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Risk and Spare Parts Inventory in Electric Utilities

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Abstract

With deregulation, utilities in the electric power sector face a much more urgent imperative to emphasize cost efficiencies as compared to the days of regulation. One major opportunity for cost savings is through reductions in spare parts inventory. Most utilities are used to carrying large volumes of expensive, relatively slow-moving units because of a high degree of risk-averseness. In this paper we discuss risk in the context of utilities, with a focus on nuclear power, and overview an ongoing research project that is aimed at incorporating risk and costs into a quantitative decision analysis framework for controlling spare parts inventories.

Keywords
Electric utilities, risk, spare parts inventory

1. Background

For many years, utilities in the United States were regulated entities. In the early twentieth century, as the necessity and popularity of electric power grew, local governments in the United States passed laws governing franchise rights for distribution of electricity. These laws allowed a single company to enter a geographical area, set up a production and distribution system, and serve homes and businesses. In return, the utility would receive a fair profit and the reassurance that another company would not enter the area and undercut its sales and investment in infrastructure. At the time, the government recognized that safe and reliable delivery of electric power was becoming a necessity in American homes and businesses, and that the utility had the "obligation to serve every home" [1].

Electric utilities became vertically integrated, meaning that one company handled all generation, transmission, distribution, and service functions and received one stream of revenue from the sale of electricity. This revenue was negotiated with the public utility commission (PUC) of the state in which the utility operated; as a result, the rate was set so as to cover the cost of business, plus an agreed upon rate of return (ROR), or profit [1].

These regulated monopolies helped to develop and expand the widespread use of electricity in the United States. However, once the system became established, regulation gradually came to be viewed over the years as preventing lower prices for customers, because incentives to reduce costs did not exist [1, 2]. In essence, the negotiated rate covered the company's total costs and included their profits as well. Thus, becoming more efficient or reducing costs were not necessarily major priorities for established utility companies. Deregulating the industry and separating generation, service, transmission, and distribution were thus seen as ways to improve the operating efficiencies of the industry [1]. In recognition of the fact that some entity had to bear the obligation to service the citizens' rights to power, an agreement was reached that distribution and service would remain regulated so as to ensure that all customers would receive power.

Therefore, generation became the competitive portion of the business; no longer could companies be guaranteed a full recovery of costs plus a negotiated profit. Generation companies had to begin operating like American companies in any other industrial sector. The first steps were actually taken as early as 1978, when Congress passed the Public Utility Regulatory Policies Act which laid the groundwork for deregulation and competition. However, the real shift to deregulation began in 1992 with the passage of the Energy Policy Act to promote greater competition in the bulk power market. California, Pennsylvania, and Rhode Island were among the first states to

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pass deregulation legislation in 1996 [3, 4]. Almost half of all states and the District of Columbia had or were planning deregulation legislation by mid-2001 [2, 4], and today, there are ten major electric power markets in the United States to service demand.

The authors have recently commenced on a research project where the objective is to study how cost structures in one major area, namely spare parts inventory, are related to risk and uncertainty, and to develop a quantitative model that relates the two; the goal is to incorporate these models into an appropriate decision support system for optimally controlling these inventories. Preliminary work is ongoing with a large electric utility that has a variety of power plants (fossil, hydro, nuclear, etc.) and is very representative of the overall power sector. In this paper we present a discussion on the issues involving spare parts and risk in electric utilities and provide an overview of our research direction.

2. Deregulation and Spare Parts

Under regulation, costs of purchasing and holding spare parts inventory to service power plants and energy delivery (distribution) were recovered in the rates charged to customers, as part of the cost of doing business. Companies operating in this environment had no incentive to reduce operating costs, including spare parts inventory, and therefore purchased and held spare units of parts that were perceived as being needed to keep the utility running, or from a safety standpoint. The latter was especially true in nuclear power. While the companies' spare parts philosophy centered on safety and very high plant reliability, the associated costs of such a policy, which are quite substantial, were generally ignored because these costs could simply be passed on to consumers. Once deregulation became effective, the business environment changed and costs related to spare parts now had to be financed from revenues. This has led to a need for both significantly more efficient spare parts management policies and processes and companies to rethink the way they manage not only spare parts, but all assets associated with power generation.

However, process reengineering with respect to spare parts has not been an overnight success for companies. A majority of the United States electric utility workforce is comprised of employees with many years of experience. In fact, depending on the utility, eleven to fifty percent of the workforce is eligible to retire within the next five to ten years [5]. These employees have been challenged with both the cultural shift and the change in business philosophy in a deregulated environment and have had to rethink and change the way they do their work. This situation presents a major conflict between both inventory carrying costs and the costs and risks of not having spare parts in stock when needed. Ramifications of not having a part in stock include the possibility of having to reduce output or quite possibly, even a plant shut down. From a more long-term perspective, doing so might interrupt the critical service of power to residential, commercial, and/or industrial customers, while damaging the company's reputation, reliability, and profitability. An electric utility makes and sells only one product: electricity. Losing the ability to sell electricity can be seriously damaging to the company's bottom line as well its long-term viability. However, the holding costs associated with carrying millions of dollars worth of slow-moving spare parts is also damaging to the bottom line, tying up resources that could be used for other company needs and projects.

A further complicating factor is that many mergers and acquisitions have occurred recently in the utility industry. This trend can be attributed to rising fuel prices, costs of upgrading systems, and to mechanisms of growth [4]. As an example, there were 331 deals across the United States and Canada in 2003 alone. In 2000, mergers in the power sector were valued at $74.9 billion [4]. Each merger creates the potential for a clash of cultures and businesses, and results in companies having to learn to operate not just in a new, deregulated business environment but also as a merged entity, which is a challenge and not a common occurrence. Specifically, in a merger, larger strategic issues take precedence over operational processes such as control of spare parts inventory. The management issues related to spare parts inventory are compounded in these situations with mixes and shifts in corporate culture. Now, more than ever, utility companies need strong processes and policies that promote lean and total quality management of spare parts inventory. A major component of these processes are inventory management models for spare parts inventory that address demand, requirements, and risk so as to provide decision support for management. Companies have attempted to implement some relatively new systems to handle spare parts, but these have been developed in and designed for the era of full regulation; thus, they may no longer be optimal or appropriate. Models designed for the deregulated era will help companies ensure the delivery of the right types of inventory in the right amount at the right time, helping them adapt to and excel in their new competitive business environment. In this paper we focus on a specific aspect of spare parts inventory, namely risk, and one particular sector namely nuclear power, in order to elucidate some of the major issues involved in developing a suitable inventory control system.

3. Risk

Risk is inherently subjective and socially construed [6, 7]. Furthermore, risk involves unacceptable consequences with very high costs that no entity wants to pay; this distinguishes it from traditional cost-benefit analysis [8]. There are two major components to risk. The first is the personal risk that employees perceive to themselves and the facility at which they work; these obviously play a role in spare parts management because ultimately, it is the employees who make the decisions to perform maintenance work, buy parts, and set part stocking levels. How they perceive the effects of their decisions in these areas influences the decisions that they make and ultimately affect the spare parts inventory at the facility. Second, the general public perceptions of risk also play a role in spare parts management. In particular, when it comes to nuclear plant operations, the nature of nuclear power and how people perceive it lead to extra diligence to prevent any plant issue, no matter how minor. This in turn leads to a large reliance on the insurance provided by spare parts on-hand. The following subsections address these two aspects of risk—personal and public.

3.1 Employee Level of Risk

The first area of risk involves employees and the outcomes of their behaviors and decisions. Employees can have large access to and autonomy in making inventory control decisions such as stocking levels, SKUs to order, order quantities and order/delivery dates. Each action yields a buy/no-buy decision that ultimately affects inventory levels and policy for spare parts management. Spare parts can be especially crucial in the nuclear power industry; in a worst case scenario, the lack of availability of a part can lead to an accident-prone situation, a plant ***derate*** (operation at reduced electric power output to improve safety/reliability) or in the worst case, a plant shutdown. Therefore, it is essential for employee behaviors relevant to perceived risk to be factored into spare parts ordering policies for electric utilities, because actions of power plant employees have consequences related to the actual risk to which they are exposed [9]. Clearly, both under and over estimations of risk can have negative effects [9].

However, perceptions of risk in the power sector have not been extensively studied from a rigorous, research perspective [9, 10]. Three relevant papers that have examined the perceptions and behaviors of employees in the nuclear sector are [9 – 11]. Sjöberg and Sjöberg [9] examined risk attitudes and risk assessments in nuclear power workers and their connections to radiation and related risks. As part of this study, the authors examined the effects of personality and job function, and the relationship between risk perceptions and job satisfaction. They looked at a large sample of employees, mainly at the maintenance level, through semi-structured interviews and a follow-up survey. Such techniques were chosen because the authors argued that standard procedures for assessment did not exist. The results showed that risk perceptions varied depending on the different definitions that employees gave to risk. These definitions were not dependent on work group, but differences were apparent based on exposure to controlled areas (i.e., protected areas of high radiation where a special suit is required to be worn to enter the area; United States federal guidelines limit the exposure to radiation per year [12]).

Sjöberg and Sjöberg [9] also found that employees with weak self-confidence and high anxiety judged job risks to be higher than other groups. Furthermore, an inverse-U relationship exists between risk of general accidents and job risk. Employees who perceive job related and nuclear risks to be low also rank other, more general risks to be low. On the other hand, employees who perceive job related and nuclear risks to be high and are more anxious *also* rank other, more general risks to be low because these risks do not seem to be as significant as nuclear related risks. A plot of these perceptions thus takes an inverted-U shape.

Kivimäki and Kalimo [10] examined risk perception of nuclear workers in comparison to workers in non-nuclear and power industries, as well as the relationship between risk attitudes and well-being / organizational commitment. The authors used a Likert based survey at a nuclear plant in Finland and found that perceptions of an accident were strongly related to organizational commitment and slightly related to job satisfaction. The authors note that it is essential to recognize which attitudes affect performance, as errors can have large negative consequences.

Kivimäki, Kalimo, and Salminen [11] extend the results in [10] in a second paper that examines safety perceptions and the relationship with organizational commitment (OC) and its components: OC-acceptance, OC-willingness, and OC-desire. OC-acceptance is traditionally defined as acceptance of the organization's goals and values; OC-willingness is the willingness to put forth effort on the organization's behalf; OC-desire is the desire to remain with the organization [11]. The authors argue that senior management must constantly balance safety and financial goals with owners, and regulatory, economic and public stakeholders. The authors propose that employees who do not agree with or trust the balance between safety and economic goals will judge risk to be higher. They found a correlation between OC-acceptance and appraisals, or employees' perceptions of the effectiveness and competence of top management. They also found the correlation between perceptions of risk and OC-acceptance to be lower and the correlation between perceived risk and OC-desire to be higher among managers. Such a result suggests the existence of two cultures in the organization—one comprised of management and another of traditional employees. These cultures have differing views of perceived nuclear risk, OC-acceptance, and OC-desire. As a result, higher managers must lead a group of employees who may have differing views of the organization and values. Higher managers are important in promoting a safe environment, especially because Kivimäki, Kalimo, and Salminen found a strong link between perceived nuclear risk and appraisals of management [11]. This result is especially important because this research proposes that managers play a large influential role in promoting a risk-averse (and therefore high) safety culture. Such a culture can greatly impact the spare parts ordering policy in effect at a utility.

In sum, the research shows that employees and their perceptions play a role in the work environment. Therefore, in a complicated system such as spare parts management, with lots of inputs and decision makers, the established concepts suggest that employees may play a role in policy implementation. Consequently, their perceptions and behaviors are important to manage for overall policy optimization. The research also presents a detailed look into perceptions and behaviors of nuclear employees, providing insights into a group that has been underrepresented in research.

While the above studies do not specifically address spare parts, the idea of a nuclear accident can be readily extended to the possibility of an undesirable situation arising from improper spare parts management. Nuclear energy has a work subculture that is consistent among utilities, so it is not unreasonable to extend the results established for the European plants to those in the United States. Results regarding behaviors such as managerial influence, risk perception, and attitudes are relevant to consider in building a dynamic and robust spare parts inventory management policy. Therefore, a research need exists to extend these ideas to spare parts inventory and validate relevant concepts for United States nuclear facilities.

3.2 Public Perceptions of Risk

Nuclear energy plants have safety cultures, which Harvey, et al. [13] cite as having no clear definition, but nonetheless constituting a key predictor of safety performance. The objective of safety is paramount in the nuclear industry, and consistently takes precedence over the business bottom line in decision making. Kivimäki and Kalimo [10] propose that nuclear organizational commitment may improve production safety and reduce the probability of a serious accident. Yule, Flin, and Murdy [14] cite a study where worker perceptions of management commitment to safety were associated with low accident rates. However, public perceptions are different from workers with respect to safety and are independent of both the inspection certifications from the United States Nuclear Regulatory Commission (NRC) and demonstrated safe operation of plants.

Historically, the general public perceives nuclear energy to be more risky than other forms of energy production [15]. Mullet, et al.'s [15] study of eighty university students found that the students ranked nuclear energy to be the most risky - regardless of the production process - when compared to eight other forms of energy, namely wood and biomass, coal, gas, oil, water, wind, geothermal, and solar. The lowest risk rankings were attributed to wood, coal, and solar technologies. Mullet, et al. [15] also cite multiple studies that rate nuclear power as having high risk; in particular ten of thirteen reviewed studies found nuclear to be the highest in terms of risk. Thomas [7] conducted a survey in Austria regarding public perceptions of the risk and benefits of energy. The author found that those against nuclear energy perceived it to lead to environmental, indirect (future and political), and psychological and physical risk. The beliefs of the public were found to be underestimated by a control group of policy makers and experts on nuclear power. The results reflect the argument put forth by Slovic [6] that the public has a broad conception of risk and that experts' risk perception are not related to the underlying dimensions of risk. Furthermore, risk conflicts result from conceptual differences between the public and experts. Slovic [6] argues that experts and the public disagree because both groups have different definitions of risk, worldviews, affective experiences/reactions, and social status. This dichotomy breeds a culture of distrust, causing the public to reject experts' risk assessments [6].

Even small issues and situations at a plant feed into the public's perception of nuclear energy. Slovic [6] argues that distrust exists between the public, industry, and risk-management experts. As a result, the public may perceive that small, routine plant issues are actually more serious than what is reported by the company. Furthermore, the trust between the public and industry is easily destroyed in that negative events are more salient and carry more weight than positive events. Such events need little credibility to be considered true, and, once distrust begins, it tends to be reinforced and perpetuated [6]. For events with extreme negative consequences, the possibility of such an event becomes salient, and small probabilities have great weight in people's perceptions [16]. Furthermore, the public is often difficult to educate on scientific concepts and facts [9], and risk and benefit become negatively correlated in their minds [16].

In general, employees might not perceive a situation to be as risky as the general public. In particular, nuclear personnel do not perceive nuclear risk to be a serious problem when compared to the public [11]. Kivimäki and Kalimo's [10] study found that plant workers estimated less likelihood of a serious accident and felt that plant safety was better when compared to a random sample of the Finnish population. However, even among employees, two safety cultures exist. Yule, Flin, and Murdy [14] found that perceptions of supervisors and management influence perceptions of commitment of senior managers by employees and argue that supervisors can have a negative impact on the safety climate by applying too much pressure on workers. Harvey, et al. [13] argue that safety culture is conceptually different for various groups of workers, especially between managers and shop floor employees. Furthermore, the authors cite that accidents can result from the existence of two separate cultures and that latent organizational failures will always drive actual individual errors [13].

Translating these ideas to spare parts, it becomes evident that lapses in ordering judgment by employees are probably indicative of a poor inventory management policy enacted by the company and/or a lack of understanding of the entire ordering process and its corporate and operational impacts by the employee. This misunderstanding or error may also stem from the employee's dedication to the nuclear safety culture without concern for the company's overall bottom line and sustainability. In an extreme case, the absence of a spare part when needed for equipment breakdown may lead to a plant accident, so considering both public and employee perceptions of nuclear safety are important when developing a sustainable spare parts inventory management policy. Nuclear accidents have high consequences but low probability of actually occurring, given that appropriate practices and NRC guidelines are followed in the plant. No one wants a nuclear plant meltdown or near miss, and this extreme outcome feeds into the spare parts ordering policies. Furthermore, the business' bottom line was ignored under regulation because monetary return for relevant operating expenditures, including spare parts, was guaranteed. This mentality carries over into current policies and is coupled with the avoidance of risk to maintain safety.

4. Research Focus

The focus of our overall research is to develop quantitative models of the risk of plant system failures that are based on both the internal (employee) and external (public) estimates of risk, and to then incorporate them with economic factors in order to develop an overall decision support system. Generation revenue losses can result when a plant system fails, causing a derate or possibly, a complete shutdown. If a spare part is not available to fix the issue, further losses result because the plant is off-line for a longer period of time. Losses can also extend beyond revenue; derate/shutdown of a plant can affect a company's stock price and bond rating, based on the public's perceptions of nuclear power. Furthermore, system failures can cause a limited condition of operation (LCO), which leads to a shutdown if the system is not repaired in a required timeframe. Understanding probabilities of individual as well as aggregate system failure and the resulting losses associated with failure will help to discern which components become critical from a business case perspective, thus influencing stocking levels and service rates of the related spare parts. Our approach is aimed at building decision trees to map out systems, probabilities, and potential losses. Results can then be presented to senior management to assess preferences to different scenarios and to develop a utility function based on their responses. Such knowledge can then be used to develop a new spare parts inventory management policy that minimizes costs and losses while maintaining proper plant management.

The overall tradeoff emphasized in this research is to balance safety of nuclear operations with cost. A plant's safety can be maintained or possibly even improved with an appropriate spare parts inventory management policy. Understanding which parts to stock and when to stock them can lead to reduced operating costs without sacrificing safety, causing the plant's management to be better prepared in the event of a system failure. Furthermore, the implications of a nuclear plant being taken off-line extend beyond the company operating the plant. Nuclear plants provide baseload generation in the United States, and removing a plant's output from the electric grid reduces available capacity, which in extreme cases can lead to blackouts. Blackouts cause customers inconvenience and possibly endanger their health, based on the current weather conditions, duration, and customers' medical conditions. They also affect the entire electric industry, beyond the generating company operating the plant, and can cost millions of dollars. Therefore, continued safe operation of nuclear plants is critical for the overall supply and availability of electricity in the United States.

The authors are examining these issues and developing corresponding models using data from a currently operational nuclear plant belonging to a Fortune 250 United States corporation in the utility industry. The intent in the research is to improve bottom-line performance and business practices with respect to spare parts management in the generation operating company while maintaining the plant's safe operating conditions. The authors aim to balance these concerns in the research and provide a model for companies to use to improve their businesses and ultimately benefit their customers. The research can also potentially be expanded beyond the United States nuclear industry, as countries expand or develop nuclear power programs, allowing spare parts management systems to be designed correctly the first time.

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