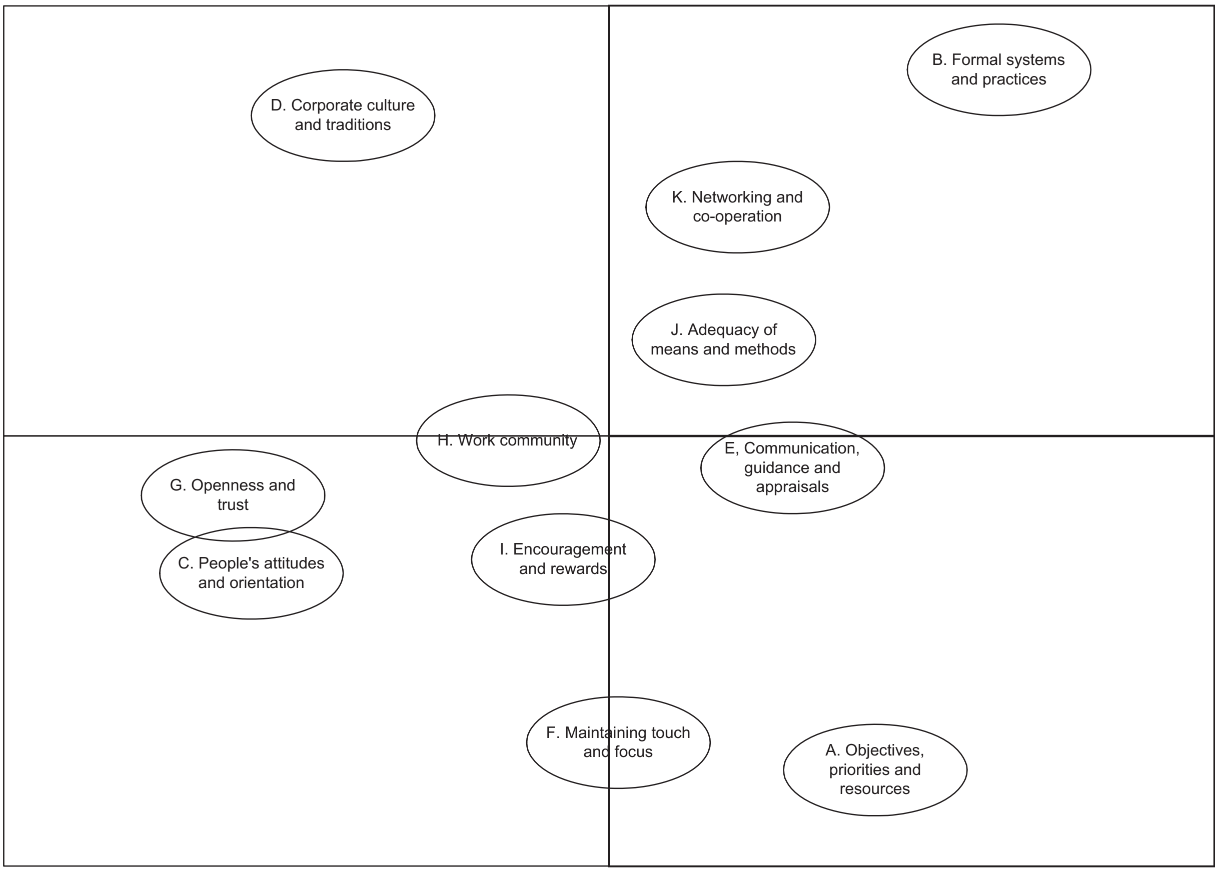

Fig. 3. Euclidean distance model of cluster centres.

ment instruments such as questionnaires by which needs and opportunities for improvements can be identified. The data from specific organisations can as such be of help in allocating resources to enhance organisational learning.

Taking a more general view on the statements, a common theme is the lack of time that prevents a strategic outlook and acts as a hindrance to organisational learning. Statements in this direction can be seen in the clusters A, E and F. The same lack of time can be seen in the statements originating from all ten nuclear power plants. This indicates a danger, because a lack of time can be a single influencing factor which broadly affects the quality of work at the plants. Reasons for the lack of time is at least in some of the plants related to organisational down-sizing.

A second general issue is connected to the complexity of the plants and their management systems that make communication and planning difficult. Statements related to complexity can be seen in the clusters E, H and I. The issue of safety culture is well understood in the light of the data, but it is interpreted in a variety of ways, because statements that can be related to safety culture are found in several clusters (Wahlström and Rollenhagen, 2004).

4. A model of organisational learning

4.1. Model needs

In building models of organisational learning that could be of help for managers in nuclear power plants there are several issues to be considered. Firstly it is necessary to understand that a model is a simplification of reality that is created for a specific purpose (Wahlström, 1994). This suggests that models have to be adapted to their users and to specific situations. Secondly the models have to be simple enough to be used in day-to-day activities, but not too simple to become trivial. Models describing organisations should be dynamic to describe competing mechanisms that influence important variables. If different models are proposed to describe specific mechanisms, they should still be possible to integrate into a common structure (Wahlström, 2007b).

A difficulty with dynamic models, i.e. models that describe interactions and development over time, is that influences seldom are unidirectional. They also contain inertia and feedback loops that are seen as time constants and sometimes as instabilities (Senge, 1990). Due to loops and multiple influencing pathways, the consequences of actions are difficult to predict and they may sometimes be opposite to what was intended.

In considering practical needs, models should address observed difficulties that the nuclear power plants have in transferring identified problems into persistent improvements. This difficulty has been seen in reactive response to incidents and in audit protocols that show recurring problems. Problems in communication may be one reason for this difficulty, because at nuclear power plants a large span of knowledge has to be bridged to combine relevant technologies and to comprehend both the big picture and details. The results from the LearnSafe project are well placed to respond to some of these needs, because they identify facilitators and hindrances for organisational learning.

4.2. A simple model

The model (Fig. 2) that was used for coding the statements in the LearnSafe project provides a good starting point for a model of organisational learning. Communication between the poles provides an important facilitator of organisational learning.

Table 1
Clusters and relevant issues from statements near to cluster centres.

Cluster	Issues	Facilitators	Hindrances
A. Objectives, priorities and resources	Time pressures Goals, objectives Resource allocation Prioritisation	Sound activity planning. Long term outlook. Ability to prioritise. Clear targets and expectations. Stability in organisational objectives	Lack of time. Lack of resources. Too broad focus. Several concurrent activities. Issues are shuffled around. Conflicting goals
B. Formal systems and practices	Systems, standards Procedures, support, tools Information management Review and feedback	Benchmarking. Support and tools. Exchange of experience. Functional mobility. Structured approach. Senior management reviews	Bureaucracy. Nuclear standards. Rigid structures. Unnecessary rules. Mass of data. Recording and accessing experience. Hierarchy
C. People's attitudes and orientation	Attitudes, orientation Motivation, self-conception Understanding Sharing of knowledge	Not in the solution restricted to facilitators	Resistance to change. Lack of motivation. Self-satisfaction. Lack of understanding. Self-conceit. Complacency. Apathy
D. Corporate culture and traditions	Corporate culture Traditions Common language Cooperation	People feel secure. Openness. Organisational loyalty. Team spirit. Caring new-comers. Willingness to listen. Informal contacts	Protection of turf. Group thinking. Traditions. Division between them and us. Criticism not allowed. Sub-optimisation. Punishing culture
E. Communication, guidance and appraisals	Communication Guidance Careers Appraisals	Availability of suitable forums. Capacity to adjust. Good contact networks. Top-down communication. Possible to try new things. Reward initiators	Reactive fire fighting. Unclear responsibilities. Lack of guidance. Top-down driven. Feedback is given only as critique. Hierarchical organisation
F. Maintaining touch and focus	Management support Realism and patience Work practices Expectancies and reality	Not in the solution restricted to facilitators	Poor loyalty to decisions. Lack of commitment. Pressure to perform. Lack of foresight and fantasy. Missing rewards. Change overload
G. Openness and trust	Openness Trust Team spirit Willingness to change	Not in the solution restricted to facilitators	Lack of questioning. Thinking in territories. Missing trust. Resistance to change. Not invented here. Lack of self-criticism. Fear of loosing face
H. Work community	Expectancies Feeling of security Acknowledgements Involvement, participation	Freedom of expression. People participate. Creative thinking. Everybody can join. Commitment, motivation, perseverance. Ability to co-operate	Not in the solution restricted to hindrances
I. Encouragement and rewards	Recognitions Rewards Pressure to perform Critical thinking endorsed	Stable and shared goals. Empowerment. Critical thinking. Internal incentives. Fads are avoided .The organisation has confidence	Not in the solution restricted to hindrances

Communication is referenced explicitly in the cluster E and implicitly in all other clusters except C and F. The learning metaphor (Fig. 1) can be seen as an internal structure within the four poles to indicate important functions for organisational learning. Impaired interconnections within and between the poles can appear as hindrances to organisational learning.

The distinction between individual and organisational learning that has been discussed in academic literature can be seen in the importance of transferring insights from individuals to organisational memory. Managers have a dual role in promoting learning both as members of and as representatives for the organisation. This duality implies that their personal orientation can have a large influence as both facilitators and hindrances for organisational learning.

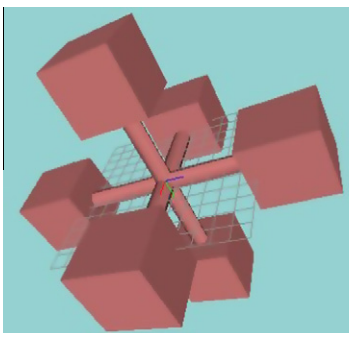

Fig. 4. A model structuring organisational learning into six poles that are interacting between each other and along three axes.

One feature of organisational learning that is not included in the model so far is connected to planned and emergent activities. This has to do with a focus on the deliberate act of creating new practices as opposed to letting them develop by themselves. Such an axis can be associated also with top-down and bottom-up induced changes of which the former often are structural and the later adaptive. This axis also has connections to the formal practices described in the management system and the informal practices of organisational culture. This axis was not included in the coding of the LearnSafe data, but in hindsight it can be seen as reflected in many of the statements. Adding this axis provides a model with three axes and six poles as indicated below (Fig. 4). It provides a general structure into which additional refinements in the form of mechanisms of influence can be integrated.

4.3. Additional mechanisms of influence that may be considered

The proposed model above gives a general structure into which additional mechanisms of influence can be added. Such mechanisms of influence cannot be derived directly from LearnSafe data, but may be proposed by other studies. The mechanisms can be assumed to regulate interactions between the poles of the structural model. When mechanisms of influence are proposed specialised methods for their assessment can be suggested.

For example a simple model containing senders, receivers and communication channels can be used to illustrate how communication may influence organisational learning. A sender codes messages in a way that s/he believes receivers will understand. Each message has an intent that can be more or less explicit. The response of a receiver to a given message depends on how its intent and content is interpreted. If a sender and a receiver have similar frames of reference, messages are likely to be understood as intended and therefore also acted upon. If not, the outcome is more uncertain and such messages may even decrease the trust senders have in the eyes of receivers. If for example messages from the management are not trusted the organisational climate may deteriorate.

Another mechanism to consider has to do with power structures that depend mainly on organisational positions, but which also is influenced by informal structures that depend on knowledge and skills. Power structures can be added as an influencing mechanism to the model by noting that power gives means to act on behalf of the organisation, it provides credibility in communication and it offers the possibility to initiate large changes with small efforts.

A final component that may be considered in assessing important influencing mechanisms are the mental models people use for understanding and maintaining control of their environment. Such models may be difficult to assess, but they are important determinants in the behaviour of people. If the models are refined, it can be assumed that people are able to respond appropriately to a larger variety of situations. These models also include the image people have of themselves. Organisations have similar models of the systems they are operating and of themselves as operators of these systems.

4.4. The definition of something better

Organisational learning carries the implication of something better. In judging what is better it is important to understand some basic dilemmas. The first one is connected with the newness of that something better, because without long term trials it can always be argued that proposed improvements may involve unknown negative consequences. A trivial approach would be to suggest modelling and simulation together with decision theory to evaluate costs and benefits of suggested new solutions. Unfortunately this approach contains as many open questions due to various sources of uncertainty.

A second dilemma is connected to the transfer of practices from one domain to another. The fact that a practice has demonstrated its fitness within one domain does not necessarily prove that it will be successful when transferred to another domain. Again modelling and simulation together with decision theory may provide insights and support, but not solutions.

A third dilemma is connected to the time period over which costs and benefits of the new practices should be accrued. A transfer to new practices always involves initial costs, which should be compensated by future benefits. The difficulty is to make reliable estimates of costs and benefits over time and to select an appropriate discounting rate. Due to these dilemmas it is likely that different persons have different opinions on the applicability of a set of new practices. These opinions will in reality be balanced against each other in a negotiation process to select a solution that builds on both systematic analysis and gut feelings.

4.5. An axis of analysis and synthesis

An often heard saying within the nuclear industry is that their organisations are good at analysing behaviour, but not as good at implementing remedies for problems found. One explanation may be found in considering an axis of analysis and synthesis or in terms of a decision process, the span between problem identification and problem solution. Practical problems involve both analysis and synthesis, but it is still important to make this distinction, because the move from problem analysis to problem solution will involve a transfer of responsibility from a specialist to a generalist, i.e. from an analyst to a manager.

Transfer of responsibility between two persons in an organisation can easily produce misunderstandings. Perhaps the largest source of misunderstandings is connected to conveying the urgency of solving a specific problem. Senior managers have several concurrent problems that should be handled with limited resources, which means that priorities have to be set. Depending on the situation, the analysts may oversell or undersell proposed changes, which may cause either unnecessary costs or postponement of important safety related changes. If proposed safety related changes are postponed too often, this may encourage the belief that safety does not have priority or that observed deviations are normal (Vaughan, 1997).

5. Implications for the nuclear industry

5.1. The recommendation to become a learning organisation

The recommendation to be a learning organisation can be given to any organisation. However, to be helpful, recommendations should be concrete and targeted to specific conditions. This implies that applicable models of organisational learning have to be placed in relation to an analysis of the organisation and its problems. A first round of distinctions is concerned with the object of organisational learning: has it to do with the plant, its people or the work processes? If an initiative to change is coming as a response to specific concerns, for example as triggered by some incident, this question may be easy to address, but it is often far more difficult to act on if it obtained in a periodic review.

The recommendation to be a learning organisation should be targeted to the types of organisation in consideration. Within the nuclear industry one can separate between three distinct phases in the lifetime of a plant. The first one may be termed design and construction, the second operation and the final phase decommissioning and dismantling (IAEA, 2001). The recommendation to become a learning organisation has apparently at least implicitly been addressed to organisations in the operational phase. This is natural, because it represents the longest part of plant life and because the two other phases may be seen as restricted projects.

The operational phase could be further subdivided in somewhat overlapping phases, which may be termed early operation, consolidation, modernisation and preparation for decommissioning. This division assumes that a phase of consolidation is required also after major modernisations. In the early operation phase organisational learning has to focus on understanding the plant and its inherent properties. In this phase it is important to identify pressing technical problems and to modify the plant to streamline it for commercial operation. The phase of consolidation should focus on a set of remaining small problems, which may or may not call for additional modifications. Modernisations are mostly triggered by technical development that provides opportunities for improved safety or competitiveness. Preparation for decommissioning brings in a spectrum of new challenges that have to be approached.

5.2. Organisational learning in a nuclear perspective

In considering facilitators and hindrances for organisational learning in a nuclear context there are some important observations. Firstly many formal systems are in place that at least on paper will facilitate organisational learning. This means that a simple explanation for deficient organisational learning is that these systems do not function efficiently. Secondly the nuclear industry is governed by regulatory requirements that enforce proven technologies and thorough reviews of changes, which may imply that the regulatory burden acts as a hindrance for changes. Thirdly the complexity of the nuclear power plants and their management systems implies that the costs of making a change are high and the benefits uncertain, which implies that a conservative decision often is not to change.

After specific mechanisms of organisational learning that act in the nuclear industry have been considered, the analysis should look for a greater detail. The proposed model of this paper may serve that purpose. A first step could be to assess possible problems on the axis of present/actual to future/ideal. Is the learning metaphor supported at both poles and is the communication between the poles efficient? The second and third step could follow the same scheme with the axes of individual/organisational and planned/emergent. Problems that are identified in this way suggest remedies quite easily.

5.3. Safety management

Requirements on safety management originate from an understanding of how accidents emerge and how safety is constructed. This understanding should be supported in both the formal and the informal systems. This suggests that in addition to instructions and other documents of the management system, people should in their training be given proper models for understanding why accidents happen and how safety is constructed.

Safety management should be well integrated in the management system, because otherwise safety activities may be seen as a concern mainly for the safety department or for the regulator. Safety management activities can be divided into feed forward and feedback paths, where the feed forward path is concerned with risk analysis and activities aimed at decreasing identified risks and the feedback paths with operational experience and corrective action programmes.

In addition to formally defined safety management activities it is important to recognise also the informal parts that are embedded in the organisational culture. If the formal and the informal systems drift away from each other, it may be necessary to initiate deliberate actions to decrease this distance. Deviations between formally defined and actual practises can be identified in normal auditing procedures. Senior managers have an important role as paragons in safety management, which is also identified in contemporary guiding documents on management systems (IAEA, 2006).

5.4. Managing organisational change

Organisational learning has to bring changes into either the formal or the informal practices to be persistent. Unfortunately it is not always clear how this process is supposed to take place. The easy approach to write new instructions however seldom fulfils its goal. Structural changes can be initiated top-down, but they usually necessitate bottom-up adaptations to be functional. Iterations are a part of this process, which may imply deviations from initial plans.

When new senior managers are appointed they often initiate organisational changes. This is natural, because they have to organise work practices to fit their own working style. Such changes are also implicitly assumed, because a normal reaction on assumed or actual organisational deficiencies is to appoint new managers. The nuclear industry has a strict line of accountability, which implies that organisational development initiatives have to be initiated and carried out in a structured process.

Organisational change will bring initial costs in the hope of later benefits. A general tendency seems to be to underestimate costs and overestimate benefits (Dawson, 2003). Organisational changes have their winners and losers, where the latter may mount a considerable resistance to change. Evolutionary changes are mostly preferable, because radical changes often cause losses of competency by people quitting. Sometimes however, an organisation may reach a state where revolutionary changes are necessary to handle bad habits that have become ingrained. Many organisations have developed lean structures with only a few hierarchical levels, but this has sometimes hampered organisational performance by removing crucial persons.

5.5. Organisational learning across organisations

Organisational learning does not necessarily take place only in one organisation at a time, but may in some cases involve two or several interacting organisations. This may take place between similar organisations in benchmarking activities, but this kind of co-operation has decreased due to strict competition legislation. Cooperation could also emerge in customer supplier relationships.

Outsourcing activities have led to regulatory concerns to which the plants have responded by making systematic competency inventories resulting in careful definitions of their core competencies. The concept of core competency is a topical issue in many organisations today (Hamel and Prahalad, 1990), it has received scholarly attention (Hafeez et al., 2002) and it has been used to distinguish between activities in an organisation that can be outsourced and those that cannot (King, 2001).

Outsourcing does not necessarily lead to impaired organisational learning. Outsourcing may instead lead to an influx of new ideas and skills for example when outsourced parts are integrated in larger specialist organisations. It is however important to recognise that organisational learning may need additional support when several organisations are involved. Nuclear power plants in Finland and Sweden have for example defined as a strategic goal to build long term contracts with supplier organisations to improve the potential for mutual organisational learning. The identification of core competency and the nurturing of intelligent customer skills are important components in such a development.

5.6. Additional balances

The proposed model of organisational learning suggests balances on three axes. With a generalisation of this model, one may look for other similar balances to be achieved. More generally one may even conjecture that successful management relies on a handling of balances between poles of requirements. One important balancing act has to do with adapting aspirations to available resources. This balance is related to the actual/ideal axis. In the LearnSafe data, failures were seen in a large number of complaints concerning time pressure.

The need to balance between traditions and renewal could also be seen in the statements. This balance has to do with the need for long term operation, which would be facilitated by a sound age profile within the organisation. Managing a sound age profile calls for a systematic hiring of new staff as well as thoughtful career and succession planning, which properly handled can facilitate organisational learning. A combination of old-timers and new-comers of the organisation have their own important place in bridging generations of personnel over the operational life of a nuclear power plant (IAEA, 2004).

6. Conclusions

The most important part of organisational learning is to close the loop from analysis to actual and persistent improvements. This can only be achieved if identified problems are brought to practical recommendations that are possible to implement. The very general recommendation to the nuclear organisations to become learning organisations must be far more concrete to be useful. This may be achieved by making theories, models and findings from research available for managers at the plants. If that could inspire them to initiate discussions and initiatives by which organisations can increase self-reflection and organisational development it is likely that safety can be improved.

Becoming a learning organisation has been marketed as a panacea for ensuring safety in nuclear power plants. This recommendation has to be qualified in several ways to be practical. One path of future research may be to validate proposed models such that they can support insights in discussions of organisational learning. More importantly however, organisational learning must be integrated into a larger research agenda on how organisational factors influence nuclear safety (Wahlström and Rollenhagen, 2007).

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Appendix A. The data analysis method

The data analysis is based on fuzzy sets (cf. Klir et al., 1997), where the statements are coded with respect to their perceived membership in the concepts defined by the selected model. The advantage of using fuzzy sets is that a statement can have loadings on one, several or all of the concepts. This means that the fuzziness of natural language is reflected more accurately than with other methods, where a binary membership function is used.

After the collection of the statements, they were coded by three independent persons, who were instructed to assign their perception of their membership in the four categories, Individual (IND), Social (SOC), Systems and procedures (SYS), and Objectives and priorities (OBJ). These four categories were to be interpreted in their widest sense according to the following descriptions:

- Individual (IND). This category relates to the personal characteristics of plant staff, such as attitudes, beliefs, orientation, know-how and capabilities. Any statement that is connected to the employees' or managers' individual attributes should therefore load this factor.
- Social (SOC). This category relates to the social and informal aspects of the plant organisation, such as values, norms, languages, cultures and daily practices. Especially issues that have to do with customary patterns of operation and interactions between various parts of the organisation should load this factor.
- Systems and procedures (SYS). This category is concerned with formal ways of structuring work at the nuclear power plant. It includes e.g. roles and responsibilities, functions and processes, instructions and manuals as well as various support systems and databases.
- Objectives and priorities (OBJ). The category has to do with the publicly expressed strategies, goals and policies of the organisation. It also refers to prioritisation and allocation of resources as they occur in practice. Therefore statements that relate to decision making in general should load this factor.

Each statement was classified on the basis of its assessed degree of membership to each issue domain (category) on the scale of 0–100 points. 100 points denote very strong membership while 0 denotes no membership. It was stressed that a statement may fit into one or several categories at the same time.

The following generic membership function applied to all four categories and it was given to assist the assignment of membership values.

Points	Meaning
90–100	The statement strongly relates to the category under consideration
40–60	The statement clearly relates to the category but only to a certain extent
0–10	The statement's relation to the category is weak or non-existent

The following example of how the coding of the statements could proceed was given.

Statement	IND	SOC	SYS	OBJ
Thinking in territories, pinching own information, desire for comfort	100	50	10	10
Difficulties in recording and accessing experience	10	50	80	5
Rationality in the strategic choice of policies regarding organisational change	20	20	20	100
Reward is given to people who speak, not to people who do things	20	30	0	80
Culture is 'all hands on deck' to solve operational problems – everything else goes out the window	20	100	20	50

Large differences in coding between the three coders were discussed and somewhat unified after which the means of the assigned memberships were calculated for each of the statements. Each statement had then obtained coordinates in a four-dimensional space and a numerical analysis could be carried out. The analysis was carried out using a hierarchical cluster analysis (cf. Hair et al., 1998).

A cluster analysis proceeds iteratively from a solution, where each data point is seen as one cluster through reducing the number of clusters by allocating neighboring statements to the same cluster and the cluster centres are recalculated. In the iteration the godness of the solution is assessed based on an agglomeration coefficient. The obtained cluster centres can be seen as a kind of generalised instance of the statements in the clusters. Finally the clusters were given names, which were based on an assessment of the statements with the shortest distance to the cluster centres.

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