DECISION MAKING AND TRADEOFFS IN THE MANAGEMENT OF SPARE PARTS INVENTORY AT UTILITIES

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Abstract
During the past decade, the United States electric utility industry has migrated from a regulated to a deregulated business environment. As a result, 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 accustomed to carrying large volumes of expensive, relatively slow-moving units because of a high degree of risk-averseness. In this paper we discuss the tradeoffs associated with keeping large amounts of inventory versus the potential revenue losses if a plant were to go off-line. We also discuss the resulting considerations with respect to inventory along with forecasting techniques and data needed to aid plant managers in making stocking decisions.

Key Words
Electric utilities, risk, spare parts inventory, forecasting, deregulation

Introduction

Many United States utilities are transitioning from a regulated to a deregulated environment. In fact, some form of regulation is currently in place in twenty-three states and the District of Columbia (Quantum, 2009). Deregulation was proposed in response to the high costs of power that were traditionally passed to the ratepayers. Under regulation, utilities set their rates to recover their costs of doing business, plus a rate of return (ROR) approved by the state's public utility commission (PUC) (Philipson and Willis, 2006). This system of cost recovery and the subsequent risk transfer to ratepayers provided little or no incentive for utility companies to operate efficiently and minimize costs (Lave et al., 2007).

Once state legislatures began deregulating electric utilities, cost recovery was no longer guaranteed for the now competitive generation aspect of the business. Distribution and transmission remained regulated to ensure that all customers have access to power. Electricity generation companies now had to operate like other traditional United States industries and businesses (Scala et al., 2009). This lack of guaranteed cost recovery extended to spare parts at the generation plants. Before deregulation, companies bought and stored parts with little regard to costs. Now, after deregulation, inventory levels are at an all-time high, and, as a result, companies need new methodologies and business practices to operate competitively and efficiently with respect to spare parts as processes and policies in use were, for the most part, designed for the era of regulation (Scala et al., 2009).

The authors are involved in a research project to examine spare parts inventory and to develop quantitative models that balance the tradeoffs between cost structures and related inventory-related risk. An example of inventory-related risk is the revenue loss associated with plant shutdown or de-rates (operation at reduced power output levels) if parts are not available when needed (Scala et al., 2009). In this paper, we discuss the limitations of current industry spare parts management policy, the data collected for analysis, forecasting methodologies for spare parts associated with electricity generation plants, and a preliminary analysis of cost tradeoffs of holding / not holding inventory.

Background

The essence of the spare part problem can be better understood by examining a specific instance. For this ongoing research, we consider a United States electric utility that holds coal, nuclear, and hydroelectric power generation assets as well as transmission assets and distribution companies. Spare parts inventory at generation facilities is at an all time high (despite deregulation), and incremental creep in both dollar value and the number of parts held has occurred for the past few years. The situation is especially prevalent at nuclear facilities, even though an ordering and management process is in place for spare parts. The nuclear industry utilizes a twelve week schedule when ordering, staging and preparing parts for plant maintenance. Presently, as soon as maintenance work is scheduled in the plant, parts are ordered for the job. This occurs approximately twelve weeks before the actual work is scheduled to begin. During this lead time, the maintenance job is often pushed back or rescheduled due to manpower constraints, urgent fixes for plant safety, budgetary restrictions, etc. However, the parts typically have already been ordered and shipped from the supplier. Compounding this situation, additional parts are typically ordered as part of a maintenance request, in the event the actual job is bigger and more comprehensive than originally expected. For example, a leaking valve might cause a whole new valve to be ordered, in addition to components of the valve. The uncertainty with respect to the size of the job can also often be attributed to nuclear safety issues; the company does not want to inadvertently send technicians into containment or high radiation zones unless absolutely necessary, as the United States federal requirements limit the amount of radiation exposure that employees may receive each year (NRC, 2008). In summary, there is significant uncertainty associated with the complexity of the maintenance.

Cultural issues also contribute to over-ordering of parts. The company wants to keep the plants safely online as much as possible and greatly prefers that (planned) outages only occur every eighteen to twenty-four months for refueling. As a result, extra parts typically are ordered to be ready for anything the technicians might encounter while completing maintenance work and running the plant. Therefore, excess parts pile up in inventory, and the problem is compounded by the fact that most parts ordered are unique to the plant and cannot be returned to the vendor.

While some aspects of the situation just described could be addressed internally as a series of operational process initiatives, there is a more strategic issue underlying the situation; namely, that the company needs to better understand which parts need to be ordered in the first place, and in what quantities and at what points in time. Currently, the company is unclear as to whether spare parts demand can be quantified so as to reflect risk as well as part requirements, in order to develop optimal ordering processes and policies. As a result, a need exists to develop a decision support tool for spare parts. This tool must balance costs against the risk of stock-out and related implications if the part is not available. Considerations must include the cost of ordering the part, the cost of holding the part in inventory, equipment life, scheduled preventative maintenance, planned equipment obsolescence, current conditions of plant equipment, etc. Overall, the availability of the plant and its output must be balanced against the demand for electricity and the plant's capacity; and having access to a reliable and robust model that handles all relevant factors will help companies make better informed decisions in spare parts management.

One aspect of potential improvement to the utilities' spare parts management process is a better understanding of spare parts demands. If companies can understand when they will need parts, then they can plan accordingly to promote just-in-time delivery and minimal inventory. Currently, work orders trigger the companies' reaction to demand for spare parts. Work orders can be issued for preventative maintenance, refueling outage-related work, or emergent issues (something breaks when the plant in on-line). Work orders typically list requests for more parts than what is actually needed, due to the cultural and containment-related issues outlined previously. However, work orders are triggers of demand and cause purchase orders to be generated for procurement of parts from the vendors.

In order to examine the current spare parts ordering policy and process at the case study generation facility, we selected a sample set of components and related parts that could lead to a plant de-rate (reduction in power output) or full shutdown in the event of failure. This set consists of 6 components and 62 parts. These types of parts are most critical to analyzing the current spare parts management policy because they have the potential for causing a significant loss in revenue if they were to fail without a replacement part being available in current inventory; such a situation would cause the plant to de-rate or shutdown to ensure safe plant operations.

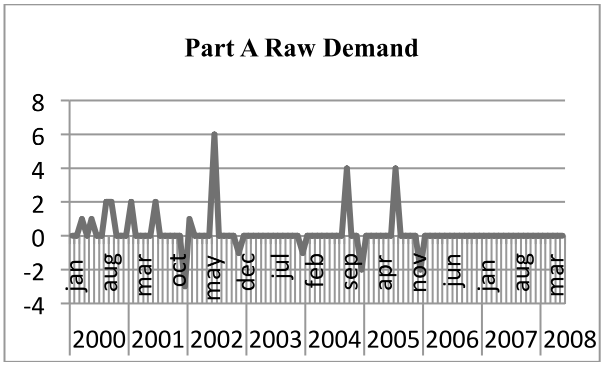
Data Collection

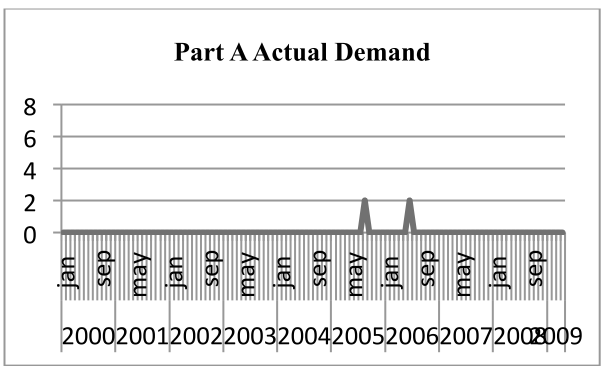
The authors collected demand and purchase order data for the parts in the sample set. At first review, the parts appeared to have relatively frequent activity over the six year historical data timeframe based on data from the parts storage warehouse. However, upon detailed examination, the authors found many instances of parts requested by the plant and then returned unused to the warehouse at the completion of the work order, thus providing evidence of over-ordering and/or overestimation, and of the fact that issues exist with the current spare parts inventory ordering process.

Each demand signal for parts was then tied back to its original work order and part traveler data to determine which demands resulted in actual consumption of a part by the plant versus a return to the warehouse. Results from this analysis indicated that few actual demands occurred over the six years of historical data and that the spare parts demands were quite sparse and intermittent when compared to the raw data from the warehouse. See Exhibit 1 for an example of raw demand data versus actual demand data tied to work orders for a particular part. The raw demand data depicts the part demands that were both consumed by the plant and returned to the warehouse; the actual demand data depicts the only the parts consumed by the plant and not returned to the warehouse.

The reason the parts were demanded is also central to the spare parts analysis. In general, parts could be demanded for emergent issues, preventative maintenance, or refueling outage related work.

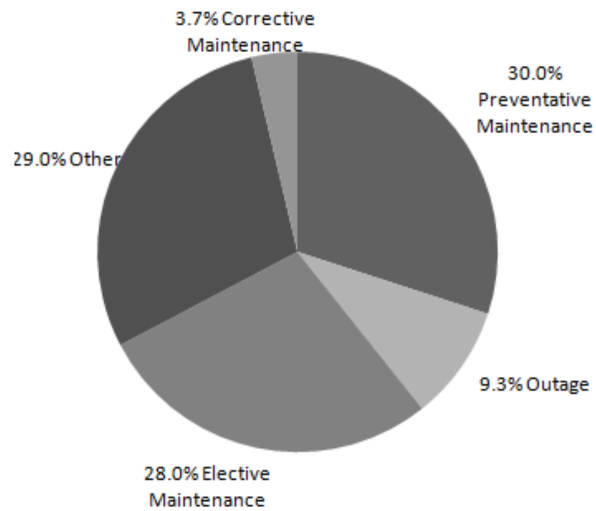
Exhibit 1. Raw Demand versus Actual Demand for Part A.





Cleansing the data and examining work orders was important to this research because of the noise from the high return rate at the warehouse. Once the data was analyzed, it became apparent that much was hidden in the raw data. Very little actual demand existed in the historical data, with even fewer corrective actions. The work order and actual demand analysis showed that only 3.7% of the demand was for corrective actions in response to situations which placed the plant in a compromised state and could have led to a plant shutdown or de-rate if not immediately remedied. Approximately 30% of demand was for preventative maintenance work, 9.3% for refueling outage, and 57% for corrective maintenance projects that did not compromise plant operations. See Exhibit 2 for a pie chart of reasons for demand. Clearly, the company is engaging in over-ordering, which is most likely related to the abundance of false demand signals as evidenced by eventual returns to the warehouse. This excessive purchasing leads to a backup of parts in inventory. As a result, examination of the root cause of the suboptimal inventory policy using the actual demand data is essential for the development of an improved policy. Clearly, situations in which the plant might potentially have to shut down or reduce output are rare; most parts requests are typical and can be scheduled and planned for with an improved ordering and forecasting process.

Exhibit 2. Pie Chart of Reasons for Demand.



On the other hand, given the tremendous costs associated with plant shutdowns or de-rates, utility companies cannot simply ignore atypical demand. Rather, they need a better understanding of costs related to holding and managing inventory and how these costs are related to the level of risk that the generation companies can tolerate. Such knowledge can lead to optimal management of costs, tradeoffs, and risk, while maintaining safe plant operations.

Forecasting

The first step in analyzing the true demand and receipt data was to develop a forecast for parts requirements. A traditional exponential smoothing forecasting method was first considered for the raw data. However, the fit was rejected because the forecasts lagged a few periods behind the actual demands. The lag in the forecast is due to the intermittent nature of spare parts demands. Furthermore, the high return rate skewed the models as traditional exponential smoothing methods typically do not have negative demands (Wilson and Keating, 2007). Clearly, alternate forecasting methods are needed for this data.

The authors are currently considering forecasting with models designed for intermittent demand, such as

Croston's method (Croston, 1972). The software package CELDi (Center for Engineering Logistics and Distribution) Intermittent Demand (CID) forecaster is designed for forecasting such demands, using various methods including Croston's method, the Syntetos and Boylan method, and the Average Demand method (Medal, et al, 2009) and is currently being evaluated for use with this data. Methods for intermittent demands are important to consider because these methods are specifically designed to handle periods of zero demand interspersed with periods of positive demand. In particular, Croston's method employs separate sets of parameters for tracking periods of zero and positive demand and generalizes to exponential smoothing if no periods of zero demand exist (Croston, 1972). Examination of these methods will determine if the fit of the data to the forecast can be improved. A better understanding of the feasibility to forecast such demands is essential to the model development.

Overall, using an intermittent demand forecasting method, such as Croston's method, can yield a better forecast than a traditional method, and the authors are currently exploring the use of the method. Such knowledge can improve general ordering policies and processes related to parts usage for preventative maintenance or planned outages. However, the probability of a corrective issue or part failure should also be considered to improve the reliability of the model. Ordering policies and processes can benefit from better lead time management, especially given the fact that lead times in the nuclear power sector can be significant. Understanding the need for parts during the lead time can help analysts and buyers plan purchases to prevent expediting of and scrambling for parts if demand should arise during lead time, thus lowering overall purchase costs. A forecast for demand can also lead to better understanding of equipment failures and replacements. Overall, a clearer understanding of parts usage contributes to identification of improvement opportunities and promotes improved process management.

While forecasts specify the timing and quantity of demand, they do not identify the specific reason for the demand. Elective maintenance, preventative maintenance, and outage related work can be scheduled and planned. Emergent corrective maintenance involves a failure of a part that requires immediate attention. Such situations are limited, and a forecast would not identify corrective versus non-corrective situations – just overall demand. There are not enough corrective demands in the data to seed a forecast based on correctives alone, and an overall forecast of all demands would lose the complexity of reason for demand, as the forecast would_predict a demand only and not the reason for it. Knowledge of failure rates, component useful lives, and maintenance rules is needed to better predict potential corrective actions in an effort to distinguish the need for immediate unplanned parts. Because failure rate data does not exist at the part level and is incomplete at the component level, the authors are currently examining methods, including fuzzy logic, to mitigate and quantify such information. Fuzzy logic quantifies the imprecision and uncertainty of subjective data (Mendel, 1995) and may be beneficial when incorporating the experiences and accumulated knowledge of maintenance technicians and engineers. Such specifics can improve the understanding of failures and potential reasons for parts demand, leading to process efficiency and improved spare parts management.

Cost Tradeoffs

Because of the potential for emergent situations and subsequent immediate parts demand, there is a need to clearly understand the cost consequences of not having parts in stock. An analysis based on this helps to identify potential revenue losses if the plant had to be off-lined or de-rated. These revenue losses are tied to the purchase of replacement power. Traditional manufacturing firms may delay a shipment in the event of a stockout or off-lining of a production line. However, no such option exists in electric utilities, as power demand and production must be constantly balanced. If demand exceeds production because of the loss of a baseload electricity plant, it can lead to a blackout in an extreme case, depending on the weather and the condition of the electric grid (Scala, et al., 2009).. Blackouts are unacceptable and could potentially endanger customer health (Scala et al., 2009). At a minimum, even with no blackouts the loss of a baseload plant causes more expensive peaking plants to begin to run in order to replace the power, thus driving up the hourly cost of power and locational marginal price (LMP) at the hub on the electric grid where the off-lined plant is located. Higher LMPs imply higher purchased power costs and more expensive power for customers, especially those on real-time pricing rates. In fact, all customers would be affected by higher rates if state PUCs approve real-time pricing (RTP) for electricity rates. Some cities and states have already adopted RTP programs, including Georgia, Chicago, New York, and Florida (Borenstein, 2009).

Clearly, generation companies pay a premium to use an alternate source of power. The value of this power is dependent on the grid conditions, transmission congestion, weather, current demand, time of day, etc. Therefore, the cost of replacement power can vary, but averages have remained rather steady over recent years. An analysis of day-ahead LMP data for PJM Interconnection's Western Hub (data available from www.pjm.com) from April 2005 to mid-June 2009 shows average prices holding steady; the 95% confidence interval limits are within approximately one dollar of the averages. See Exhibit 3 for summary statistics of the Western Hub data. Summer months are June, July, and August. Winter months are December, January, and February. Shoulder months are all remaining months of the year.

Because confidence intervals for costs are tight, companies can use the average values as a proxy in planning for potential costs of purchased power. The current United States economic recession has driven power prices lower than the current averages, and as a result, companies today might incur less of an impact if power is needed. Nonetheless, procuring emergency purchased power will in general involve a significant amount of resources and revenue loss, regardless of economic conditions.

Exhibit 3. Day-Ahead LMP Summary Statistics.

Onpeak

	Minimum LMP	Average LMP	Maximum LMP	Variance	St. Dev.	Lower 95% CI	Upper 95% CI
Summer	$ 27.17	$ 83.96	$ 369.39	1791.80	42.33	$ 82.74	$ 85.17
Winter	$ 23.62	$ 66.59	$ 225.00	667.58	25.84	$ 65.79	$ 67.39
Shoulder	$ 26.13	$ 64.77	$ 199.78	515.54	22.71	$ 64.30	$ 65.25

Offpeak

	Minimum LMP	Average LMP	Maximum LMP	Variance	St. Dev.	Lower 95% CI	Upper 95% CI
Summer	$ 3.51	$ 49.35	$ 256.68	787.90	28.07	$ 48.59	$ 50.11
Winter	$ 18.99	$ 51.64	$ 203.31	478.59	21.88	$ 51.01	$ 52.27
Shoulder	$ 3.25	$ 43.43	$ 160.00	361.76	19.02	$ 43.06	$ 43.80

Overall, purchased power costs tend to be much more substantial than carrying inventory, once part lead time and repair time are factored in. However, few part demands are tied to a situation where plant output can be reduced. In general, generation companies believe that spare parts inventory is protecting plant safety, but in reality, the inventory covers the risk of a revenue loss. Nuclear generation plants must be operated safely to maintain United States Nuclear Regulatory Commission (NRC) approval and remain in operation. Many automatic controls are in place to shut down the entire plant without human intervention in the event of a compromised situation. The probability of a catastrophic situation is extremely low, and the controls help to prevent an accident. Therefore, in essence, holding inventory covers the risk of revenue loss from off-lining the plant. Elective maintenance, preventative maintenance, and outage related work can be scheduled with parts arriving just-in-time. Inventory, would only need to be held to hedge against a corrective action requiring immediate attention.

Conclusions

Overall, through the research, the authors are developing a framework for companies to understand their spare parts inventory costs and potential costs if parts are not available when required. The risk of revenue loss is central to the methodology and is tied to the probabilities of equipment failure, leading to a corrective action. Considering spare parts management at generation plants, especially nuclear plants, in terms of revenue loss is to our knowledge a new concept. Under regulation, costs of doing business were recovered in customers' electricity rates; optimally managing costs were not of particular concern, especially in the name of safe plant operations. However, safe operations are not dependent on spare parts inventory. Understandably, generation companies prefer to keep nuclear plants running once synched to the electric grid because the marginal operating costs of the plants are relatively low, compared to the LMP prices at which the power can be sold. These plants return a large profit, so companies prefer to reduce power only for refueling outages, as long as safe operations are maintained.

However, a better business plan may allow for the possibility of some small de-rates or power reductions to conserve capital and dollars currently tied up in spare parts inventory. At a minimum, companies need to refresh their thinking about operations in a deregulated environment versus the cost-covering regulated environment. The authors' research addresses these issues and opportunities. In conclusion, allowing companies to understand their tradeoffs with respect to spare parts will enable them to instill better processes and policies for spare parts management, enabling them to become more efficient, more cost-conscious, and better engineered to fit their operating and business environment, while maintaining company and shareholder expectations.

Because this research is ongoing and a work in progress, future work includes continual data collection and analysis with development of models and forthcoming recommendations. The authors plan to fully develop forecasting models for the spare parts as well as a cost tradeoffs analysis that includes management input. Furthermore, a risk profile for spare parts is to be developed, leading to part classifications based on the potential revenue impact or loss to the utility. The overall research benefits the engineering manager as it provides a framework for a decision support tool that can be used by supply chain buyers and analysts in their daily job functions, leading to improved quantified and logical buy/no buy decisions for spare parts that are appropriate for the competitive deregulated electricity generation business environment.

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Thank you for your interest in this research!

Here is some helpful information for citing the paper.

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