ELECTRIC POWER
RESEARCH INSTITUTE

Leading Business Performance Indicators for Nuclear Power Enterprises

Leading Business Performance Indicators for Nuclear Power Enterprises

1013488

Final Report, March 2007

EPRI Project Manager
S. Hess

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This report was prepared by

Electric Power Research Institute (EPRI)
3420 Hillview Ave.
Palo Alto, CA 94304

Principal Investigators
S. Hess
G. Sliter

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Leading Business Performance Indicators for Nuclear Power Enterprises. EPRI, Palo Alto, CA: 2007. 1013488.

REPORT SUMMARY

A collaborative industry effort has reviewed performance indicators (PIs) that are currently collected and monitored for various purposes. This review was conducted to determine which ones, with suitable modification, could be used to provide leading indication of business performance. The intent was to produce a concise list of candidate leading business performance indicators (BPIs) for assistance in managing nuclear power plants. The results of this research can be implemented to improve the evaluation and monitoring of plant business performance.

Background

This report addresses one of the barriers (or, viewed another way, one of the opportunities) of the Electric Power Research Institute's (EPRI's) Nuclear Asset Management (NAM) program. This barrier was initially characterized as "the need for bottom-to-top BPIs that enable enhancement and tracking of plant/fleet value." This need reflects the fact that current plant PI programs and the PIs identified in the Nuclear Energy Institute's (NEI's) Standard Nuclear Performance Model (SNPM) were developed in the era of economic regulation of nuclear power. The emphasis in the EPRI program and in this report is on the business aspects of performance measurement. To reflect the dynamic and evolving nature of asset management, this barrier has recently been recast as "provide measures of NAM performance and business value." This broadened barrier more accurately characterizes the objectives and challenges that need to be addressed in the measurement of business performance. Within this context, the results and recommendations contained in this report represent only an initial step.

One of the major industry needs identified by the NAM program is improved bottom-to-top financial PIs and BPIs that enable enhancement and tracking of the value of nuclear power plants and fleets. Although safety indicators are prescribed by the U.S. Nuclear Regulatory Commission (NRC) and Institute of Nuclear Power Operations (INPO), all plants have selected a large set of additional indicators to measure and evaluate aspects of business performance. However, many of these indicators are lagging and not leading, and the plant indicators generally differ from those implied as standard in the SNPM.

A systematic approach was needed to identify the most effective leading indicators of business performance for plants to consider: this report describes the general framework for such an approach. Then, the approach is used to evaluate existing performance measures to identify those that provide the best leading indication of business performance. The intent of the research contained in this report is to equip plants' business decision makers with a set of indicators that can be easily and immediately implemented (or adapted from existing measures). Identification of new (and more innovative) measures of business value was not attempted and remains an activity for future research.

Objective

- To provide a concise list of candidate leading BPIs that can increase the effectiveness of the indicators currently in use by all plants and be used by nuclear asset managers to improve plant business performance and value, motivate and improve staff behavior, allocate resources efficiently, and facilitate performance benchmarking with other plants—all while maintaining an acceptable level of nuclear safety

Approach

Industry leaders of the communities of practice for the core processes in the SNPM used expert judgment and screening based on carefully formulated properties of effective PIs to identify candidate leading PIs that influence outcome indicators, making up a tree-like value model. A technical advisory group of industry NAM experts then evaluated these candidates to develop a succinct list of indicators with applicable implementation bases to give plant management the ability to proactively evaluate potential changes in business performance and to more thoroughly investigate degradation in performance while still at an incipient stage.

Results

The collaborative effort produced a list of leading indicators that operational plants can implement right away. The report also describes past work and the state of practice of performance measurement in nuclear power plants.

EPRI Perspective

One characteristic of highly effective organizations is a continual search for ways to enhance performance, culture, and work environment. This report is intended to be a significant step in the understanding, improvement, and standardization of leading PIs for nuclear power plants. Lagging indicators give results in value and performance after the fact, often when it is too late to correct any observed shortfalls. This report focuses on leading indicators, that is, operational and behavioral parameters that drive results and are harbingers of future plant value and economic performance. This report extends the work of a white paper on BPIs published in EPRI report 1011000, *Business Performance Indicators for Nuclear Asset Management*.

Keywords

Nuclear asset management (NAM)
Performance indicators (PIs)
Strategic objectives
Value models

ACKNOWLEDGMENTS

EPRI thanks Jeremy Bloom and David Ziebell of EPRI for their contributions to this research.

The following are the members of the EPRI Business Performance Indicator technical advisory group (TAG):

Mitch Baughman	Duke Energy, Chairman
Donna Keck	Duke Energy
Susan Korn	Exelon
Bret Leslie	Southern Company
Ken Riches	American Electric Power
Tim Schlimpert	MCR
Jim Slider	Nuclear Energy Institute
Phillip Young	Exelon

EPRI is grateful for the support of the TAG members. EPRI is also grateful for collaboration from the industry communities of practice that supported this work. The work was supported by the NAM User Group and EPRI Nuclear Power Sector core funding.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The performance of any company or business unit within a company is measured as the degree to which it achieves its objectives. The high-level objectives of nuclear power enterprises (that is, plants, fleets, and companies) include safety, reliability, profitability, and environmental protection. The mixtures of these elements vary and are dependent upon the regulatory and economic environments in which organizations operate. Important tools for effectively managing performance and achieving the desired outcomes are monitoring, trending, and evaluating indicators of these attributes. This monitoring is conducted through measurements that are broadly referred to as *performance indicators* (PIs).

As in all heavy process industries, companies that operate nuclear power plants have developed and implemented a comprehensive suite of indicators that measure performance of the key organizational outcomes described in the preceding paragraph. Every nuclear power facility has some form of PI or key performance indicator (KPI) program. These programs select the PIs to be monitored, periodically compile and store values for PIs, and report the data to management for evaluation and action.

The primary uses of PIs are the following:

- To track, increase, and protect enterprise value
- To determine the trend in how an enterprise is meeting its own objectives
- To determine the trend in how an enterprise is doing compared with the competition (*benchmarking*) and (particularly in heavily regulated industries) to share good practices
- To motivate staff by setting appropriate performance and incentive goals
- To identify technical or organizational problems
- To alert management to take action to prevent future lapses in performance (for example, they might identify the aspects of physical assets, staff, information, and processes that could benefit from increased management attention)

A popular maxim that permeates the philosophy of performance management is “You can’t manage what you can’t measure.”

The nuclear power industry has also developed a Standard Nuclear Performance Model (SNPM) [1]. This model serves as a structured framework that defines the functions that need to be performed in order to operate a commercial nuclear power generating station. The framework also serves as a useful structure for measuring performance and specifying applicable PIs.

Industry communities of practice (CoPs) have been organized for each of the identified SNPM core and enabling processes. In the model, these processes are *operate plant* (OP), *work management* (WM), *equipment reliability* (ER), *configuration management* (CM), *materials and services* (MS), *training* (T), *loss prevention* (LP), *support services* (SS), and *nuclear fuel*. One outcome of the CoPs has been the development of PIs to support measurement of the performance associated with the respective process. The study described in this report used this evolving and extensive list as an initial master list of PIs.

This report addresses one of the barriers (or, viewed another way, one of the opportunities) of the Electric Power Research Institute's (EPRI's) Nuclear Asset Management (NAM) program. This barrier was initially characterized as "the need for bottom-to-top business PIs that enable enhancement and tracking of plant/fleet value." This need reflects the fact that the current plant PI programs and the PIs identified in the SNPM were developed in the era of economic regulation of nuclear power.

The emphasis in the EPRI program and in this report is on the business aspects of performance measurement. In no way does this imply that safety performance does not retain an important (and even primary) role. The safety aspects of nuclear power plant performance are addressed by the in-depth PI programs of the U.S. Nuclear Regulatory Commission (NRC), the Institute of Nuclear Power Operations (INPO), and the World Association of Nuclear Operators (WANO). To reflect the dynamic and evolving nature of asset management, the barrier has recently been recast as "provide measures of NAM performance and business value." This broadened definition more accurately characterizes the objectives and challenges that need to be addressed in the measurement of business performance. Within this context, the results and recommendations contained in this report represent only an initial step.

As a first step in addressing the barrier, it is recognized that the existing suite of nuclear plant PIs could benefit from greater emphasis on business aspects. Thus, factors that motivated this EPRI study of improved business performance indicators (BPIs) are as follows:

- The wide variation in PI types used throughout the industry—they can not all be best practices, and costs can be reduced by pinpointing those that provide the most effective indication of performance and add the most value to the enterprise.
- PIs recommended by the SNPM have not been universally recognized or endorsed by the industry.
- There is less incentive to share good business practices in a competitive industry than there is to share good safety practices.
- No studies have focused specifically on which, if any, subset of PIs is effective in foretelling future economic/business performance. Such PIs are called *leading indicators. Lagging indicators* reflect current economic performance, giving guidance to managers only after the fact.

This report takes a significant step toward identifying a consensus set of useful and effective candidate leading BPIs that plants can implement to improve the business aspects of their PI programs. Additionally, development of consistency of the PI definitions would improve industrywide benchmarking.

1.1 Objective

The purposes of this report are to present a concise list of candidate leading BPIs that can increase the effectiveness of the PIs currently in use by all plants and be used by nuclear asset managers to improve plant business performance and value, to motivate and improve the behavior of staff, to allocate resources efficiently, and to facilitate performance benchmarking with other plants—all while maintaining an adequate level of nuclear safety.

The Nuclear Energy Institute's (NEI's) document *Nuclear Asset Management Process Description and Guide* (NEI AP-940) [2] cites PIs as a key component of a plant's asset management program. In addition, two EPRI reports have laid a foundation for improving BPIs: *Nuclear Power Financial Indicators for a Competitive Market* [3] (the first EPRI NAM User Group report) and *Business Performance Indicators for Nuclear Asset Management* [4]. The latter report points out that one of the best ways to develop effective BPIs is through value modeling.

1.2 Approach

Nuclear power plants are large, complex industrial facilities. Their operation and management require the smooth and effective functioning of thousands of components, many hundreds of employees, and dozens of processes. Therefore, figuring out how the performances of these components, employees, and processes are best monitored and managed is a daunting task.

The practice of using PIs as an important input to management has evolved gradually over the four decades of commercial nuclear power operation. The biggest drivers of performance measurement were the NRC and INPO, which began in earnest to develop safety performance measures after the accident at Three Mile Island in 1979 [5, 6]. As a result of these initial efforts (and subsequent refinements), plants have been compiling and submitting safety performance measures to the NRC and INPO/WANO since 1990.

On the other hand, the voluntary use of additional PIs for business and management purposes developed more or less independently through the many plant owners and operators. This development occurred with little application of systematic approaches and, typical of the U.S. nuclear power industry, little standardization. The first attempt to bring some degree of standardization to the economic operation of nuclear power plants was NEI's SNPM, which has undergone significant development and refinement over the past five years. This project has shown that the set of PIs (other than regulated ones) in the current revision of the SNPM report is far from being a standard set that has been vetted and uniformly applied by the industry.

Note that due to significant differences in the economic and regulatory environments under which different plants operate (for example, the traditional regulated rate structure versus merchant plant open-market pricing) and the varying business objectives of plant operators, complete standardization of business-related PIs is neither expected nor desired. However, what is universally applicable is the need for plant management to be able to identify conditions that might predict a future change in the business performance of the station. The ability to identify these conditions at their incipient stage would permit plant management to investigate the root causes and address them before the conditions degrade and have a significant business impact. It is this objective that is the focus of this report.

The main approach of this report is to use value mapping as a systematic basis for identifying potentially effective leading BPIs. However, because detailed value models of nuclear power plants do not exist, the approach continues to rely heavily on the experience and judgment of industry experts organized into CoPs by the NEI SNPM program. A few of the CoPs have made significant progress in exploring effective indicators in their process areas. For example, the Equipment Reliability Working Group (ERWG), the Configuration Management Benchmarking Group, and the Materials & Services CoP have completed initial efforts to identify and track PIs.

Although not among its original purposes, this project turned out to be a catalyst for continuing the SNPM's quest to identify useful and effective PIs, with emphasis on business aspects and on leading, in contrast to lagging, indicators. Appendix B of the SNPM report [1] describes KPIs at the following four levels:

- Overall goals and measures
- Process output or results goals and measures for each key business process
- Process internal goals and measures that support each process output
- Task-level measures

These levels are displayed in the SNPM report with the pyramid shown in Figure 1-1.

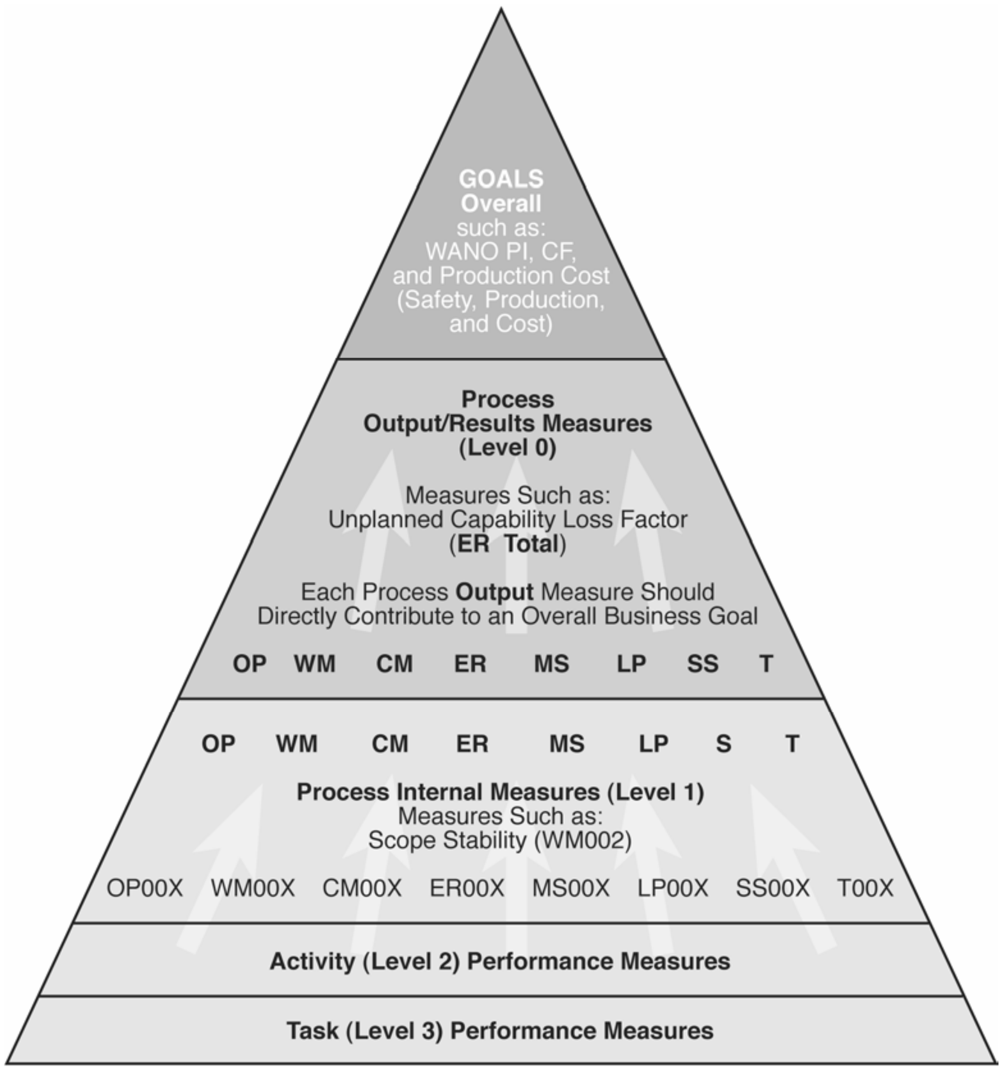

Figure 1-1
SNPM Performance Goals and Performance Measures Pyramid [1]

This pyramid was a good starting point and foundation for the BPI value model constructed in this project. Note that the pyramid numbers the levels 0, 1, 2, and 3 but that these labels are not used in the PI descriptions in the SNPM report. The SNPM report states that "a business focus on ensuring process internal performance rolls up to support process outputs that in turn contribute(s) to achieving overall company/plant goals." This roll-up process was explored further in this project.

As discussed in Section 3 of this report, the experiences and judgments of CoP representatives were used to screen the hundreds of extant PIs to come up with a workable set of candidate leading PI types. This project encouraged industry collaboration and consensus among plant owners and operators, the NAM CoP, other SNPM CoPs, NEI, INPO, and EUCG (formerly the

Electric Utility Cost Group). The EUCG has been compiling nuclear power plant cost data for many years, providing benchmarking information for the industry. The EUCG has been an active player in the SNPM program and shares the goal of identifying a standard set of not only cost parameters but PIs in all SNPM core processes for the purpose of benchmarking.

Because value-based expert judgment can go only so far in identifying effective leading indicators, the research described herein and the previous EPRI research [4] looked for systematic frameworks and analytical approaches to supplement expert experience and judgment. Such tools can be used in the future to augment the leading indicator candidates from this work. The findings and recommendations from this research are discussed in Section 4. Section 5 identifies potential further work on BPIs envisioned by EPRI and the Business Performance Indicator Technical Advisory Group.

2 PERFORMANCE INDICATORS AS MEASURES OF VALUE

The concept of using a value model to identify effective BPIs is discussed in the EPRI report *Business Performance Indicators for Nuclear Asset Management* [4]. In this section, value modeling information is presented as a guide to allow asset managers to exploit value modeling as it relates to selecting leading BPIs.

The value of a nuclear power enterprise is characterized not only by financial objectives but also by non-financial objectives, such as reliability, safety, and environmental quality. Companies need a systematic framework for managing success. It is the responsibility of nuclear power owner and operator executives to identify as clearly as possible the objectives of their enterprises, which consist of corporate, fleet, and plant assets. In addition to the physical plant, these assets include finances, material, information, processes, and people. At the highest level, the objective of executives is to maximize the value of the enterprise's assets to all stakeholders. Stakeholders include electricity users (who want safe, reliable, and affordable electricity); nuclear generating companies and shareholders (who want profitability in a competitive marketplace); company employees (who want challenging, rewarding, and stable jobs); regulators (who must protect public health and safety); and members of the general public (who want safe, environmentally clean power production and fair business practices).

Performance is the degree to which objectives are met and enterprise value is enhanced. Thus, it is logical that effective PIs should be based on a model of value. *Value modeling* is the construction of objectives, value attributes, and means of quantifying the attributes. A value model can be used to formulate PIs and as the basis for making investment decisions regarding proposed capital, operations, maintenance, and process improvement decisions (see, for example, the EPRI report *Pilot Application of Enterprise Project Prioritization Process at Nebraska Public Power District* [7]; it describes a demonstration at the enterprise level). Note that the aspect of value modeling discussed in this report is at a high level, making it useful for identifying candidate leading indicators of business performance. We note that a detailed and complete value model is one that can translate quantified values of equipment reliability, human performance, and process measures into quantified estimates of safety, reliability, profitability, and environmental outcomes.

2.1 Enterprise Objectives and PIs

Value modeling for any type of enterprise begins with a formulation of high-level company objectives (sometimes called *strategic objectives* or *strategies*). For our treatment of nuclear power enterprise value modeling, we begin with this prototypical nuclear power plant objective: deliver safe, clean, and reliable nuclear power while maintaining market position. An alternative version of this objective is to deliver nuclear power reliably while maintaining safety, the health of the environment, and profitability. Both statements can be broken down into the following generic types of objectives:

- Safety
- Reliability
- Profitability
- Environment

An additional high-level objective for generating companies is customer satisfaction. However, for nuclear power generation enterprises, the customer is the electricity grid or market. Satisfaction of these customers is provided by meeting reliability and supply targets.

The comprehensiveness of the preceding objectives was validated by comparing them to the strategic objectives of nuclear power plant owners as they appear on the Internet and to the responses of 18 nuclear power plant operators to the following question in an NEI survey: "What are the top five strategies/values for your company or plant?"

PIs measure the achievement of objectives. Note that some of the preceding objectives can be measured directly by means of natural PIs, such as stock value or profit margin (for profitability objectives) and power output or capacity factor (for reliability objectives). The objective of safety is less tangible and more difficult to quantify, especially for low-probability, high-consequence events. For modeling value, we identify parameters that allow us to quantify the achievement of objectives. These parameters are called *attributes*. The careful choice of attributes clarifies the meaning of each objective and facilitates the selection of meaningful PIs. Some PIs are themselves value attributes (also defined as *goals*, *metrics*, *outcome indicators*, or *lagging indicators*), whereas others are not direct measures of performance but measures of processes that drive future performance (such as process indicators or leading indicators). Note that values and objectives can be quantitative or qualitative, but value attributes and PIs must be quantitative.

Later in this section, we explain how the preceding objectives form the basis for a generic nuclear power enterprise value model. First, however, we discuss PI types and the ways in which they are related to objectives.

2.2 Definitions of PI Types

2.2.1 PI

For the purposes of this report, we define a *PI* as a quantitative parameter that measures the extent to which physical assets, staff, information, or processes of a plant, fleet, or corporation create value (that is, the extent to which they meet company-defined objectives and goals).

To be useful, a PI should possess the following characteristics:

- Useful for decision making: It has a clearly understood impact on the underlying values and objectives that it represents.
- Well-defined: The PI definition is unambiguous and clearly identifies the quantity being measured, including the data and procedure required to calculate it; the data must not be subject to differences in interpretation.
- Aligned: Its magnitude and/or change in magnitude over time has a high correlation with the value attribute being measured and/or changes in it.
- Measurable: It is characterized consistently by a quantitative, verifiable parameter (in other words, it is neither qualitative nor subjective).
- Stable (non-volatile): Its magnitude varies reasonably continuously and is not subject to substantial local short-term random variations (for some indicators, rolling averages can be used to smooth or stabilize data).
- Operational: Information to determine the PI is available with a reasonable amount of effort; it is simple to calculate and use.
- Actionable: Yhe measured results are able to be modified by some action taken by management.

PIs intended to be used for benchmarking of performance against other companies need to have two additional properties. First, they must be generic—the PI must not be subject to conditions or practices that can be expected to differ significantly from plant to plant. Second, they must be normalized, meaning that where appropriate, indicators should be normalized by dividing by a size parameter, such as rated capacity or number of employees.

2.2.2 Outcome Indicator

For the purposes of this report, an *outcome indicator* is defined as a PI that characterizes past, current, or future value and is a result of unit, plant, or fleet performance (operation) or of the effect of one or more leading indicators.

Properties of an Outcome Indicator

Outcome indicators must be direct. That is, the PI should provide a measure of either an objective (value) or a component thereof (a component of value is a quantity that contributes directly to a sum, yielding a value of a higher level).

2.2.3 Process Indicator

For the purposes of this report, a *process indicator* is defined as a PI that measures how well one or more of an organization's processes is being carried out.

Properties of a Process Indicator

An effective process indicator is not an objective or value (or component thereof) in and of itself, but rather has a significant effect (current or lagging) on an objective or value. Also, a good process indicator is unambiguous, showing a clear (but not necessarily quantifiable) relationship between the leading indicator and one or more outcome indicators (objectives/values).

2.2.4 Leading Indicator

For the purposes of this report, a *leading indicator* is defined as a process or outcome indicator, the changes in which are drivers or precursors of future changes in plant value.

Properties of a Leading Indicator

The following are properties of a useful leading indicator:

- It is a harbinger of future value.
- A change in its magnitude takes some time (called *lead time*) to be reflected in the affected outcome indicators (objectives/values).
- It alerts management to the potential need for action.

All PIs are either outcome or process measures. Process indicators are by definition leading because it is evident that processes eventually impact outcomes, whereas outcome indicators can be lagging or leading. High-level outcome indicators are clearly lagging, but certain lower level outcome indicators can be both lagging (affected by leading process indicators) and leading (they affect higher level lagging outcome indicators).

In many cases, the leading nature of outcome indicators consists simply of an extrapolation of past performance. For instance, if a plant's performance measurement system tracks capacity factor, the management might look at the upward or downward trend as a leading indicator of future performance. Although such extrapolation might be appropriate for certain kinds of PIs, two issues suggest that past performance might not be a good indicator of future performance in many cases. First, when conditions in the past differ markedly from the future, simple extrapolation might fail to identify the discontinuity. Second, when performance depends on the influence of factors subject to substantial uncertainty, PIs can vary randomly, with no usable trend for predicting future performance.

Note that all outcome indicators are useful for tracking an organization's performance—mainly for benchmarking against other organizations. Some outcome indicators and all process indicators are useful for tracking and managing an organization's internal performance.

3 USING THE VALUE MODEL TO IDENTIFY EXISTING LEADING INDICATORS

In Section 2, the following were identified as generic, high-level objectives for nuclear power enterprises:

- Safety
- Reliability
- Profitability
- Environment

In the nuclear power industry, the keepers of safety PIs are the NRC and INPO. This project did not investigate safety-related PIs. However, some review of safety PIs was conducted because the level of safety achieved is directly related to the degree to which plant structures, systems, and components operate reliably; to be profitable, a plant must operate at a sufficient level of safety to meet or exceed regulatory requirements; and many PIs in such areas as reliability and human performance pertain to both the business and safety aspects of an enterprise.

As the first step in creating the desired list of candidate leading BPIs, nuclear power plant PIs of all types from all sources were compiled. These sources included the SNPM report, several plant-specific PI programs, technical papers, and the PI initiatives of industry groups serving as CoPs. These activities generated important input to the screening process described in greater detail in this section.

The compilation of existing PIs was screened using the definitions in Section 2 and separated into lists of outcome and process indicators. When the definitions were applied, a substantial number of indicators were rejected on the grounds that they lacked the properties essential to an effective leading indicator of business performance.

3.1 Outcome Indicators

The resulting list of outcome indicators for the objective of reliability is shown in Table 3-1, and the list for the objective of profitability is shown in Table 3-2. Outcome indicators that appear in the SNPM report are noted in the Source columns with an SNPM process code (CM, WM, MS, and so on). A single letter designation (A, B, D, F, or J) in a Source column denotes that an indicator is included in a specific plant's PI program. Note that many of the SNPM PIs are not included in the programs of any of the plants for which EPRI had information. A detailed comparison has shown that only roughly 10% of the PIs in the SNPM are included in the programs of the plants for which we had information. This finding leads to the conclusion that the evolving list of indicators in the ongoing periodic revisions to the SNPM report are not yet standard in the sense that they generally reflect industry practice.

Table 3-1
Outcome Indicators for the Objective of Reliability

Outcome Indicator Level A	Source	Outcome Indicator Level B	Source	Outcome Indicator Level C	Source
Total power generated	A, B, D, F				
Capacity factor	Goal				
Unit capability factor (UCLF)	ER-0, INPO				
		Forced loss rate (or forced outage rate)	ER-0, J, ERWG, INPO		
		Unplanned loss of effective full-power days	A		
		Lost generation days	A		
		Lost generation events	A		
		Outage extension days	A		
		Refueling outage duration	B		
		Post-refueling outage events	ERWG		
		Component unavailability (Mitigating Systems Performing Index [MSPI])	ER-0		
		Maintenance lost generation	ER-0		
		Maintenance lost capability	ER-0		
		Personnel error lost capability	ER-0		
		Component failure lost capability	ER-0		
				WANO Fuel Reliability Index	NF001, INPO
				WANO chemistry indicator	OP003, ERWG

Table 3-1 (continued)
Outcome Indicators for the Objective of Reliability

Outcome Indicator Level A	Source	Outcome Indicator Level B	Source	Outcome Indicator Level C	Source
				INPO AP-913 critical component failures	ER003, ERWG

Notes:

Abbreviations in the Source columns in Tables 3-1 through 3-6 correspond to the following:

- *A, B, D, F,* and *J* indicate that the PI program information was provided directly by a utility.
- *Goal*, *ER-0*, and *NF001* signify that the indicator was derived from the SNPM report.
- *ERWG* indicates that the PI is one of the set used by the ERWG in the calculation of the Equipment Reliability Index.
- *NSCSL* stands for Nuclear Supply Chain Strategic Leadership.
- *INPO* stands for Institute of Nuclear Power Operations.

Table 3-2
Outcome Indicators for the Objective of Profitability

Outcome Indicator Level A	Source	Outcome Indicator Level B	Source
Earnings per share	A		
Return on capital employed	A		
Return on equity (ROE)	Goal		
Earnings before interest and taxes (EBIT)	Goal		
Profit margin			
Revenue from the nuclear power plant	Goal		
Total generating cost			
		Thermal performance	D
		Revenue from marketing excess inventory to other utilities	MS-1

Table 3-2 (continued)
Outcome Indicators for the Objective of Profitability

Outcome Indicator Level A	Source	Outcome Indicator Level B	Source
		Non-fuel operations and maintenance (O&M) expenses	A, F
		Total operating cost (dollars per megawatt-hour [$/MWh])	A, F, J
		Unit operations cost	OP-0
		Unit WM cost	WM-0
		Station overtime	A, D, F
		Unit MS cost	MS-0
		Materials cost	
		Procurement services cost	
		Inventory value	NSCSL
		Cost of information management per employee	SS-1
		Maintenance cost	ER
		Capital costs	WM-1, ER
		Outage costs	A, B
		Nuclear fuel expense (mills/kilowatt-hour [kWh])	A
		Variable fuel costs ($/MWh)	D
		Administrative and general expenses	A

From the previous discussion on the attributes of values and outcome indicators, we can view the outcome indicators in Tables 3-1 and 3-2 as essentially making up value model trees.

Table 3-3 is a list of the outcome indicators for the objective of safety. It consists mainly of indicators prescribed by the NRC and INPO. Other indicators on the list demonstrate that plants use their own judgment in measuring additional safety indicators.

Table 3-3
Outcome Indicators for the Objective of Safety

Outcome Indicator	Source
NRC indicators	NRC
INPO Performance Indicator Index	INPO
Unplanned automatic scrams per 7,000 hours critical	INPO
Safety system performance	ERWG, INPO
Collective radiation exposure	WM007/8, INPO
Industrial safety accident rate	INPO
Regulatory inspections findings	D
Safety system unavailability	ER002
Safety system performance (MSPI)	ERWG, D
Reactivity management	A, D, F
Reactor core safety	A
Safety performance incident rate	F
Significant events	D
Radiation protection indicator	D
Occupational Safety and Health Administration (OSHA) Recordable Accident Rate	B, D, J
Personal injuries	A, F
Employee safety index	A

Table 3-4 lists the outcome indicators for the objective of environment. Interestingly, all of these PIs are plant-specific indicators. The SNPM does not identify any outcome PIs in this area.

Table 3-4
Outcome Indicators for the Objective of Environment

Outcome Indicator	Source
Radiation releases	A
Radioactive material outside the radiological control area (RCA)	A
Radwaste system treatment curies released	A
Reportable environmental events	A
Notice of environmental violations	A, D
Radioactive waste	D
Gaseous effluents activity (noble gas)	F
Radiological liquid activity release	F
Radiological liquid release volume	F
Radiological liquid tritium released	F
Environmental index	F

3.2 Process Indicators

Once outcome indicators were identified, the rest of the indicators in the long initial list could be classified as process indicators. The following steps were applied to each process indicator to decide which to select as a candidate leading BPI to attach to the value model tree:

1. Is the process indicator quantitative (that is, not subjective) and able to be measured consistently and with a reasonable amount of effort? If no, reject. If yes, go to the next step.
2. Is the process indicator ambiguous? For an ambiguous indicator, it is not clear that a change in its magnitude is always a contributor to plant value. For example, the indicator "number of correction action program action items not completed" would not necessarily be an effective process indicator because a low value could be due to either a small number of problems needing correction (indicating favorable performance) or failing to enter problems into the program (indicating unfavorable performance). As a result of this trait, ambiguous indicators were excluded from the list.
3. For an unambiguous indicator, identify the outcome indicator or indicators that the process indicator can affect.

4. Is the effect expected to be immediate or to be realized only after some lead time has elapsed? If the impact is immediate, reject the PI as a candidate leading indicator.[1] If an identifiable lead time exists, go to the next step.
5. Identify which outcome indicator or indicators are affected (that is, which values the process indicator affects).
6. Is the magnitude of the effect on one or more outcome indicators (and therefore on plant value) judged to be significant with respect to other candidate leading indicators? If no, reject it as a candidate leading indicator. If yes, enter it in the table of candidate leading BPIs, showing the outcome indicators that it affects. We note that this step represented the screening criteria that depended most on subjective judgment. Thus, at this stage, if any doubt existed as to the significance of the PI on plant value, the indicator was included in the candidate list.

These screening questions were addressed at a meeting of the Business Performance Indicator Technical Advisory Group, which consists of utility representatives and volunteer expert consultants. Also, representatives of several SNPM CoPs were invited to the meeting to contribute expert knowledge in the various core processes (with several representatives attending or participating by phone). Those CoPs not able to participate at the meeting were invited to suggest leading indicators in their areas or to review leading indicators proposed by EPRI.

3.3 Leading Process Indicators

It was expected that the screening process would identify both a number of leading indicators that affect multiple outcome indicators within a given high-level objective and outcome indicators for multiple objectives. Therefore, the screening process involved placing candidate process/leading indicators on the value trees in Tables 3-1 through 3-4. It was expected that the result would be best displayed by four rather detailed spreadsheets showing several layers of outcome and process indicators on each, with the leading indicators hanging on many branches of the value tree.

The actual findings, however, contradicted the expectations. Although some leading indicators indeed affect multiple value areas, in all cases a given leading indicator was judged to affect primarily a single outcome indicator in a particular objective. Selecting the various outcomes that a leading indicator affected turned out to be a difficult task and cumbersome to display. Furthermore, it was realized that identifying the number of outcome indicators that might be affected by a leading indicator does not contribute to our knowledge of the relative importance of the indicator (because it is possible, for example, that one leading indicator affecting only one measure of outcome has a greater impact on plant value than another that affects several outcome measures).

As shown in Table 3-5 for reliability, 14 leading process indicators were identified, affecting primarily only two outcome indicators (values)—one at Level B (unplanned loss of effective full-power days) and the other at Level C (INPO AP-913 critical component failures).

[1] As it turned out, no process indicators were judged to have an immediate effect on value. This finding led to the conclusion stated previously that process indicators are, by definition, leading indicators.

Table 3-5
Process Indicators for Reliability

Outcome Indicator Affected	Process Indicator	Source
Unplanned loss of effective full-power days	Unplanned power changes per 7000 hours critical	ER003, ERWG, NRC
	Unplanned limiting condition for operation (LCO) entries	ERWG, A, D
	Operator workarounds	ERWG, D, F
INPO AP-913 Critical Component Failures	Percentage of actions in system health reports completed	ER003, ERWG
	Timely completion of preventive maintenance (PM)	ERWG
	Deferred PM	WM003, ER003, ERWG, J
	Schedule scope stability	WM002, ERWG, D, F
	Schedule adherence	WM (AP-928), ERWG
	Total on-line maintenance backlog	ERWG, F
	On-line elective maintenance backlog	ER, A
	On-line corrective maintenance backlog	WM004, ERWG, J
	Age of red and yellow systems	ER002, ERWG
	Percentage of work orders completed as fix-it-now	WM009
	Percentage of outage work orders ready	WM001

A review of the information in Table 3-5 clearly shows that there are many attributes that can estimate business value and future performance. These candidate PIs present a list that is too large to be of practical value. However, it does suggest that a combination or modification of these PIs would result in a BPI that is leading in nature and correlated to business value. To meet this objective, there must be a specific logical link between the PI and the reason that it is a leading indicator (and specifically whether it is the value, trend, or something else that provides this indication). Once a complete suite of candidate leading BPIs is developed (see Section 3.6), the list will be evaluated for these characteristics and a succinct catalog of recommended BPIs will be provided (see Section 3.7).

As shown in Table 3-6 for profitability, four process indicators were identified; the four indicators affect three outcome indicators (values) at Level B—operations cost, WM cost, and MS cost. Here, some explanation of the first PI (contaminated floor space) is in order. At first glance, it would appear that this PI does not link directly to business value. However, over the years, it has served as a useful metric in distinguishing those plants that have been viewed favorably by the regulator from those that have not. In effect, this metric has served as a surrogate measure of the extent to which plant and corporate managements are willing to invest in programs and projects that do not yield any immediate financial payback. As discussed previously, if doubt existed as to the usefulness of the PI to provide a leading indication of business value, the PI was retained as a candidate leading BPI at this level. The aspects and possible utility of this PI will be discussed further in Section 3.7.

Table 3-6
Process Indicators for Profitability

Outcome Indicator Affected	Process Indicator	Source
Unit operations cost	Contaminated floor space	A
Unit WM cost	Maintenance work order rework	A, F, J
Unit MS cost	Procurement process to total purchase cost ratio	NSCSL
	Ratio of returned to issued material items	NSCSL

Thus, of the many dozens of existing process indicators for the objectives of reliability and profitability, the majority were rejected as significant leading PIs. They either did not possess the properties of leading indicators described in Section 2 (they were difficult to define accurately, ambiguous, subjective, and so on), or they were judged to have an inconsequential effect on outcome indicators (values).

The screening process for the safety and environment objectives did not lead to identification of leading process indicators. All the PIs that measured performance related to these two objectives were outcome rather than process indicators (see Tables 3-3 and 3-4). This, however, does not mean that there are no leading process indicators that influence safety and environment: instead, it means that these values are affected by process indicators deemed to correlate with plant reliability more directly, affecting safety and environment through the principle that a reliable plant will be a safe plant that also protects the environment. We defer to the NRC and INPO for identifying standard leading indicators for safety. Similarly, the environment will be protected if all systems, structures, and components perform as designed—that is, if they achieve the objective of reliability.

3.4 Leading Outcome Indicators

As discussed in Section 2, outcome indicators can be either lagging or leading depending on one's frame of reference.

For reliability and profitability, indicators at a high level (Level A in Tables 3-1 and 3-2) are clearly lagging. Indicators at Levels B and C for reliability (see Table 3-1) and Level B for profitability (see Table 3-2) are lagging with respect to the process indicator level, but they can also serve as leading indicators for the high-level lagging indicators of value. For example, for reliability, an increase in maintenance lost generation can on one hand be the result of (and thus give lagging indication of) an increase in human performance errors. On the other hand, it can be a leading alert for a future drop in unit capability factor. For profitability, any trends in the Level B indicators can be a leading alert for future deterioration of Level A value attributes.

3.4.1 NAM PIs

The SNPM process referred to as *provide business services* consists of activities associated with planning, budgeting, cost control, and accounting. This includes the development and administration of NAM, which, according to NEI AP-940 [2], consists of the following functions and processes:

- Strategic planning
- Generation planning
- Project evaluation and ranking
- Long-range planning
- Budgeting
- Plant/fleet valuation

The business services process is the responsibility of the EUCG, and NEI AP-940 is the responsibility of the Nuclear Asset Management Community of Practice.

One of the subprocesses of the project evaluation and ranking process is project review. One of the steps in this subprocess is to assess PIs, the goal of which is to make sure that PIs are applied consistently across projects and that they reflect all key information.

The appendix of NEI AP-940 identifies the following NAM overall KPIs:

- ROE: net income divided by shareholders' equity
- EBIT: revenues less expense (nuclear fuel expenses, O&M expenses, general and administrative expenses, depreciation, amortization, and general taxes)
- Profit margin: net income divided by revenues

- Production cost: total production expenses as reported by the Federal Energy Regulatory Commission (FERC)
- Capacity factor: annual net electrical generation at the output breakers (in MWh) divided by the product of the period hours and the net maximum dependable capacity (MDC) expressed in MW

The first three of these high-level PIs are included in the profitability value model in Table 3-2, the fourth (production cost) is replaced by total generating cost in Table 3-2, and the fifth (capacity factor) is included in the reliability value model in Table 3-1.

3.4.2 NAM Indicators Proposed in Previous EPRI Project

The previous EPRI report that investigated BPIs—*Business Performance Indicators for Nuclear Asset Management* [4]—proposed three parameters as leading PIs for measuring the value created from investments including capital and large, periodic O&M expenditures. These three proposed indicators were examined in the context of the definitions and properties of leading indicators established in the current report. As discussed in the following paragraphs, only one of the three was deemed to have the requisite properties of a useful leading indicator.

The first indicator evaluated was the ratio of achieved to predicted net present value (NPV) of the investment portfolio. EPRI conducted a survey of Wall Street analysts and plant owners and compared the financial indicators for nuclear plants to those used in the commercial airline and telecommunications industries. The research concluded that NPV is "the most fundamental measure of (business) value" [3]. Thus, the degree to which the NPV predicted by project evaluations is achieved would serve as a useful leading BPI. If achieved values could be measured, one could calculate the ratio of achieved cumulative value to the predicted NPV and use the ratio as a meaningful measure of business value. A low value for this indicator could indicate that too many projects that do not create value are included in the portfolio and/or that estimates of value were too optimistic. In either case, the PI would indicate that project evaluation and selection practices could be improved.

Tracking the achieved value of a project or portfolio of projects is difficult. Appendix C contains a brief description of one possible approach that is in widespread use in the aerospace and defense sectors: the EVMS. Whether this approach is applicable to and can be adopted by the nuclear power industry should be further investigated. Such an investigation was not conducted as part of the project described in this report; it remains a future research activity.

The second indicator proposed in the EPRI report *Nuclear Power Financial Indicators for a Competitive Market* [3] that was reviewed was the percentage of "must-do" project investments. A common practice in portfolio evaluation and selection is to designate certain proposed projects as must-do. Examples are projects viewed as necessary to meet regulatory demands and projects that are directed by executive or senior management. With the resources to cover these projects set aside, only discretionary projects are subjected to the scrutiny of a comprehensive portfolio evaluation. The indicator would be the ratio of the cost of must-do projects to the total investment amount. A lower percentage would indicate that good investment practices are in use (in other words, every discretionary investment is viewed as an opportunity). A high percentage could indicate one or more of the following problems:

- Must-do or management-directed projects are “gold-plated” and might be used as excuses to not fund other, smaller projects that are independently evaluated.
- Given that some quantity of must-do projects is inevitable (for example, projects required to meet regulatory mandates), a high value for this indicator might reflect a shortfall in the overall investment budget allocated to maintaining the asset base.
- There might be lower cost alternatives to must-do projects that are not being actively considered.
- Risks have not been appropriately managed, and a poor relationship with a stakeholder (a regulator, for example) has resulted, requiring a larger-than-desired investment to improve that relationship. We note that this situation can occur if the investment allocation process does not sufficiently consider non-financial attributes for which assignment of quantifiable values and integration into the decision process is problematic.

Too often, the must-do designation arises because insufficient effort has been made to identify alternative solutions that address the root causes of performance problems.

Although this proposed indicator has a valid basis and intent, it has a property that causes us to reject it as a leading indicator of business value. Namely, this indicator would be volatile, subject to many external and random influences. Year to year, the cost of projects classified as must-do could vary greatly due to emerging regulatory or other issues. Also, use of the proposed indicator could imply that it is not appropriate for management to evaluate changing business and external conditions and apply its prerogatives to address them in a manner which they deem appropriate. Rejection of this parameter should not be interpreted as a refuting of the principle embedded in it—that is, designating a project with a must-do status could inappropriately deprive it of the beneficial practice of searching for alternative projects or actions that have greater value and adequately meet the objective of the prescribed must-do approach. However, this principle is better enforced by management’s insistence that all projects benefit from a thorough review and evaluation of alternatives than by attempting to trend a simple ratio.

The final indicator evaluated was the percentage of proposed investments that have no alternatives evaluated in the portfolio analysis. These might include alternative designs or approaches that have notably different resources or investment risk levels as well as alternative implementation strategies that facilitate management of events or changes in investment levels. Alternatives do not include “projects not done.” The term *notably different resources* would apply to any key resource, including financial, constrained categories of labor, outage-critical path time, or consumable environmental impacts (such as tons of carbon emissions). The term *evaluated in the portfolio analysis* is needed to address the fact that alternatives can be identified but then eliminated early in the decision process. Such alternatives should not be counted as alternatives for the purpose of this indicator because they, by definition, do not provide opportunities to improve the portfolio. A higher value of this indicator would suggest that good investment practices are in use. A low value could indicate that the most cost-effective projects do not even make it to the portfolio evaluation table. This indicator was rejected as a candidate for an effective leading indicator of business performance because it does not provide a measure of one of the more important aspects of good portfolio construction—that is, that in-depth innovative thinking is applied to inventing cost-effective alternatives for all projects of substantial size (both must-do and discretionary). In other words, the quality of conceived and proposed alternatives is more important than a simple count of projects with alternatives that could in some cases be perfunctory in nature—token alternatives.

Further consideration of all the process steps in NEI AP-940 did not reveal any additional potentially effective NAM PIs. This should not be a disincentive for the industry to continue the search.

In summary, we have identified only one candidate as a leading PI for the NAM process. That indicator is the ratio of achieved to predicted NPV of the investment portfolio. Note that there is no established method for measuring this indicator at present. Therefore, we will refrain from including it on the candidate list of leading indicators. Its further development and use constitutes a task for future research.

3.5 Human PIs

This section gives a brief overview of the extensive research that has been undertaken on the subject of human performance in nuclear power plants and proposes a list of candidate leading human PIs.

The process of monitoring human performance appears as just one of several plant activity areas in the SNPM subprocess LP002, *provide performance monitoring and improvement services.* In actuality, because humans run the whole enterprise, their performance is inseparable from all of the SNPM core processes and realistically needs to be treated with a more complete view. In a recent study titled "Developing Human Performance Measures," researchers at Idaho National Laboratories state that "human performance in routine plant operations is a(n) ubiquitous, obscure, and pervasive issue. The effects of poor human performance may be revealed long after the human activity occurs, and in locations remote from the locus of the behavior. In fact, it is unlikely that there is only one measure or result that can be attributed to past poor human performance. Further, human performances in plant operations are impacted by a multitude of diverse and hard to specify factors" [8].

We believe that these "diverse factors" include the results of all the processes and management systems by which one controls the physical plant to achieve the high-level goals (safety, reliability, profitability, and environmental protection). Also included in the category of diverse factors are the leadership and cultural attributes of an organization. Some attempt has been made to account for these diverse factors in probabilistic risk assessment (PRA) through the discipline of human reliability analysis (HRA). More recently, a method for incorporating cultural attributes into PRAs has been proposed [9], and an assessment approach has been developed that evaluates the extent to which plant programs and processes effectively manage nuclear safety risk and possess an ingrained risk management culture [10]. However, contributing to the industry's current attempt to address cultural issues in the wake of the damaged Davis Besse reactor head is beyond the scope of this report. It is clearly a challenge to identify a direct or even a proxy measure of a company's risk management (or safety) culture, although it is intuitively obvious how important this is.

Despite the consensus that human performance is important, directly measuring human performance, let alone culture, has proven to be difficult. People can and do function independently, and they are largely autonomous parts of the organization, far from being mere cogs in the machine. The organization is the system within which people act to achieve any result, yet "the understanding of organizational behavior is much less complete than for physical systems. The identification of relevant dependent and independent variables is unclear. Further, the 'equations of motion' for such systems are unknown" [8]. Interestingly, the previously cited Idaho National Laboratory study [8] points out, as we do in Section 5, that system dynamics modeling can be a fruitful way to construct those "equations of motion." We also note that EPRI has investigated an approach that applies dynamic systems modeling to evaluate the impact of programmatic and process performance on nuclear safety and risk [11, 12, 13]. Because this dynamical model and the risk management assessment mentioned previously [10] were developed using the SNPM functions as a starting point, they might be a promising avenue for future investigation.

Rightfully, the industry's considerable effort in improving human performance has been driven and continues to be driven by safety as an important priority, both for regulatory authorities and the industry. Human performance is also an important driver of profitability.

Human performance improvement efforts have resulted in numerous indicators being proposed and used by various utilities. NEI benchmarking has identified several widely used indicators, INPO has developed a common set of indicators that is being piloted in the industry, and EPRI has developed two approaches to leading indicators of human performance that are intended to be harbingers of overall performance trends if used properly [9]. Human performance improvement efforts have also been combined with self-assessment and corrective action programs (CAPs) that can also guide the development of effective PIs. An example of human performance's cross-cutting influence on some low-level outcome indicators is the maintenance rework indicator already identified by the screening process and displayed in Table 3-1. Therefore, our approach has already made progress in identifying human performance measures.

Additional human PIs were sought by screening the many indicators used by plants and the indicators that appear in the literature about human performance in nuclear power plants. This screening resulted in the additional indicators shown in Table 3-7; these are intended to be a concise candidate set sufficient to measure and track human performance.

Table 3-7
Candidate Human PIs

Outcome Indicators
• Total number of events (normalized to labor hours)
• Number of events due to human error (normalized to labor hours)
• Component mispositionings (per 10,000 operations labor hours)
Process/Leading Indicator
• Average age of CAP (or self-assessment) action items not completed

It should be noted that all these indicators require particular attention when defining what is and what is not to be counted. In addition, to enable comparisons between plants, certain assumptions have to be verified—for example, the assumption that the types of findings that go into the CAP at Plant A would also go into the CAP at most or all other plants. Other assumptions might need to be verified. For example, what constitutes an event for the purposes of the human error indicator, and what constitutes an event due to human error?

For these indicators to be useful, criteria must be consistent across the industry. These standardization checks are likely to be more important for human performance-related indicators than for indicators associated with physical processes because pumps and valves do not resent being measured, nor do they make judgment calls that could alter the counting or tracking of an event or issue. Human PIs are often perceived as reflections of the staff's competence, and indeed, such indicators are commonly used to establish staff rewards and sanctions. To the extent that this is the case, great care must be exercised to ensure that the data are accurate and consistently defined and not biased or manipulated.

3.6 Summary of Candidate Leading PIs

The final steps in generating a list of candidate leading PIs are (1) to designate the outcome and process indicators identified in Tables 3-1 through 3-7 into the categories of leading and lagging and then (2) to combine the resulting leading indicator list with the additional indicators identified from the NAM and human performance areas discussed in Sections 3.4 and 3.5.

Recall that we previously concluded that all process indicators are leading indicators of value. It is not so straightforward to designate outcome indicators as leading or lagging: they can be either depending on the frame of reference. We can say only that higher level outcome indicators will almost always be lagging, but lower level ones can be lagging or leading.

For the reliability objective, there are three levels of outcome indicators—A, B, and C (see Table 3-1). For our purposes, it appears reasonable to designate the Level B outcome indicators as lagging (because they are the result of Level C indicators and process indicators) and the Level C outcome indicators as possibly leading (because they can affect the Level B outcome indicator of component failure lost capability).

For the profitability objective, there are only two levels of outcome indicators, A and B (see Table 3-2). All of the Level B indicators are cost components. It is true that these can be leading indicators for the outcomes in Level A, but the leading effect has more to do with simple extrapolation to rising or falling cost components and less to do with a cause/effect relationship, as we saw with the Level C indictors for reliability. Therefore, for our purposes, we will designate Level B as lagging so that there are no outcome leading indicators for profitability. In a similar way, we will designate the human performance outcome indicators in Table 3-7 as leading. Note that these designations have some degree of arbitrariness; nonetheless, they are proposed as being practical and useful for our purpose of identifying candidate leading BPIs.

The foregoing rationale led to the list of 25 candidate leading indicators presented in Table 3-8. Note that 11 of the indicators are included in the set needed to calculate the Equipment Reliability Index being developed by the ERWG. These 11 are already being validated with data from plants as part of an ERWG effort. Thus, only 14 are candidates for inclusion in any future industry validation program.

Table 3-8
Candidate Leading PIs

Candidate Leading Indicator	Objective/Value	Outcome/ Process
Unplanned power changes per 7000 hours critical	Reliability (ERWG)	Process
Unplanned LCO entries	Reliability (ERWG)	Process
Operator workarounds	Reliability (ERWG)	Process
Percentage of actions in system health reports completed	Reliability (ERWG)	Process
Timely completion of PM	Reliability (ERWG)	Process
Deferred PM	Reliability (ERWG)	Process
Schedule scope stability	Reliability (ERWG)	Process
Schedule adherence	Reliability (ERWG)	Process
Total on-line maintenance backlog	Reliability (ERWG)	Process
On-line corrective maintenance backlog	Reliability (ERWG)	Process
On-line elective maintenance backlog	Reliability	Process
Age of red and yellow systems	Reliability (ERWG)	Process
Percentage of work orders completed as fix-it-now	Reliability	Process
Percentage of outage work orders ready	Reliability	Process

Table 3-8 (continued)
Candidate Leading PIs

Candidate Leading Indicator	Objective/Value	Outcome/ Process
Contaminated floor space	Profitability	Process
Maintenance work order rework	Profitability	Process
Procurement process to total purchase cost ratio	Profitability	Process
Ratio of returned to issued material items	Profitability	Process
Average age of CAP (or self-assessment) action items not completed	Cross-cutting (human performance)	Process
WANO Fuel Reliability Index	Reliability	Outcome
WANO Chemistry Indicator	Reliability (ERWG)	Outcome
INPO AP-913 critical component failures	Reliability (ERWG)	Outcome
Total number of events	Cross-cutting (human performance)	Outcome
Number of events due to human error	Cross-cutting (human performance)	Outcome
Component mispositionings	Cross-cutting (human performance)	Outcome

3.7 Evaluation of Candidate Leading BPIs

As stated in the Report Summary, the objective of this report is to present a concise list of candidate leading BPIs that can increase the effectiveness of the indicators currently in use by all plants and can be used by nuclear asset managers to improve plant business performance and value, motivate and improve staff behavior, allocate resources efficiently, and facilitate performance benchmarking with other plants—all while maintaining an acceptable level of nuclear safety. The list of candidate PIs set forth in Table 3-8 is a starting point. However, to achieve this objective, further analysis of the list is required in two areas. First, the number of candidates (25) is too large and not a concise list to implement. Second, and more important, a basis for implementation needs to be established.

To accomplish this task, the candidate list shown in Table 3-8 was reviewed by the project's TAG. The characteristics of the candidate PIs were evaluated. To be considered a useful leading BPI, a candidate PI needs to possess the following characteristics:

- The PI must be implementable; that is, it must be capable of being obtained using readily available data.
- The PI must be calculable; that is, it must be quantifiable using a standard repeatable procedure.
- The PI must be consistent. Given the same input data, its results will remain stable both over time and across plants. In addition, the interpretation of the PI will be similar from plant to plant.

Those indicators that were not believed to be useful as leading indicators of business performance were eliminated from the list. Those that were identified as potentially useful were further analyzed and refined, and a basis for the usefulness of the PI was developed. The rest of this section presents summary analyses of the 25 candidate PIs.

PI-01: Unplanned Power Changes per 7000 Hours of Critical Operation

This indicator is typically characterized by small numbers (such as zero or one occurrences per year per plant, with an industry average of approximately one scram per year). The event monitored is also considered significant from a management perspective. Historically (and logically), there is a correlation between this variable and both regulatory perception and business performance; however, this is manifest only over long periods and provides an indication of performance issues only after a significant business impact has occurred. Thus, this PI results in predominantly lagging indication of performance and was deleted as a leading BPI.

PI-02: Unplanned LCO Entries

PI-02 measures how often technical specification LCOs are entered as the result of emergent events. Its trend can furnish an early indication of degrading plant performance and give management early indication that there is an increased possibility for a significant event leading to significant business impact. This indicator can be modified to produce a more meaningful measure of business value by weighting the results by the duration of the allowed outage time (AOT). Thus

Weighted Unplanned LCO Entry Time

that can be defined by the relationship

Unplanned LCO time x (m*aximum AOT / LCO AOT*).

The weighting proposed provides a significant improvement in the assessment of business value because short-duration LCOs (for example, 72 hours) generate a significant increase in business risk over long LCOs (with a typical maximum set at 30 days). This proposed weighting lends a mechanism to account for this business risk in this BPI. Both the raw data value and trend of these parameters should be collected and reviewed.

PI-03: Operator Workarounds

This PI indicates the potential for human errors or initiated events due to the requirement for operators to operate the plant in a manner that is different from the design. However, there can be significant variation in the level of what constitutes a workaround and the level of management's acceptance of workarounds. Management's changes in these expectations and requirements would significantly modify the outcomes of this PI. Because this PI is subject to a broad range of interpretation, it would be difficult to implement in a consistent manner, both across the industry and within an enterprise (either at the plant or fleet level) over time. Thus, this PI was deleted as a leading BPI.

PI-04: Percentage of Actions in System Health Reports Completed

This PI measures the extent to which corrective actions, once identified, get completed and the time required to resolve these issues. However, there can be significant variation in the level of effort and time required to complete the identified corrective actions. Additionally, management changes in the requirements would significantly modify the outcomes of these attributes. Similar to PI-03, this PI is subject to a broad range of interpretation and would be difficult to implement in a consistent manner, both across the industry and within an enterprise (either at the plant or fleet level) over time. Thus, this PI was deleted as a leading BPI.

PI-05: Timely Completion of PM

PI-05 and PI-06 provide indication of the effectiveness of the PM and predictive maintenance (PdM) programs. There is a demonstrable correlation between ineffective PM and PdM programs and systems, structures, and components (SSC) reliability and performance that has a direct impact on business performance. To meet NRC regulations (such as the Maintenance Rule) and management business objectives, many plants have classified critical PM and PdM tasks that must be performed. Similar to requirements for technical specification surveillance testing, many plants also permit performance of a scheduled task to exceed its specified frequency by an amount permitted by management (the allowance is typically 25% and referred to as a *grace period*). These characteristics could be used to specify a useful leading BPI. Thus, we recommend revising these PIs to the following:

Ratio of critical PM/PdM tasks overdue or in grace period to total critical PM/PdM tasks

Because overdue tasks possess more business risk than those that are still within their grace period, this PI could be augmented by providing overdue tasks with a greater weighting than tasks still within the grace period. For plants that have specified multiple levels of functional importance, this PI also could be modified by providing an additional weighting based on the degree of SSC functional importance. We note that because the methods used to assess the degree of differentiation of these attributes differ across the industry, details on the assignment of any weighting factors should be developed based on the processes in place at each plant.

An increase in this ratio over time could draw attention to plant processes that are not effectively ensuring equipment reliability, which eventually could lead to an increased number of trips and decreased plant electrical output. Note that if the plant implementation of PM/PdM tasks is effective to the point of not requiring entrance into the grace period for critical PM projects, the metric could be modified to encompass all scheduled PM/PdM tasks.

PI-06: Deferred PM

This PI is addressed in the preceding discussion of PI-05.

PI-07: Schedule Scope Stability

This and the next PI measure the effectiveness of the plant work management process. These attributes have been demonstrated to provide valuable measures of this process, with broad implications for plant business performance. Thus, these metrics result in useful measures of future business performance. We note that it might be possible to improve the value of these indicators by providing a mechanism to account for the loading of the schedules and the fraction of task completed. Investigation of mechanisms to accomplish these potential improvements (for example, data needs and calculation procedure) was not performed and would constitute a future research task.

PI-08: Schedule Adherence

This PI is addressed in the preceding discussion of PI-07.

PI-09: Total On-Line Maintenance Backlog

For PI-09, PI-10, and PI-11, we note that these PIs are not independent and are related by

Total on-line backlog = o*n-line corrective backlog* + o*n-line elective backlog*.

Thus, these PIs all monitor some aspect of the plant’s maintenance backlog. Historically (and logically), there is a correlation between high levels of backlog and poor regulatory perception and business performance (for example, plant capacity factor). Over the past decade or so, many plants have significantly reduced backlog (of all forms) through implementation of structured work week planning and execution processes, fix-it-now teams, and so on. However, the corrective maintenance backlog can be viewed as a sign of SSC deficiencies that are outstanding and for which corrective measures have not been implemented. If this number grows in relation to the total maintenance backlog, the plant's control processes are not effectively resolving the problems in a timely manner. Note that this evaluation should be limited to on-line corrective maintenance activities (because outage backlog will increase during the course of the plant operating cycle and then decrease as a step function after the outage). Due to the relationship previously shown, this PI does not give plants any additional information than is contained in PI-10 and PI-11 and thus was deleted as a leading BPI. However, the following two PIs are useful measures of future business performance and should be monitored.

PI-10: On-Line Corrective Maintenance Backlog

As described under PI-09, this parameter provides a useful indication of future plant business performance. This is true both for the raw number (and its trend) and the ratio of the on-line corrective backlog to total on-line backlog. Thus, the following two indicators should be included as leading BPIs: (1) the on-line corrective maintenance backlog and (2) the ratio of on-line corrective maintenance backlog to the total on-line backlog.

Both the raw data value and trend of these parameters should be collected and reviewed. We note that in this classification, the measure includes activities that are identified by a plant's condition-based maintenance program. Also, for the PI that represents the ratio of corrective to total on-line backlog, we note that an increase in this ratio over time could be indicative of plant processes that do not effectively ensure equipment reliability, which eventually could lead to an increased number of trips and decreased plant electrical output. Thus, this PI is expected to yield proactive indication of the effectiveness of the work management process.

PI-11: On-Line Elective Maintenance Backlog

Similar comments made for PI-10 also apply to this measure. Thus, the following should be included as leading BPIs: (1) the on-line elective maintenance backlog and (2) the ratio of on-line elective maintenance backlog to the total on-line backlog. Both the raw data value and trend of these parameters should be collected and reviewed.

PI-12: Age of Red and Yellow Systems

Typically, this indicator is characterized by changes that occur over long timeframes (a poorly performing system, for example, will require the expenditure of significant time and resources to restore its performance to acceptable levels). Historically, there is a strong correlation between this variable and both regulatory perception and business performance. However, because issues associated with poorly performing systems have already had significant business impact, this PI does not result in information that is anticipatory in nature. Thus, it was deleted as a leading BPI.

PI-13: Percentage of Work Orders Completed as Fix-It-Now

This PI provides an assessment of the extent to which minor plant material and SSC performance issues are addressed in an expeditious manner. However, there can be significant variation in the level of tasks permitted under a fix-it-now program versus those that require a formal work management system. Management's changes in these requirements would significantly modify the outcomes of this PI. Thus, this PI is subject to a broad range of interpretation and would be difficult to implement in a consistent manner, both across the industry and within an enterprise (either at the plant or fleet level) over time; for this reason, PI-13 was deleted as a leading BPI.

PI-14: Percentage of Outage Work Orders Ready

PI-14 is essentially a measure of how fast an outage item, once identified, can be planned and integrated into the outage scope. However, there is wide variation in the definitions of *ready*. As such, this PI does not meet the requirement for consistency and thus was deleted as a leading BPI.

PI-15: Contaminated Floor Space

PI-15 assesses the effectiveness of the radiation protection and contamination control programs. This PI is listed here because it previously served as a surrogate measure for the degree to which plant management would invest in activities that did not provide an immediate financial payback. However, over time plants have reduced the fraction of contaminated floor space to very low levels so that this PI no longer supplies this information. Thus, it was deleted as a leading BPI. However, we do note that it would be useful if a similar measure that possessed similar characteristics could be identified.

PI-16: Maintenance Work Order Rework

This PI speaks to the effectiveness of human performance in addressing identified plant deficiencies. Its trend can show a very early indication of degrading human performance and alert management to an increased possibility for a significant event that might lead to significant business impact. Thus, it provides useful anticipatory information on business performance. It also produces a useful measure of plant cultural interactions. Therefore, the raw data value and trend of this parameter should be evaluated.

PI-17: Procurement Process to Total Purchase Cost Ratio

PI-17 and PI-18 measure the efficiency (as compared to the effectiveness) of the materials management (including procurement) process. Although these PIs give some indication of business performance, process efficiency provides a second-order effect, and thus these PIs were eliminated from the leading BPI list.

PI-18: Ratio of Returned to Issued Material Items

This PI is addressed in the discussion of PI-17.

PI-19: Average Age of CAP (or Self-Assessment) Action Items Not Completed

Similar to PI-04, this PI measures the extent to which corrective actions, once identified, are completed and how long is required to address and close these issues. The basis presented for PI-04 also applies to PI-19; thus, PI-19 was deleted as a leading BPI.

PI-20: WANO Fuel Reliability Index

This indicator is typically characterized by a small number of minor failures. Additionally, failures usually are due to manufacturing issues from the fuel supplier. Although minor fuel failures can have substantial business impact (such as requiring plant derates to limit out-gassing), PI-20 does not usually point to plant issues over which management has significant control. Thus, the indicator was eliminated from the list of leading BPIs.

PI-21: WANO Chemistry Indicator

This indicator measures a contributing factor to the small number of minor fuel failures observed. As discussed under PI-20, these failures can have substantial business impact. However, in contrast to PI-20, this variable truly measures a precursor and thus is useful as a leading indicator of performance. This indicator also commands significant senior management attention and focus. Although PI-21 does not represent an ideal indicator, both its value and trend should be monitored as leading indicators of business performance.

PI-22: INPO AP-913 Critical Component Failures

This PI represents a roll-up of indicators monitored to meet the NRC's Maintenance Rule (10CFR50.65) requirements. At the level of individual systems/trains used for Maintenance Rule monitoring, this type of PI is characterized by small numbers (that is, zero or one critical failures per year for most SSCs). Because this type of parameter is required to meet NRC regulations, it has significant management focus; therefore, this indicator is more reactive in nature than forward-looking, and it is not anticipatory in nature. This PI was rejected as a leading BPI.

PI-23: Total Number of Events

This indicator measures the degree to which a plant is challenged. Because it is broad in scope (with potentially different definitions at different plants), its application as a leading BPI is problematic (that is, it does not meet the consistency criterion discussed at the beginning of this section). Thus, this PI was deleted as a leading BPI. However, see the discussion of PI-24 for a method by which PI-23 can be combined into a useful leading BPI.

PI-24: Number of Events Due to Human Error

This indicator is a subset of PI-23 that focuses on human performance. However, as an indicator of business performance, what is critical about this PI is its relative relationship to the total number of events. A large or increasing fraction of events caused by human error can supply proactive indication of plant process or cultural issues that warrant management attention and improvement. In order to provide this measure, we recommend that PI-24 be modified to *ratio of number of events due to human error to total number of events.*

PI-25: Component Mispositionings

Most often, this indicator has been caused by human error, and thus it predominantly represents a subset of PI-24. Consequently, it was deleted as a leading BPI.

Table 3-9 summarizes the list of leading BPIs.

Table 3-9
Leading BPIs

Leading BPI	Type	SNPM Process	Characteristics Monitored
Weighted unplanned LCO entry time	Outcome	ER	Value and trend
Ratio of critical PM/PdM tasks overdue or in grace period to total critical PM/PdM tasks	Process	WM	Value and trend
Schedule scope stability	Process	WM	Value and trend
Schedule adherence	Process	WM	Value and trend
On-line corrective maintenance backlog	Process	WM	Value and trend
Ratio of on-line corrective maintenance backlog to total on-line backlog	Process	WM	Value and trend
On-line elective maintenance backlog	Process	WM	Value and trend
Ratio of on-line elective maintenance backlog to total on-line backlog	Process	WM	Value and trend
Maintenance work order rework	Process	WM	Value and trend
WANO Chemistry Index	Process	OP	Value and trend
Ratio of number of events due to human error to total number of events	Process	Cross-cutting	Value and trend

Finally, we note that during the TAG's review of the candidate BPI list (and the development of this final list of leading BPIs), there were several ideas for new indicators that could also provide useful measures of business value and/or proactive indication of changes in business performance. Examples include the following:

- Measures of budget compliance
- Fraction of clearances written and applied to clearances requested
- Same or similar work clearances issued on the same equipment within a short timeframe

None of these ideas was investigated further during this project. However, the TAG believed that the unexplored ideas should be investigated in a future research project.

4
USEFUL METHODS FOR FORMULATING PERFORMANCE INDICATORS

This section describes two methods that might be useful for formulating new PIs that could be capable of measuring business value and performance. The first—the Balanced Scorecard (BSC)—establishes a framework for formulating PIs for any process operation, including process operations of a nuclear power plant. The second, system dynamics, can be used to analytically model how leading indicators affect plant performance after a lag time. Two other notable methods that might be used to formulate new PIs—BusinessGenetics® and the EVMS—are also described in this section, with expanded discussion contained in Appendices B and C.

We note that other methods also may be used to achieve this objective. Two that are of note but were not thoroughly investigated in the research were Business Genetics© and the Earned Value Management System (EVMS). BusinessGenetics©, is a systematic way to develop detailed plant process mappings. The diagrams it creates may exhibit important flows through a plant process that can serve as effective process indicators. A brief summary of the Business Genetics© process is provided in Appendix B. The Earned Value Management System (EVMS) provides an approach to measure the amount of work actually performed on a project and to forecast its cost and completion date. The method relies on a key measure known as the earned value which enables one to compute performance indices for cost and schedule. These indicators describe project performance compared with the original plans and assumptions. These PIs also enable one to forecast future project performance. A brief summary of EVMS is provided in Appendix C.

4.1 BSC

The BSC approach is a performance measurement and performance management system developed by Robert Kaplan and David Norton of the Harvard Business School [14, 15]. BSC has been adopted by a wide range of organizations both public and private, and it is in use by a number of nuclear power plant owners.

The BSC is a conceptual framework for translating a company's strategic vision into a set of PIs distributed among these four perspectives:

- Financial
- Customer
- Internal business processes
- Learning and growth

Indicators are maintained to measure an organization's progress toward achieving its vision; other indicators are maintained to measure the long-term drivers of success. Through the BSC, an organization monitors its current performance (its finances, customer satisfaction, and business process results) and its efforts to improve processes, motivate and educate employees, and enhance information systems—in short, the organization’s ability to learn and improve.

4.1.1 The Four Perspectives of the BSC

Definitions of the BSC’s four perspectives follow:

- *Financial*: Financial objectives generally represent clear short- and long-range targets, such as budget performance and profitability. In addition to its focus on profit, this perspective captures cost efficiency and cost-effectiveness (that is, the extent to which maximum value is delivered to the customer for each dollar spent).
- *Customer*: This perspective captures the ability of the organization to deliver quality goods and services, effective delivery, and overall customer satisfaction. Customer and stakeholder satisfaction are as important as financial results because the organization has a stewardship responsibility and the goal of maximizing return. For nuclear power plants, the satisfaction of the ultimate customer—the electricity consumer—depends on many factors beyond the purview of the plant. Although the main immediate customer for a nuclear power plant is the electricity market (through a grid), the definition of *customer* might be broadened to include economic, safety, and environmental regulators and the public at large, all of whom are concerned with the performance and safety of the nuclear plant.
- *Internal business processes*: This perspective provides data regarding the internal business results that lead to financial success and satisfied customers. Because performance expectations are achieved through internal business processes, to meet organizational objectives and customer expectations, organizations must identify the key business processes at which they must excel. Key processes are monitored to ensure that outcomes are satisfactory.
- *Learning and growth*: This perspective captures the ability of employees, information systems, and organizational alignment to manage the business and adapt to change. Processes will succeed only if adequately skilled and motivated employees supplied with accurate and timely information are driving them. This perspective takes on increased importance in organizations such as nuclear utilities that are undergoing radical change in an increasingly competitive but still highly regulated industry. In order to meet changing requirements and customer expectations, employees might be asked to take on dramatically new responsibilities and might be required to have or adapt to skills, capabilities, technologies, and organizational designs that were not expected or available before.

4.1.2 Performance Objectives and Management

These are critical success factors in achieving the organization's mission, vision, and strategy. Failure to achieve them would likely result in a significant decrease in customer satisfaction, system performance, employee satisfaction or retention, and effective financial management.

The BSC arms the organization with a structured methodology for using performance measurement information to help set agreed-upon performance goals, allocate and prioritize resources, inform managers to either confirm or change current policy or program directions to meet those goals, and report on the success in meeting those goals.

4.1.3 Properties of BSC Performance Measures

Each objective should be supported by at least one measure that will gauge an organization's performance against that objective. Measures should be precisely defined, with the definition including the population to be measured, the method of measurement, the data source, and the time period for the measurement. Whenever possible, these measures should be written as mathematical formulae. An ideal measure will be all of the following:

- Leading: it forecasts future trends
- Objective: the measure is not a judgment call
- Controllable: the results are substantially under the direct control of the organization, with potential outside influences minimized
- Simple: it is easily understood and measures only one thing
- Timely: the measure reflects recent or current performance
- Accurate: the measure is a reliable, precise, sensitive indicator of results
- Graded: it yields traceable data that are not limited to binary yes/no measures
- Cost-effective: it involves data that are worth the cost of gathering
- Useful: it provides data needed by the organization to manage the business
- Motivating: achieving the targets drives good business decisions, avoiding over-expenditure, over-compliance, manipulation, or reduction in morale

These characteristics both mirror and complement the desirable properties of the leading indicators presented in Section 2. For the most part, a BSC approach is consistent with the value model approach described in this report. As with the value model approach, it counts on process measures for its leading PIs.

Those using this report to improve nuclear plant PI programs might find it useful to adopt BSC concepts to support their goals. And those already using the BSC approach might find that the concept of value modeling developed herein can complement and strengthen their BSC program.

4.2 System Dynamics Modeling and Analysis

A useful tool for identification or formulation of effective leading BPIs would be a mathematical model of plant organization and work processes that could be used to simulate the effect of changes in management-controlled factors such as staffing, procedures, and training on plant performance. We previously mentioned an approach and model developed to address this issue for nuclear safety [10–13]. However, this model's focus is too narrow for our purpose of identifying indicators of business value.

In this project, we identified and reviewed a workable organizational and process model that uses system dynamics modeling with software called the *Operational Risk Simulation Model* (ORSIM) [16] developed by the Massachusetts Institute of Technology (MIT). This methodology has been applied by MIT to identify nuclear power plant maintenance best practices and was used in a 2001 MIT report on identifying PIs for nuclear power plants [17]. In this section, we give a brief overview of the methodology and the successes obtained to date in applying it to nuclear power plants.

4.2.1 Overview of System Dynamics Modeling

The operational performance of a nuclear power plant can be viewed as a time-dependent result of the interactions among a large number of system constituents, both physical and organizational. For example, if maintenance work is lagging behind schedule, we can ask whether this is because of poor equipment performance or low staff productivity. But, if due to low staff productivity, what would cause the productivity to be so low? It might be because the workers are overworked (the cause of a new problem—high error and accident rates), or it could be due to other causes, including combinations of influences. Because the relationships among system constituents are often nonlinear and coupled, the only way to analyze their *a priori* impact on plant business performance is through computer simulation.

ORSIM (and its predecessor OPSIM—the *Nuclear Power Plant Operations Management Simulator*) makes use of the systems dynamics technique, which was pioneered at MIT [18] and has been in use for almost half a century. System modeling quantifies the effects of mutual feedback among the sectors that perform nuclear power plant operations, planning, maintenance, engineering, management, and so forth (see Figure 4-1).

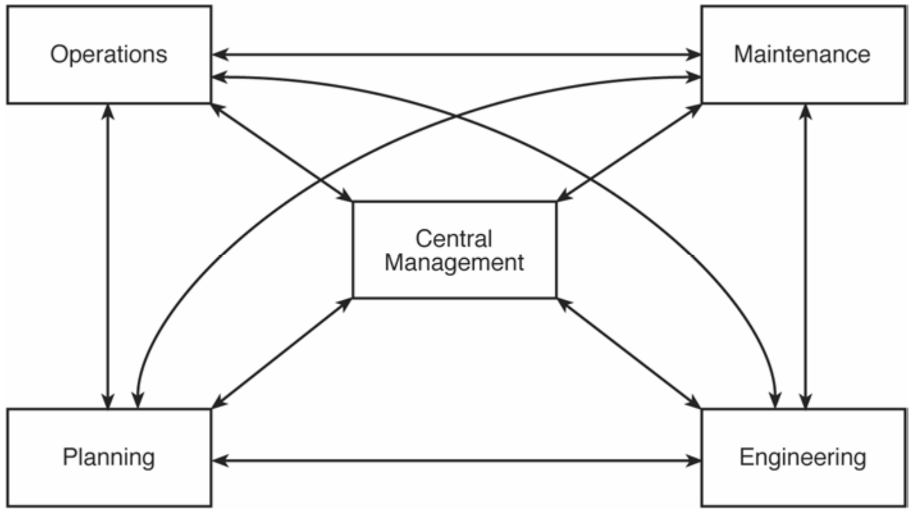

Figure 4-1
Skeleton Structure of the ORSIM

All the sectors interact with plant physical systems in one way or another. Generally, within a typical sector, there is a work generation rate governed by specific mechanisms, an inventory or backlog of work to be done, and a work accomplishment rate. Work creation occurs during operation and is unique for each sector. These rates, if unbalanced, can accumulate into backlogs. The backlogs are reduced by the rate at which work is accomplished, which is determined by the number of people assigned to the tasks and their productivity.

An example of a building block in a system dynamics model is shown in Figure 4-2. Note the feedback loops inherent in the process model.

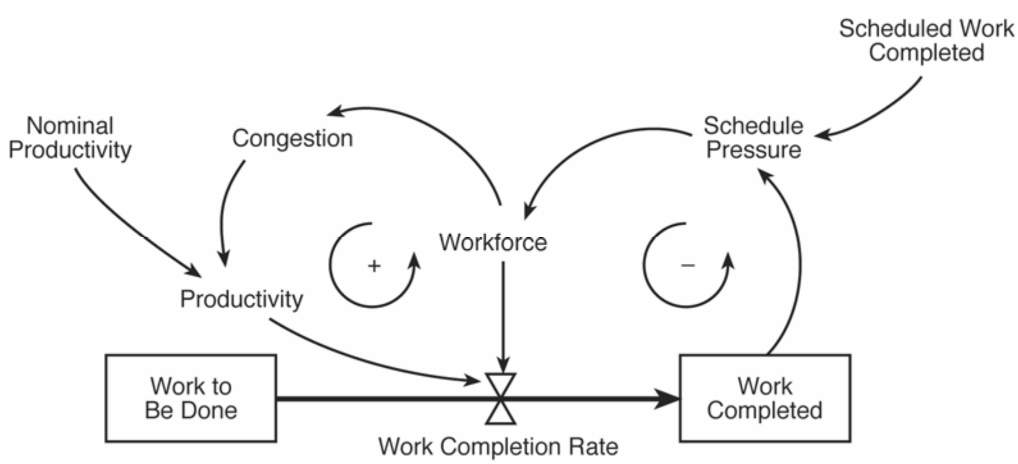

Figure 4-2
System Structure Example: A Simplified Work Flow Causal Loop Diagram

Relationships among the variables are quantified with equations containing variables such as rates, accumulations, data, and system constants. The solution of the equations simulates the functioning of the represented system.

Figure 4-3 gives an idea of the complexity of an ORSIM developed for a nuclear power plant. This model is intended to represent the maintenance workflow process. A complete plant model would consist of many such diagrams.

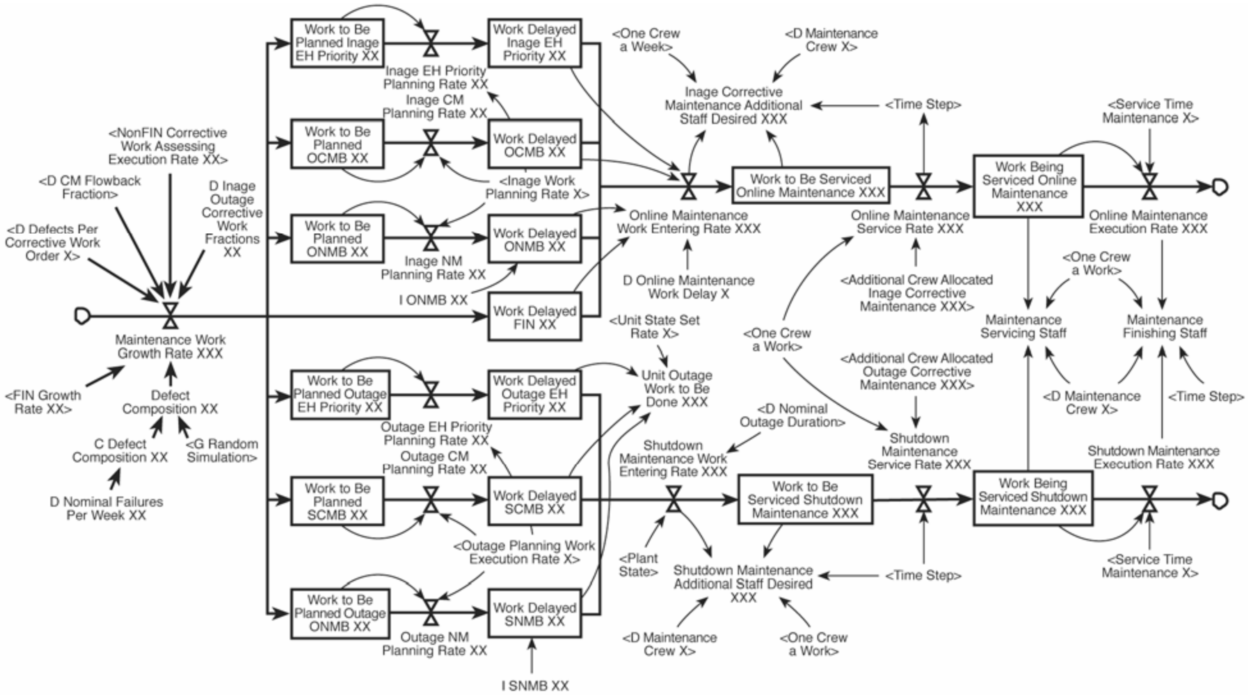

Figure 4-3
Maintenance Workflow Diagram

As shown in Figure 4-4, the model output is the evolution of system variables based upon the input initial conditions, in-process events, and corresponding actions. The ultimate output is power generation. (Although current models address power generation, they can be enhanced to calculate the corresponding labor and hardware costs to examine the effects on profitability.) For examining the effectiveness and importance of candidate leading indicators (or supporting formulation of new and innovative ones), the model would calculate the effect of a change in an indicator on system outputs.

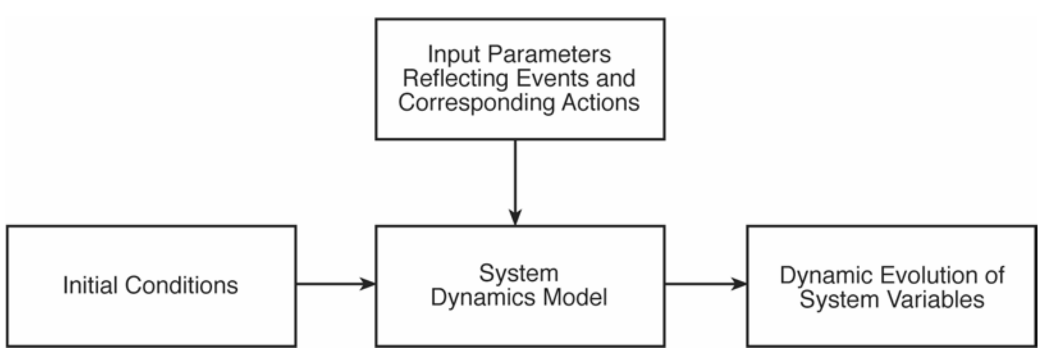

Figure 4-4
How the System Dynamics Model Works

4.2.2 OPSIM Use in a Study of Nuclear Power Plant PIs

OPSIM was used in a 2001 MIT study [17], the objective of which was to develop a methodology for identifying and validating PIs for assessing and predicting nuclear power plant overall performance (both safety and economic) in a systematic, quantitative way.

The study used historical operation records of candidate indicators from three target plants to identify and validate plant-specific correlations by means of quantitative data analysis. Of particular interest were "leading indicators, which can provide advance warnings of deterioration of performance before the direct outcome indicators are affected" [17]. A regression-based lead/lag time series analysis method was applied to the case studies. This method did not produce stable and reliable results with the data available at the target plants and was not able to identify any leading indicators with certainty. As a result, the researchers shifted to correlation and multivariate regression analysis. Correlations varied from plant to plant and from time to time at the target plants. However, the method did shed light on the relative importance of PIs, which can help to rank and prioritize them.

4.2.3 Identification of Candidate Indicators

The indicators addressed by the MIT PI study [17] were those determined in interviews with target plant participants to have strong correlations with performance. The list of candidate indicators developed from the research was viewed as being extensive enough to cover all important factors affecting plant operation and yet small enough that data collection and analysis in both the study and in plant practice would be focused and manageable. To ensure a thorough and workable list of candidate indicators, a refinement and screening phase was carried out after the identification phase.

The input and outcome variables examined in the MIT study are displayed in Table 4-1. Under the classification scheme discussed in Section 2, these can generally be considered process and outcome indicators. It is important to note that the goal of this MIT study was not to obtain a complete list of important PIs, but rather to lay out a systematic approach that others can follow to identify PIs and validate their importance and usefulness.

Table 4-1
PIs Examined in the MIT Study

Input Variables
Number of work orders in the backlog
Number of corrective maintenance work orders in the backlog
Mean age of corrective maintenance work orders in the backlog
Mean age of 10 oldest corrective maintenance work orders in the backlog
Number of PM work orders in the backlog

Table 4-1 (continued)
PIs Examined in the MIT Study

Input Variables
Number of tool pouch work orders (minor defects usually fixed on the spot without planning) in the backlog
Number of more significant events (MSEs) identified through a plant-specific problem investigation process (PIP)
Number of less significant events (LSEs) identified through a PIP
Success fraction in planning and scheduling, calculated by dividing the number of work order tasks completed in a given week by the number of tasks scheduled in that week (and summing for the entire year)
Supervisor availability
Number of crews in the plant's O&M department
Number of staff members available for non-planning work
Employee recordable injury rate, defined as the number of employees who suffered recordable injuries
Number of staff members (including both managers and technicians) who transferred between divisions at the plant or to other plants or locations
Total schedule adherence, defined as the fraction of work orders that are completed on schedule
Maintenance quality, defined as the number of work orders reworked divided by the number of work orders in the month
Maintenance planning quality, defined as the fraction of planned work orders that need to be replanned in a month
Number of emergent work orders that are added in the month, including nuclear safety issues, plant reliability issues, and cost reduction issues
Number of components that have been mispositioned in the month
Rewards awarded to plant personnel with superior performance in the year
PM work schedule adherence, defined as the fraction of PM work orders that are completed on schedule
Site recordable injury rate, defined as the number of employees who suffered recordable injuries on the site
Number of plant event reports (PERs) completed in a month
Fraction of PERs that are completed on time in a month

Table 4-1 (continued)
PIs Examined in the MIT Study

Input Variables
Total number of PERs in the backlog
Score of a plant-specific peer assessment of the plant's maintenance and modification work in a month
Number of modification work orders in the backlog
Industrial safety accident rate, defined as the number of accidents that result in lost work time, restricted work, or fatalities per 200,000 worker-hours
Outcome Variables
INPO Performance Index, a composite index constructed using nine INPO PIs
Derate frequency, defined as the number of hours that the plant was derated from full electricity generation capacity in the month
Operating capacity factor
Unplanned capability loss factor

A major finding of the MIT study was that the data available from the pilot plants were not sufficient to validate and support formulation of industrywide PIs. It was believed that more extensive and standardized data collection programs were needed to produce useful results.

4.2.4 Pilot Project on the Use of Maintenance Best Practices

In the MIT project conducted for EPRI [16], the ORSIM methodology was applied in two studies. In the first, ORSIM was customized and tuned to characterize the baseline condition and performance of a pilot nuclear power plant located in Canada. This study demonstrated that customization of ORSIM is not difficult and that, once customized, ORSIM can serve as a helpful tool for identifying existing problems and investigating the effects on performance due to changes in maintenance practices and policies. The pilot study also observed inefficient use of planning staff and an overload of plant modification work for engineers.

Regarding the second study, EPRI worked with nuclear power plant teams to identify the most important good practices and hallmarks of effective maintenance management. These practices and the related excellence performance matrix were summarized in two EPRI reports [19, 20].

Two EPRI practices were selected to demonstrate how to use ORSIM to investigate the implications of practices on plant performance. Each study began by establishing both how plant policies and practices affect the ORSIM variables and the quantifications of these effects. A matrix of reliability, economics, and stability performance indices was developed to help identify potential problem areas.

The first practice examined was *craft perform peer field observation*. Here, ORSIM results showed that improved productivity is far less efficient in reducing work backlog than improved quality, given that the available workforce is sufficient. This is because improved productivity only reduced the time a work order remains in the system by a small amount, with most of the delays coming from stages prior to execution, whereas improved quality significantly reduced the flow rates between maintenance processes. The backlog, which is a product of flow rates and delay times, is therefore far smaller in the improved quality case than in the improved productivity case.

The second practice examined was *employees at all levels are encouraged to identify and report problems in accordance with Corrective Action Program criteria.* ORSIM results revealed that a good safety culture, even if it requires some resources to maintain, can improve the operational performance of a plant because efficient defect discovery helps reduce the unobservable backlog of undiscovered defects. This improves material conditions and reduces the defect generation rate.

4.3 Other Potential Approaches

In addition to the approaches discussed in Sections 4.1 (BSC) and 4.2 (ORSIM), two other approaches were identified that might be applicable to development of improved indicators of business value and performance. These methods include BusinessGenetics process mapping and the EVMS.

Due to time limitations, the potential for application of these approaches was not evaluated during this project. However, for the convenience of the reader, a brief description of the BusinessGenetics process is presented in Appendix B. Similarly, a brief description of EVMS appears in Appendix C. Thorough evaluation/application of either of these methods for the purpose of developing business value measures and leading PIs constitutes a subject for future research.

4.4 Conclusion

The foregoing applications of ORSIM both in the pilot plant study of maintenance performance and in the examination of the effects of maintenance improvement practices are evidence that, theoretically at least, system modeling can be used to study the effects of process changes on plant performance. This capability appears to be useful in examining the relative effects that changes in candidate leading process PIs can have on plant performance.

Although this capability sounds promising, we must recognize just how challenging it is to construct representative models of complex plant processes and—even more challenging—to determine both the analytical form of the mathematical relationships among plant activity inputs and outputs and the values of parameters in the equations needed to calibrate the model against real world plant processes and human performance.

5 CONCLUSIONS AND RECOMMENDATIONS

Through the research described in this report, the existing suite of industry PIs was reviewed to identify those that, with possible modifications, could serve as a concise set of leading BPIs. The intent was to provide nuclear plant personnel responsible for asset management with measures that can be used to improve plant business performance and value, motivate and improve staff behavior, allocate resources efficiently, and facilitate performance benchmarking with other plants, all while maintaining an acceptable level of nuclear safety. Section 3 presents the results of this research—it consists of a concise set of leading BPIs (with basis). Because these PIs are essentially measured, to varying degrees, to meet other objectives at operating plants, they can be easily implemented without any need for extensive testing and validation.

We note that the further evaluation of the additional indicators suggested by the TAG (briefly mentioned in Section 3.9) should be performed to determine if they possess the characteristics of leading BPIs. Additionally, research to address aspects of business performance that have not been adequately evaluated would be beneficial. Several possible areas of investigation identified by the TAG include the following:

- Performance monitoring and analysis of measures of plant culture (including both nuclear safety and business aspects). This could include measures of the extent to which minor issues are permitted to linger (that is, are tolerated) and thus possess the potential to develop into significant issues. Another possibility is development of a measure of the degree to which aggressive action is taken to identify and address emerging issues.
- Measuring the effectiveness of the material management function, such as how plant inventory and spare parts are managed, including the capability to support critical plant maintenance needs and the capability to control costs.
- Development of measures of how effective projects are managed and the degree to which the anticipated return on investment (ROI) was achieved.

Because these ideas are not part of typical PI programs in place now, they would require some degree of field validation to verify their applicability and utility if implemented.

A secondary objective of this project was to investigate systematic approaches to model plant processes for the purpose of developing measures of new and innovative business value that would permit nuclear asset managers the capacity to assess the performance of their facilities' asset management functions. Several approaches to achieving this objective were reviewed, including the BSC, system dynamics modeling, BusinessGenetics, and EVMS. Extending this work through application of one or more of these approaches would result in improvements in the capability of plants to effectively evaluate and monitor the effectiveness of their asset management programs. As a first step in achieving this outcome, process mapping of the NEI

AP-940 NAM process would serve as a useful structure from which industry benchmarking could be performed. This mapping and benchmarking should be used to identify industry best practices and to prioritize areas in which additional research (for both analytical methods and tools) should be conducted. Mapping will identify the need for new measures of business value and the anticipated benefits that will be gained from them. Finally, as a complement to this activity, the academic literature (that is, operations research and business/management journals) should be surveyed to identify recent advances and trends in the state of the art of business performance evaluation.

6
REFERENCES

1. Nuclear Energy Institute. *The Standard Nuclear Performance Model – A Process Management Approach*, Revision 4 (a Nuclear Asset Management Community of Practice report). Washington, D.C., 2004.
2. Nuclear Energy Institute. *Nuclear Asset Management Process Description and Guide*. NEI AP-940, Revision 0. Washington, D.C., 2005.
3. *Nuclear Power Financial Indicators for a Competitive Market*. EPRI, Palo Alto, CA: 2001. 1003050.
4. *Business Performance Indicators for Nuclear Asset Management*. EPRI, Palo Alto, CA: 2005. 1011000.
5. U.S. Nuclear Regulatory Commission. Interoffice Task Group on Performance Indicators. *Performance Indicator Program Plan for Nuclear Power Plants*. Washington, D.C., 1986.
6. G. B. Fader, "Industrywide Nuclear Power Plant Performance Indicator Program." *Transactions of the American Nuclear Society*, Vol. 54, Suppl. 1 (1987).
7. *Pilot Application of Enterprise Project Prioritization Process at Nebraska Public Power District*. EPRI, Palo Alto, CA: 2006. 1012954.
8. B. Hallbert et al., "Developing Human Performance Measures." Idaho National Laboratory. Project letter report prepared for USNRC Office of Nuclear Regulatory Research, March 2006.
9. *Final Report on Leading Indicators of Human Performance*. EPRI, Palo Alto, CA: 2001. 1003033.
10. *Risk Management Effectiveness Assessment Application Guide*. EPRI, Palo Alto, CA: 2005. 1011761.
11. *A Dynamical Systems Model for Nuclear Power Plant Risk Management*. EPRI, Palo Alto, CA: 2003. 1007969.
12. S. M. Hess, A. M. Albano, and J. P. Gaertner, "Development of a Dynamical Systems Model of Plant Programmatic Performance on Nuclear Power Plant Safety Risk." *Reliability Engineering and System Safety*, Vol. 90, No. 1 (October 2005).
13. S. M. Hess, A. M. Albano, and J. P. Gaertner, "Analysis and Insights from a Dynamical Model of Nuclear Plant Safety Risk." *Reliability Engineering and System Safety*, Vol. 92, No. 1 (January 2007).
14. R. S. Kaplan and D. P. Norton, "The Balanced Scorecard: Measures That Drive Performance." *Harvard Business Review*, January/February 1992.

15. R. S. Kaplan and D. P. Norton, *The Balanced Scorecard: Translating Strategy Into Action*. Harvard Business School Press, Boston, MA, 1996.

16. *The Operational Risk Simulation Model (ORSIM)*. EPRI, Palo Alto, CA: 2006. 1011911.

17. Y. Siu, M. Golay, and K. Hansen, "Identification of Performance Indicators for Nuclear Power Plants." MIT Report MIT-NSP-TR-006. Massachusetts Institute of Technology, Cambridge, MA, 2001.

18. *Managerial Applications of System Dynamics,* E. B. Roberts, Ed. MIT Press, Cambridge, MA, 1978.

19. *Guideline for Assessing Maintenance Effectiveness: A Self-Assessment Guideline for Nuclear Power Plants.* EPRI, Palo Alto, CA: 2002. 1002932.

20. *Metrics for Assessing Maintenance Effectiveness.* EPRI, Palo Alto, CA: 2003. 1007604.

21. *Earned Value Management Systems*. ANSI/EIA 748-A-1998. American National Standards Institute, Washington, D.C., 1998.

A
ACRONYMS AND ABBREVIATIONS

AC	actual cost
ANSI	American National Standards Institute
AOT	allowed outage time
BPI	business performance indicator
BSC	Balanced Scorecard
CAP	corrective action program
CM	configuration management (an SNPM process)
CoP	community of practice
CV	cost variance
EBIT	earnings before interest and taxes
EIA	Electronic Industries Alliance
ER	equipment reliability (an SNPM process)
ERWG	Equipment Reliability Working Group
EUCG	Electric Utility Cost Group
EV	earned value
EVM	earned value management
EVMS	Earned Value Management System
FERC	Federal Energy Regulatory Commission
HRA	human reliability analysis
INPO	Institute of Nuclear Power Operations
KPI	key performance indicator
LCO	limiting conditions for operation
LP	loss prevention (an SNPM process)
LSE	less significant event
MDC	maximum dependable capacity

MIT	Massachusetts Institute of Technology
MS	materials and services (an SNPM process)
MSE	more significant event
MSPI	Mitigating Systems Performing Index
MW	megawatt
MWh	megawatt-hour
NAM	nuclear asset management
NEI	Nuclear Energy Institute
NPV	net present value
NRC	U. S. Nuclear Regulatory Commission
NSCSL	Nuclear Supply Chain Strategic Leadership
O&M	operations and maintenance
OP	operate plant (an SNPM process)
ORSIM	Operational Risk Simulation Model
OSHA	Occupational Safety and Health Administration
PdM	predictive maintenance
PER	plant event report
PI	performance indicator
PIP	problem investigation process
PM	preventive maintenance
PRA	probabilistic risk assessment
PV	planned value
RCA	radiological control area
ROE	return on equity
ROI	return on investment
SNPM	Standard Nuclear Process Model
SS	support services (an SNPM process)
SSC	systems, structures, and components
SV	schedule variance
T	training (an SNPM process)

TAG	technical advisory group
WANO	World Association of Nuclear Operators
WM	work management (an SNPM process)
xBML	eXtended Business Modeling Language™

B
BUSINESSGENETICS PROCESS MAPPING

Several nuclear power plant operators have begun to use a method and software that show promise as useful tools for constructing detailed and repeatable models of plant processes. The experience of these utilities indicates that BusinessGenetics modeling is useful for pointing out important process parameters to serve as leading performance indicators (PIs).

B.1 Background

It is evident that there is a direct cause-and-effect relationship between business operations, the performance of the business, and the indicators used to measure that performance. The better one understands the underlying plant and business operation, the more successful one will be selecting effective PIs and using them to improve processes or human performance, thereby increasing plant value over time. The maxims are "If you cannot describe it, you cannot improve it" and "The better you describe it, the better your improvement is likely to be." The nuclear power industry could benefit from a logical and systematic approach for describing business/plant operations and processes and their integral interaction with PIs. It also would be beneficial to possess a centralized knowledge repository from which one could monitor the performance of key processes through their respective indicators.

Over the past two years, a portion of the commercial nuclear industry has been exposed to the business operation definition methodology, called the *eXtended Business Modeling Language*™ (xBML). This method has been successfully deployed in complex industries other than nuclear power (as examples, telecommunications, manufacturing, finance and banking, entertainment, federal government, defense, and services).

The xBML method embraces all aspects of a business operation. It accounts for human resources (that is, the "who") performing work (the "what") at a facility location (the "where") at a point in time (the "when") and the information sources (the "which") needed to perform the work. When these aspects (or *dimensions*) of a business operation have been expressed in the xBML format, the relationship between business dimensions and PIs can be graphically represented and understood.

Conventional methods and tools for understanding business operations (for example, flow charts, Visio diagrams, Rummler-Braiche swim lanes, and so forth) address only some aspects of the business operation (usually activities and responsibilities). Therefore, they tend to be limited in their ability to model how PIs can (and usually do) interact with other aspects of the business operation (temporal governance, information availability, locality, and so forth).

The xBML method is based upon a set of definitive and prescriptive rules to aid the practitioner in systematically and repeatedly defining the business operations. This is particularly useful if facilities wish to share and compare business operation models (to foster best practices, promote operational standardization, ensure regulatory compliance, and so on). Because the xBML approach uses the same prescribed common denominator (in this case, the xBML programming rules), business operation data can be shared and understood by all those who apply the rules and symbols of the methodology.

xBML output (business operation and process) models are stored in an accessible and centralized database. This permits sharing models between plants and facilities. The xBML method and structured electronic database of business operations data have two additional capabilities: (1) business data can be formally analyzed (using industry standard business analysis methodologies such as Six Sigma, Cycle Time Analysis, and so on), and (2) PIs can be embedded into the business operation definitions, producing a graphic representation of how each indicator is affected by the business operation.

B.2 Application of xBML in Developing PIs

Figures B-1 and B-2 represent an initial attempt at demonstrating how xBML could be used to depict, associate, and ultimately report the ways in which effective leading BPIs are integrated within the business operation and processes: therefore allowing traceability and analysis of plant performance according to indicator targets and objectives that have been established. Figure B-1 displays an example model of the process to manage emergent work within an xBML “how” model.

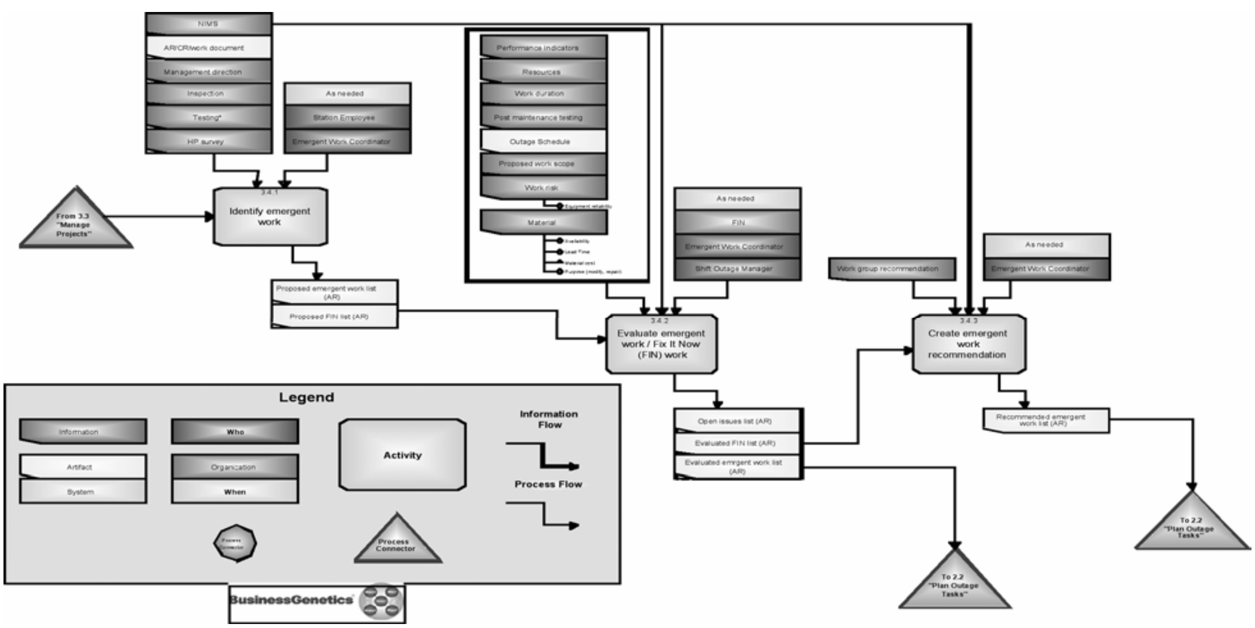

Figure B-1
Example xBML Subprocess Model
Courtesy of BusinessGenetics®

The process diagram shown in Figure B-1 is a small and detailed subset of activities, roles, information, locality, and timeframes that exist within the process *manage emergent work*, which is itself a subprocess within the larger process of *perform nuclear refueling outage*. Figure B-1 is designed to demonstrate how xBML depicts a subset of detailed business dimensions (that is, the what, who, which, where, and when) within the modeled process.

In addition to depicting all of the business process dimensions for any process, xBML can capture PIs and any other relevant metadata in the form of xBML profiles. These profiles can be associated with any and all of the objects in the model and can be used to generate reports from the data collected in these profiles.

Figure B-2 illustrates the activity *create emergent work recommendation* with hypothetical leading indicators to demonstrate how profiles can be customized (that is, by capturing any information one desires to capture) and associated with object within an xBML model.

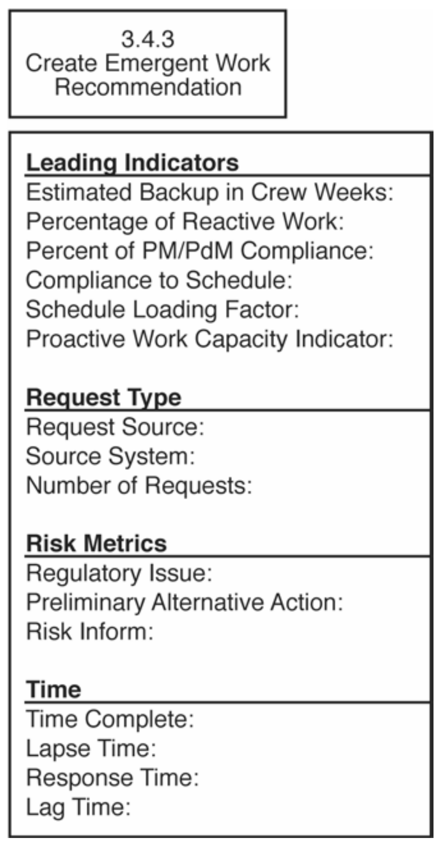

Figure B-2
Example Use of xBML Model to Develop Leading BPIs
Courtesy of BusinessGenetics®

Based on the preceding discussion, it is evident that the xBML method and language provide a structured approach to developing an understanding of the relationship between processes and PIs that warrant monitoring, trending, evaluation, and management action in connection with a plant's performance measurement program. Its application to commercial nuclear power plants to achieve this objective warrants further investigation.

C
EARNED VALUE MANAGEMENT SYSTEM

Organizations that execute good project management practices evaluate approved projects both during implementation and at completion. A determination is made as to the extent to which the assumptions and benefits that went into the business case that resulted in the project's approval have been achieved. Therefore, a useful indicator would be tracking of both planned project performance and expected benefit versus the actual results obtained. In this ideal situation, the performance evaluation component would be through a measure of EV, and the benefit component would be through a measure of NPV. In this appendix, we posit the use of earned value management (EVM) as a useful PI. As discussed in Section 4, EVM provides a measure for an important constituent of NPV—namely, the EV of the project both during the project's implementation phase and at completion. EVM also measures schedule adherence and cost performance. Unlike NPV, EVM does not address the value of a project subsequent to its completion.

C.1 History of EVM

EVM is an accepted method in project management. It has been used extensively for government, military, and commercial industry projects for the past 40 years. EVM emerged as a financial analysis specialty in U.S. government programs in the 1960s and since then, it has become a significant branch of project management in many industries.

The genesis of EVM was in industrial manufacturing at the turn of the twentieth century, but the idea took root in the United States Department of Defense only in the 1960s. The concept was considered overly burdensome and not very adaptable by Department of Defense contractors who were mandated to use it. In 1967, the Department of Defense established criteria for use of EVM, but still the technique was generally ignored or resisted. It was considered a financial control tool that could be delegated to analysts.

By the late 1980s and early 1990s, EVM was being used by the United States National Aeronautics and Space Administration, Department of Energy, and other government agencies. It has emerged as a project management methodology to be understood and used by managers and executives, not just EVM specialists. The construction industry was an early commercial adopter of EVM. By 1998, ownership of EVM was transferred to industry by adoption of the American National Standards Institute (ANSI)/Electronic Industries Alliance (EIA) 748-A standard [21], published in May 1998 and reaffirmed in August 2002. Efforts to simplify and generalize EVM gained momentum in the early 2000s. EVM also received greater attention from publicly traded companies in response to the Sarbanes-Oxley Act of 2002.

C.2 Brief Overview of EVM

Conventional project management practices estimate and track project cost and schedule. During a project and upon completion, performance is measured and assessed by separately comparing cost and schedule to their estimates. Also, because detailed scheduling and cost tracking can be burdensome, they are typically implemented for large projects only.

EVM is a project management technique that objectively tracks the physical accomplishment of work. It is a common framework that combines measurements of planned performance, schedule performance, and cost performance within a single integrated methodology. EVM enhances the conventional method by tracking EV, which is the budgeted cost of work completed to date, and comparing it with *planned value* (PV), which is the cost of work scheduled to be completed to date. The conventional tracked cost of the planned tasks to date that were identified in the project schedule is called the *actual cost* (AC).

EV answers the question "How much work has actually been completed to date?" PV answers the question "How much did we plan to spend as of this date?" AC answers the question "How much have we spent to date?" The project manager periodically identifies every detailed element of work that has been completed and sums the EV, PV, and AC for each of these completed elements. EVM requires the planning, budgeting, and scheduling of work in time-phased increments. EVM implementations for large projects include additional features, such as indicators and forecasts of cost performance and schedule performance. Therefore, it is more labor-intensive than the conventional approach and is normally used only for projects of a value sufficient to make EVM cost-effective. However, EVM can be scaled to be useful even for small projects that do not track project costs.

The key parameters calculated by EVM are variances and performance indices for both cost and schedule, as follows:

Cost variance (CV) = EV – AC

For this indicator, results that are greater than or equal to zero are good; this indicates that the project is meeting its budget targets. Similarly,

Cost performance index = EV/AC

Results that are greater than or equal to zero indicate acceptable performance. Note that because EV is the budgeted cost to date, a high value could mean that the baseline budgeted cost was conservatively high, which in many cases is not good because it could tie up funds that otherwise would be available for other purposes.

Schedule variance (SV) = EV – PV

Again, results that are greater than or equal to zero indicate acceptable performance. And finally,

Schedule performance index = EV/PV

with greater than or equal to zero again indicating acceptable performance. Note that in EVM, schedule and cost must be expressed in the same units (either dollars or worker-hours). Also, these parameters are useful only during the planned duration of a project; after the planned completion date, SV and the performance index are by definition equal to zero and one, respectively. Eventually, the SV will disappear because all the planned work has been completed or earned. However, the measurement of the project's CV is a different matter. The CV consists of the EV achieved less the actual costs consumed to obtain the EV. The CV is the more critical of the two relationships because poor cost performance is normally non-recoverable for the work performed. If one overruns the costs for completed work, it will likely not be offset by performance on subsequent tasks.

The limitations of EVM include the following:

- The need to carefully predict and control its implementation cost lest it outweigh the benefits obtained.
- There is no provision for measuring quality (EVM is only one tool in the project manager's toolbox).
- It requires that projects use a project-ready accounting system and a suitable scheduling system. In practice, the collection of accurate and timely AC data can be the most difficult aspect of implementing EVM.

According to the definitions in Section 2, cost and schedule indices should be viewed as leading indicators for project performance and upon project completion, as lagging or leading indicators of plant value. Note that both project and plant NPV decrease directly in proportion to the final EVM's CV. Also, the final actual cost of a project should include any cost penalty associated with a schedule overrun, such as impact on the cost of O&M, plant generation, or other planned projects.

Although cost and schedule EVM parameters during a project are useful chiefly as leading PIs for a project manager, they could be aggregated for all projects in a portfolio as a leading indicator useful to plant management.

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California; Charlotte, North Carolina; and Knoxville, Tennessee, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together...Shaping the Future of Electricity

Program:

Nuclear Power

Printed on recycled paper in the United States of America

1013488

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com