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Productivity Impacts from Knowledge Management

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ABSTRACT

This is a longitudinal case study that explored the relationship between use of organizational memory, knowledge, knowledge management, and knowledge worker productivity within the engineering group at a nuclear power plant. Three data points were taken over five years. The group used a Knowledge Management System (KMS) and it was found that the system improved effectiveness/productivity of the organization. The organization had not identified measures for determining productivity improvements so the key results of the case study are models showing the impact of knowledge use on productivity.

Keywords: Knowledge Management, Organizational Memory, Organizational Learning, and Knowledge Management Systems

INTRODUCTION

Kaplan and Norton's (1992) Balanced Business Scorecard measures the value of IS to the organization with one of the factors considered being the ability of the organization to sustain learning and improvement. Learning, and organizational learning, is the process by which experience is used to modify current and future actions. Huysman, Fischer, and Heng (1994) as well as Walsh and Ungson (1991) believe organizational learning has organizational memory (OM) as a component. Stein and Zwass (1995) and Walsh and Ungson (1991) define OM as the means by which knowledge from the past is brought to bear on present activities, thus resulting in higher or lower levels of organizational effectiveness. Improving effectiveness can result in improved organizational performance and adding value to the organization. Organizational learning uses OM as its knowledge base. Davenport and Prusak (1998) define knowledge as an evolving mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information that in organizations often becomes embedded in documents or repositories and in the organizational routines, processes, practices, and norms. Alavi and Leidner (2001) view organizational knowledge and OM as synonymous labels.

Knowledge management (KM) is defined by Malhotra (1998) as that process established to capture and use knowledge in an organization for the purpose of improving organizational performance. We refine KM to be the process of selectively applying knowledge from previous experiences of decision making to current and future decision making activities with the express purpose of improving the organization's effectiveness. Jennex and Olfman (2002) view KM and OM as manifestations of the same process only in different organizations. User organizations 'do' knowledge management; they identify key knowledge artifacts for retention and establish processes for capturing it. OM is what IT support organizations 'do'; they provide the infrastructure and support for storing, searching, and retrieving knowledge artifacts. OL results when users utilize captured knowledge. That OL may not always have a positive effect is examined by the monitoring of organizational effectiveness. Effectiveness can improve, get worse, or remain the same. How effectiveness changes influences the feedback provided to the organization using the knowledge. Figure 1 illustrates these relationships.

Additionally, Strassmann (1990) and Rubin (1994) propose that adding value to the organization or the organization's customers improves the productivity of the organization. Rubin (1994) defines "added value" as being the result of improved organizational performance.

Knowledge Management Systems, KMS, are systems designed to manage organizational knowledge. Alavi and Leidner (2001) clarify KMS as IT-based systems developed to support/enhance the processes of knowledge creation, storage/retrieval, transfer, and application. Additionally a KMS supports knowledge management through the creation of network based Organizational Memory, OM, and support for virtual project teams and organizations and communities of practice. A final goal of a KMS is to support knowledge creation.

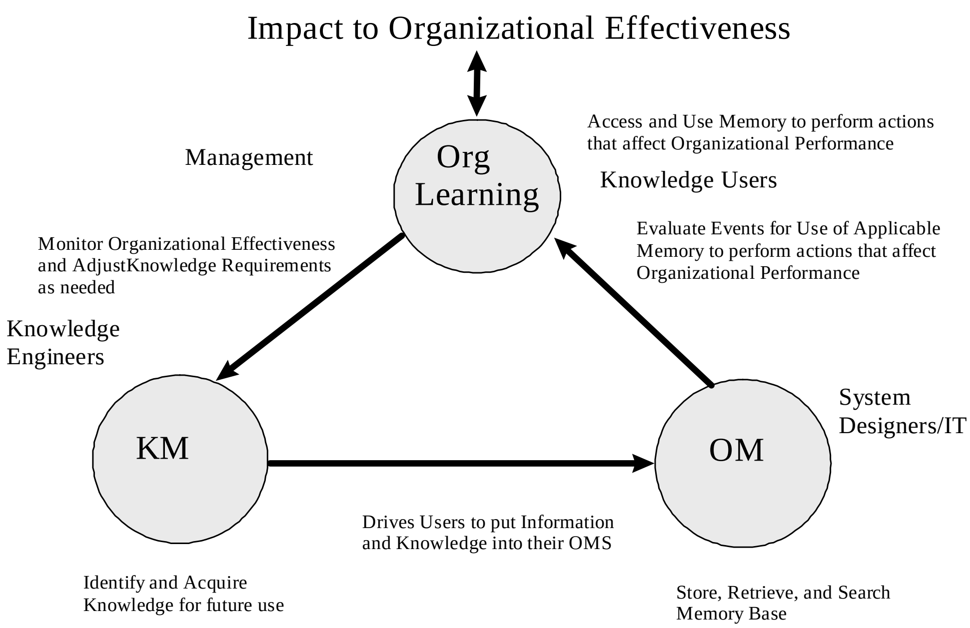

Figure 1. The KM/OM/OL Model (Jennex and Olfman, 2002)

An organization implements a Knowledge Management System (KMS) to improve its ability to capture, store, and reuse knowledge with the expectation that it will improve its learning and overall performance through improved decision making. Ultimately, organizations implement a KMS to help the organization to learn and improve with the expectation that organizational effectiveness/productivity will improve. This case looks at an organization that manages and uses knowledge to determine if KM truly does improve productivity.

This exploratory longitudinal study sought to discover how knowledge use affects organizational productivity. The study covers 5 years with data collected during three time periods. The first time period was in 1996 with the second being in 1998 and the third in 2001. The first period utilized a survey and 40 interviews. The second occurred after the organization had completed a voluntary retirement program resulting in a 25% turnover in staff and utilized a survey and 10 interviews with new members to the organization. The third occurred while the organization was undergoing reorganization and reduction in force and utilized 22 interviews, 14 with interviewees from the first period, 6 with interviewees from the second period, and two with key managers leading the reorganization. All three data collection periods also included document review and direct observation for a period of several weeks during the data collection period.

BACKGROUND

The subject engineering organization is part of a large, United States based, investor-owned utility. The utility is over 100 years old, has a service area of over 50,000 square miles, provides electricity to over 11 million people via 4.3 million residential and business accounts, and had operating revenues of approximately $8.7 billion in 2002. Utility net revenue has fluctuated wildly the last few years with a $2.1 billion loss in 2000, $2.4 billion in earnings in 2001 (primarily due to one time benefits from restructuring and other initiatives), and decreasing to $1.2 billion in earnings in 2002. To service its customers the utility operates a transmission and distribution system and several large electrical generation plants and is organized into 3 main line divisions, Transmission and Distribution, Power Generation, and Customer Service. Divisions such as Human Resources, Security, and Information Technology (IT) support the line divisions. The utility has approximately 12,500 employees.

The Power Generation division is organized into operating units dedicated to supporting specific power generation sites. Each operating unit has line organizations such as Operations, Maintenance, Engineering, and Chemistry/Health Physics. Power Generation operating units are supported by dedicated units from the corporate support divisions (Security, Human Resources, IT). The station technical engineering organization used for this study is part of the nuclear operating unit of the Power Generation division and is located at the largest electrical generation site operated by the utility. At the time of the study the engineering organization consisted of approximately 100 engineers organized into groups that support facility systems or programs.

An engineering organization was selected for the study as:

- Engineers are knowledge workers and make decisions as a part of their job function.
- Engineers use knowledge to make decisions.
- Engineer productivity is improved by increasing the speed and/or quality of the decisions they make.

This engineering organization was selected because it was accessible. Also, this organization resolves equipment and operational problems within a nuclear facility. They utilize performance and maintenance histories, lessons learned, and previous problem resolutions to arrive at new solutions or courses of action. How well they do this is reflected in how well the facility operates.

KNOWLEDGE MANAGEMENT SYSTEM

The organization did not have a formal KM strategy or KMS when the study began. However, the organization did have KMS repositories and components although they weren't recognized as such. The organization's knowledge was found to reside in: documents, databases, and individual memories (yours and others). Interviews and surveys found several repositories supporting these locations and it was determined that the de facto KMS was these components. Table 1 documents the de facto KMS and shows the type of repository, the system supporting the repository, and the types of knowledge found in the repository.

These KMS components were found to be overlapping systems with each containing elements from the others. This was especially true for most IT components because process automation and reengineering led to the replacement of many documents and processes with IT substitutes. A few changes in the KMS were noted over the course of the case. The most significant was a decrease in importance of Email. This was attributed to changing the Email system from CCMail to Lotus Notes. The change was performed without converting Email archives causing the loss of knowledge. This experience taught the organization not to rely on Email as a repository. Another important change was the reduction in the reliance on the "work done" sections of MOSAIC. Cost cutting process changes resulted in these sections being stored in the Corporate Document Management (CDM) system. This led to the addition of CDM to the KMS, which was the only component added during the course of the study.

An important observation on KMS use was that amount of use was not a good indicator of the impact of KMS use. Several long term organizational members echoed the sentiment that it was not how often engineers used the KMS but rather that it was the one time that they absolutely had to find knowledge or found unexpected knowledge that proved the worth of the KMS. An example of this was the use of the KMS to capture lessons learned and best practices associated with refueling activities. These activities occur on an approximate 18-month cycle that was sufficient time to forget what had been learned during the last cycle or to have new members with no experience taking over these activities.

This made evaluating the impact of the KMS on productivity difficult as a common measure of impact is to multiply impact by the numbers of time used. This measure wouldn't have reflected the actual impact on productivity. This was especially true since engineers, supervisors, and managers were consistent in agreeing the KMS made them more productive and effective. It is determined that it is more important that engineers use the system when appropriate. An instrument from Thompson, Higgins, and Howell (1991) was adapted to measure engineer intent to use the KMS. The Thompson, Higgins, and Howell (1991) instrument, the Perceived Benefit Model, is based on a study of workers' attitudes and behaviors with respect to optional computer usage. This is based on the theory that the perception of future consequences predicts future actions. The implication was that the utilization of a PC in an optional use environment would be influenced by the individual's feelings, habits, and expected consequences of using PCs; and the social norms and environment governing PC use. The developed instrument was adapted to measure the relationships between social factors concerning KM use; perceived KMS complexity; perceived KM job fit; and perceived long-term consequences of KM use with respect to the utilization of KM. An additional factor, fear of job loss, was added to determine if fear affected an engineer's willingness to contribute to the KM. Table 2 reflects measurements of engineer perceptions affecting future use of the KMS and show that the engineers will probably use the KMS when appropriate.

Repository	System	Contents
Document Based	CDM	Documents: memos, correspondence, drawings, procedures, vendor info, Records: completed procedures, tests, surveillances, Maintenance Orders, Reports
	Engineer Library	Drawings, Licensing Documents, Codes, Standards, NUREGS, Regulatory Guides, Design Basis Documents, System Descriptions, EPRI Documents, Reports, Old Non-Conformance Reports, Correspondence, Vendor Info
	Training Master File	Qualification Guides, Answer Keys, Event evaluations, Lesson Plans, Task Analyses, Various Training Materials
Computer	MOSAIC	Equipment maintenance history, problem reports/resolutions, root cause and corrective actions, lessons learned.
	NCDB	Drawing Revision History, Base Engineering Info., Program History and Info., Document History, Calculations
	TOPIC	Hypertext files of Licensing Documents, ISEG Evaluations, Reports, Correspondence
	NDMS	Procedures, procedure history, and change basis documents
	Internet	Vendor/Utility/NRC Info.
Self	Your Files	Email archives, files, notebooks, in head memory, etc.
Other	Coworker	Email archives, files, notebooks, in head memory, etc.
	External various	Various external entity files, includes INPO and NPRDS, EPRI, NRC, Vendors, User's Groups, Trade Groups

CDM-Corporate Document Management, NUREGS-Nuclear Regulations, EPRI-Electric Power Research Institute, ISEG-Independent Safety Engineering Group, INPO-Institute for Nuclear Power Operation, NPRDS-Nuclear Plant Reliability Database System, NCDB-Nuclear Consolidated Database, NDMS-Nuclear Document Management System, MOSAIC-maintenance system, TOPIC-licensing database

Table 1, KMS Components

Perceived Benefit Factor	Score	Result
Social factors	4.08	Organizational culture encourages use of the KMS
Complexity (inverse scored)	2.38	Not complex, supports use of the KMS
Job fit, near term consequences	4.56	Fit job well, supports use of the KMS
Job fit, long term consequences	3.36	Neutral
Fear of Job Loss	2.32	No support, no fear found

Note: score is based on a 5-point scale where 5 = "strongly agree."

Table 2, Perceptions Affecting Usage

Finally, before it could be determined that the KMS had an impact on productivity, it had to be shown that the KMS was effective in performing its KM functions. This was done using Stein and Zwass' (1995) adaptation of Quinn and Rhorbaugh's (1983) Competing Values Model to assess KMS effectiveness. Table 3 summarizes these findings. Data was collected via 20 interviews and coded and analyzed using a 5-point Likert scale (1 is strongly agree). The scores lead to the conclusion that the KMS was considered effective.

Factor	Score	Result
Integration	2	Good time/spatial integration, support effective KMS
Adaptation	2	Boundary spanning done, outside information brought in, supports effective KMS
Goal Attainment	1	Goals/ performance tracked, support effective KMS
Pattern Maintenance	1.5	Procedures/revisions, individual skills tracked, supports effective KMS

Note: score is based on a 5-point scale where 1 is "strongly agree."

Table 3, Results of Effectiveness Functions

Further qualitative analysis of effectiveness utilized structured interviews that asked for opinions and examples on the effectiveness of the KMS. A consensus was found that the KMS made the subject audience more effective. Nearly all agreed that most past decision information could be retrieved within a couple of hours and usually within minutes. However, nearly all agreed that the KMS could be better. Elements of these interviews were used in the stages 2 and 3 and found the same results. Examples of comments include:

"It (the KMS) helps us to keep from reinventing the wheel. Every decision we make is not a new decision. Our systems help us to do this."

"We have much more capability now than we did. As a Shift Technical Advisor (STA) we can do so much more than we could ten years ago. There is almost too much data."

"The information is there but the tools are slow, systems crash, and the information and tools are unreliable."

The last comment demonstrates that while the KMS was considered effective, it was found wanting in the areas of hardware performance and overall integration. Users with less than a high end processor found the systems slow and cumbersome. Lack of adequate RAM was a common issue (initially 32 Mbytes were needed, expanding to 128 Mbytes - each data point found over half the subjects had half (or less) of the necessary RAM). Also, users noted that there were many tools and sources but no observed intentional cohesion between them. It was noted that all the systems are Windows based so data could be copied/cut and pasted, providing basic integration. However, no master plan for developing or maintaining the KMS was developed during the period of the research and no evidence was found suggesting this would ever be done. This indicates that the KMS will continue to lack cohesion and will not improve in effectiveness. The two observed changes in the KMS, noted above, actually reduced effectiveness by increasing access times. Also, reducing dependence on Email, while better for reliability, accuracy, and security, reduced individual effectiveness by removing an easy to use, readily accessible repository.

KNOWLEDGE USE

The organization is driven to capture and use knowledge. Since it is a nuclear plant it falls under the guidance of the United States Nuclear Regulatory Commission (NRC). The NRC mandates that nuclear plants learn from events so that they are not repeated. Each nuclear site has an independent safety engineering group tasked with reviewing events from other sites for applicability to their site. Additionally, knowledge on event experience is promulgated to each site through official NRC documents. The result is that an inquiring and knowledge sharing culture is fostered throughout the nuclear industry. This site had an excellent knowledge sharing culture and interviews and surveys found that engineers were almost as likely to capture knowledge because they thought it a good idea as they were due to regulatory requirements. Table 2 shows the top 15 drivers (out of 25 total drivers) that influence engineers to capture knowledge. These drivers are shown ranked by their importance. Additionally, their frequency of use is shown as it shows that importance has little to do with how often the driver is used.

Driver or Reason Something is Captured in the KMS	n	Importance (Std Dev)	Frequency (Std Dev)
NRC requirement	19	1.05 (0.24)	3.26 (1.31)
You believe it is important to capture the knowledge	22	1.18 (0.41)	1.84 (1.30)
Procedure requirement	19	1.32 (0.47)	2.27 (1.03)
Near Miss Event	17	1.53 (0.64)	3.39 (0.96)
Management/Supervisor directive	20	1.55 (0.70)	2.29 (1.36)
Site Event	18	1.56 (0.62)	3.21 (1.22)
AR Assignment	20	1.60 (0.71)	2.19 (1.05)
Data/Trend Analysis	19	1.63 (0.49)	2.67 (0.90)
Lesson Learned	17	1.71 (0.59)	3.08 (0.76)
Other Regulatory requirement	14	1.71 (0.65)	2.93 (1.54)
Industry Event	20	1.75 (0.55)	3.44 (1.15)
Good Practice	19	1.79 (0.64)	2.67 (1.18)
INPO Recommendation	15	1.80 (0.56)	3.47 (1.25)
Group/Task Force recommendation	17	1.82 (0.35)	3.86 (1.03)
Co-Worker recommendation	18	1.83 (0.66)	2.56 (1.37)

n=# of respondents using the driver; Importance: 1=Very Important, 2=Important, 3=Not Very Important; Frequency: 1=Daily, 2=Weekly, 3=Monthly, 4=more than monthly, less than yearly, 5=Yearly

Table 2, Knowledge Driver Ratings

PRODUCTIVITY FINDINGS

The research question for this study was whether engineer use of the KMS results in improved productivity. Two areas of productivity were defined and examined. The first was individual engineer productivity as it was assumed that for engineers to continue to use the KMS there must be a perceived benefit. The second was organizational productivity as it was assumed that for organizations to continue to support a KMS there must be a benefit at the organizational level. This is consistent with the individual and organizational impact outcomes of DeLone and McLean's (1991) IS Success Model. The following paragraphs report the characterization of both forms of productivity.

Engineer Productivity

The standard measure for productivity is the ratio of resources used to products generated (Strassmann, 1990). This does not readily apply to most engineers. Instead, effectiveness was used as a measure of engineer productivity where effectiveness is a function of quantity and quality of engineering work accomplished. Engineering work in the context of the nuclear power facility was found to be related to decision support. Engineers performed evaluations and made recommendations to resolve plant issues, usually under time or resource pressure. Sometimes the work included implementing the decision. In all cases, the engineer was measured on the timeliness, correctness, and quality of the decision support as determined by the supporting documentation and the satisfaction of the client. The study explored engineering productivity and determined a model for it. Interviews were used to outline what measures the managers used to evaluate their engineers and to identify what measures the engineers' thought should be used. While no unique set of measures was identified, several factors together could be used for this measure: Figure 2 illustrates the personal productivity model derived for the subject organization.

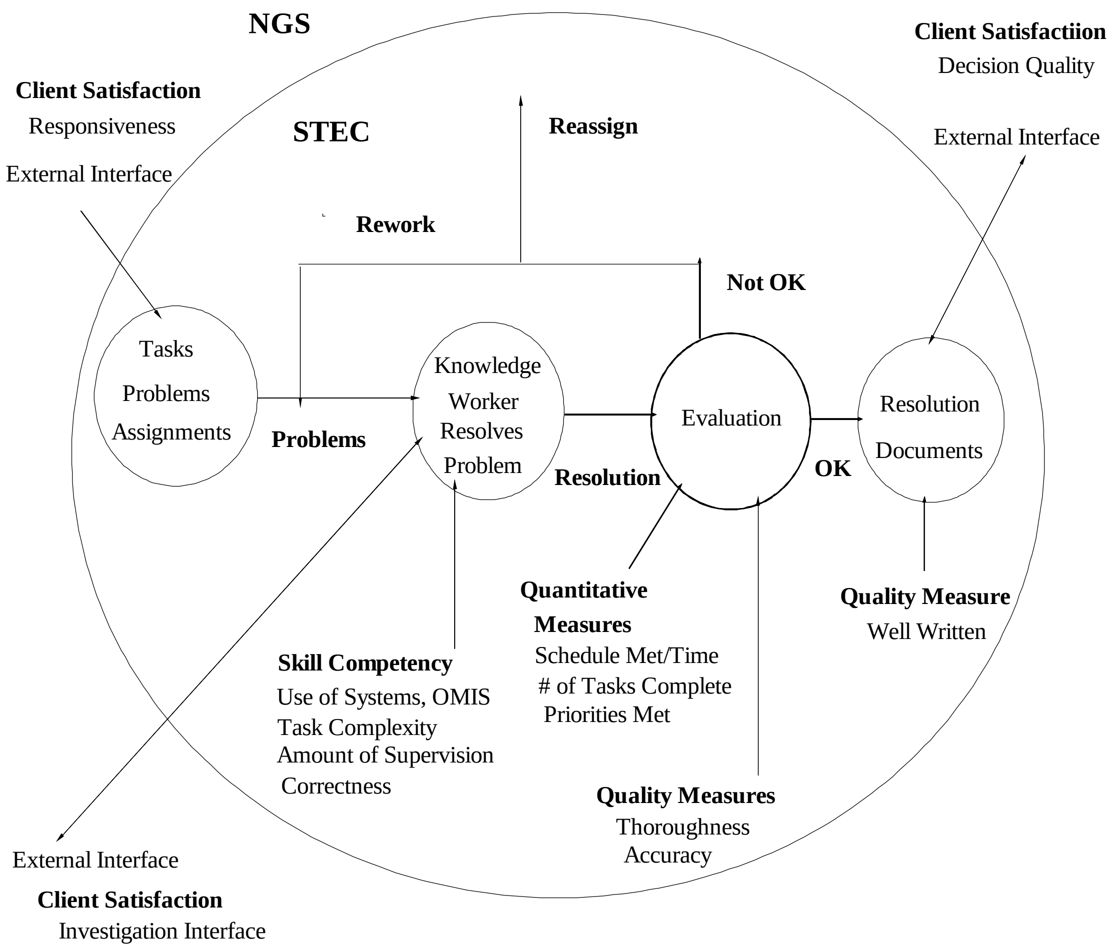

Figure 2, Engineer Productivity Model

The Engineer Productivity Model has several quantitative, qualitative, and competency measures that are directly impacted by the use of the KMS. These measures are:

- Timeliness in completing assignments
- Number of assignments completed
- Identifying and completing high priority assignments
- Completeness of solutions
- Quality of solutions (well written with complete documentation)
- Solving problems the first time
- Amount of work that has to be repeated
- Complexity of work that can be assigned to a worker
- Amount of backlog.

Using this characterization of productivity it was found that use of the KMS was considered a basic skill that each engineer was expected to possess. Use of the KMS was expected to improve the ability of the engineer to find and retrieve key information and knowledge that would aid the engineer in meeting deadlines and completing assigned work. Management rated as best engineers those who used the KMS to generate work with sufficient quality such that little to no rework was required and the clients were satisfied. Engineers who met these expectations were rewarded with pay increases, promotions, and more interesting assignments, providing additional extrinsic motivation for the engineer to use the KMS.

Organizational Productivity

Identifying productivity measures for the organization was more difficult than identifying them for the engineers. Two approaches were used. The first looked at the performance assessments done by external organizations. These provide an effectiveness assessment of productivity. The second looked at performance relative to the goals in the business plan and preset key performance indicators.

Approach #1

The first measure was based on the SALP, Systematic Assessment of Licensee Performance, Reports issued by the NRC. Review of scores issued since 1988 showed an increase from a rating of 2 to a rating of 1 in 1996, the time of the first stage of this research (see Table 5). Observed strengths in 1996 included the depth of component failure analysis; timely and thorough support for operations and maintenance activities; excellent diagnoses of equipment failures and investigation and resolution of emerging issues; operability determinations were well written and reflected conservative engineering judgment; and engineering self-assessments and resultant corrective actions were determined to be superior.

This rating dropped to a 2 in 1997 (time of the second stage) due to inconsistencies in management oversight and the quality in provision of engineering support to a few activities. However, it was noted that engineering had strong performance in resolving issues and determining corrective actions, self-assessment, and outage support (NRC News, 1997). The SALP program was suspended in 1998, as it was perceived that local government, insurance carriers, and others used ratings as objective measures of performance and not as self-assessment indicators. The SALP program was replaced by periodic plant performance reviews (NRC News, 1998). The plant performance review is a comprehensive review of plant processes with just the overall assessment released to the public; particular findings are given to the plant as guides for improvement but are not made public. The subject site was given acceptable ratings for the remainder of the study period.

Year	Engineering Rating	Overall Rating
1997	2	1.5
1996	1	1.5
1994	2	1.5
1993	2	1.43
1991	2	1.57
1990	2	1.43
1989	3	1.71
1988	2	1.82

Table 5, SALP Ratings

The other part of the external evaluation process is the site evaluation performed by the Institute of Nuclear Power Operations, INPO. An evaluation was conducted during the spring of 1996 and resulted in a 1 rating. This rating was maintained throughout the 5 years of the study. A history of these ratings is not included, as the organization did not grant permission to publish it.

The external assessments identified several strengths directly related to engineer effectiveness. These include decision-making, root cause analysis, problem resolution, timeliness, and operability assessment documentation. This indicates a direct link between engineer productivity and organization productivity. Also, since internal engineering effectiveness assessments were positive and organization effectiveness is rated highly, it can be inferred that engineer effectiveness does directly impact organizational effectiveness.

Approach #2

The second measure was how well the organization's performance matched the expectations of its business plan and key performance indicators. The first data point found only a few goals related to the subject organization and few performance indicators and goals that could be used to determine productivity. Two indicators were linked to knowledge use: unit capacity and unplanned automatic shutdowns. Unit capacity and unplanned automatic shutdowns are influenced by how well the engineers evaluate and correct problems. Both factors improved over time. These two factors plus unplanned outages and duration of outages became the standard measure within the organization and throughout the industry during this study. Reporting and monitoring of these factors significantly improved during the course of the study. Originally, information on how the site was performing was distributed infrequently with little attention paid to it. During the last two years, as management became more aware of KM and the need for measuring effectiveness, the process was changed. Currently, performance information is available on the site's Intranet. Also a quarterly report is produced that discusses how the site is performing and pays particular attention to lessons learned, what is working well, what is not working well, and where there are problems.

Originally, this approach was not considered valuable as a measure of effectiveness. However, it is now considered to be a very effective measure and has replaced the first SALP approach as the method of choice for assessing organizational effectiveness. Table 6 lists the capacity factors for the units of the site. The table also lists the cumulative capacity factor because refueling outages cause lower capacity factors in the year they occur and the cumulative tends to show the overall impact of improvements in performance. Table 6 shows generally improving performance for both units during the period of the study (1996-2002). The dip in 1997 is due to special, first time cleaning activities that caused refueling outages to be extended and is considered an anomaly in the generally improving trend. The dip for Unit 3 in 2001 is due to time needed to repair the turbine following an accident during startup following completion of the refueling outage. This accident was not due to activities performed by the subject-engineering group and therefore was not considered a failure in KM.

Year	**U2 Capacity Factor %**	**U2 Cumulative%**	**U3 Capacity Factor%**	**U3 Cumulative%**
1990	88.65	69.47	69.78	69.75
1991	61.55	68.48	91.89	72.91
1992	93.58	71.27	72.00	72.79
1993	81.67	72.31	75.34	73.08
1994	99.32	74.77	96.69	75.44
1995	69.3	74.31	79.29	75.79
1996	90.97	75.59	93.17	77.24
1997	71.01	75.27	72.33	76.86
1998	89.94	76.24	95.75	78.21
1999	87.95	76.98	88.96	78.93
2000	90.69	77.78	101.55	80.34
2001	101.27	79.09	60.03	79.15
2002	90.80	79.70	100.92	80.36

Note: a capacity factor greater than 100% is possible because capacity factor calculations are based on the original reactor rating of 1070 MW but the reactors are approved for operation at 1105 MW

Table 6, Capacity Factors, Actual and Cumulative (PRIS, 2003)

CONCLUSIONS

Deregulation cost the organization dearly as they had to reduce staff and cut budget. The result was that the organization developed a finer appreciation for the impact of KM on productivity as well as the limitations of their KMS. The main challenge will be in improving the KMS while creating formal measures of KMS success and KM impacts on productivity and effectiveness. The organization has made a start in this direction by appointing a responsible manager for KM and by beginning to develop a formal KM strategy.

Additionally, many organizations have reported difficulty in measuring the impact of KM on organizational productivity/effectiveness. This case shows that an organization can find these measures if they look deep into the organization. The following reflect the lessons learned from this case:

- Measures reflecting the impact of knowledge use can be found for individuals and the organization.
- Formal management of KM is needed to guide the development of KM and the KMS. Without this oversight the KMS tends to not be as integrated or usable as it could be. Additionally, the KMS may lack the capacity or processing power needed to transfer and use knowledge.
- A KM strategy is needed to guide management in identifying and measuring the impacts of KM on the organization.
- Amount of use is not a good measure for KM or KMS success of effectiveness. However, intent to use is a good measure.

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