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Influence Diagram Modeling of Nuclear Spare Parts Process

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Abstract

Spare parts inventory levels at nuclear generation plants have neared all-time highs at some facilities. As part of an ongoing research project, the authors are developing a decision making framework for nuclear spare parts management. This paper describes the use of an influence diagram model to represent the existing spare parts process at a United States nuclear facility. We then discuss how this model can be extended to develop an interview protocol for subsequent data collection using the Analytic Hierarchy Process. The influence diagram drives the overall analysis of determining best practices for the spare parts process for continuous improvement.

Keywords
Electric utilities, influence diagram, spare parts, nuclear power

1. Background

The United States nuclear energy industry has faced challenges in recent years. Plants are aging, and many states have begun to deregulate electricity generation. Under regulation, costs of doing business were recovered in customer rates. However, under deregulation, cost recovery of generation-related expenses is no longer guaranteed as utilities are now operating as competitive businesses [1]. Therefore, management processes must be re-engineered to support the competitive business environment. One such area that needs particular attention is plant spare part management.

Spare parts inventories have neared all-time highs at some nuclear facilities. Under regulation, the costs of buying and holding spare parts were recovered. Parts were kept on-hand in the name of plant safety. However, Scala, Needy, and Rajgopal [2] argue that plants have many safety systems in place to effectively shut down the plant if it became compromised in some way and that spare parts are more typically held to prevent revenue loss. As a result, a need exists to improve spare parts management support. The authors are engaged in a research project to address spare parts management and are working to build a quantitative model that minimizes plant downtime and revenue loss while maintaining plant safety. For a further discussion on deregulation and the nuclear spare parts problem, see [1, 2].

The authors' model will address the criticality of the part with respect to the utility's bottom line. That is, if something fails in the plant, and the parts are not available to fix it, the plant may have to be off-lined or de-rated, depending on the system that failed and the lead time necessary to obtain the required spare parts. The authors' model aims to avoid these situations and will weight parts that can lead to off-lining or de-rating more heavily. Therefore, the model will address spare parts from a business perspective while maintaining plant safety. This will improve the current industry policies and practices, by providing an understanding of how parts can affect the company bottom line. Furthermore, nuclear companies and other industries can employ the methodology developed to continuously improve their spare parts management policies. This methodology includes the use of influence diagrams and the Analytic Hierarchy Process. This paper focuses on the development of an influence diagram for the spare parts process.

2. Influence Diagrams

An influence diagram is a pictorial representation of a decision problem. All relevant factors and forces, both quantitative and qualitative, are depicted in one single figure. Variables that are stochastic or have an element of chance are represented typically by circles or ovals, while variables that are decisions and can be controlled by the decision maker are represented by square boxes. Relationships between variables are depicted by arcs, with a directed arc from block A to block B implying that item A influences item B. A connection between blocks is not necessarily causal. Influence diagrams allow people with limited understanding of the overall process or with limited technical backgrounds to understand the process and inputs to the decision problem and can be developed as a collaborative effort between a decision maker and an analyst. For a detailed discussion of the theory of influence diagrams, see [3]. A discussion on probabilistic elements of and analyzing influence diagrams through use of computer algorithms is given in [4, 5].

2.1 Examples of Use of Influence Diagrams

Influence diagrams are commonly used to map out problem variables and the relationships between the variables. Examples of the use of influence diagrams are varied and include pitcher substitution in Major League Baseball [6], risk management and policy options post-eradication of the polio virus [7], testing strategies for pharmaceutical drug candidates [8], evaluation of military alternatives for countering weapons of mass destruction [9], maritime risk assessment and decision support [10], infection risk communication in plague bioterrism attacks [11], modeling classroom newsvendor problems [12], diagnostic testing in manufacturing [13], and safety assessments of products containing nanoparticles [14].

2.2 Use of Influence Diagrams in Modeling Spare Parts Process in Nuclear Plants

An influence diagram was chosen to depict the current inputs to the spare parts process for a number of reasons. An influence diagram clearly depicts all factors and forces in the problem, allowing the problem analysts and decision makers to see all elements that affect the overall decision problem, in this case spare parts inventory. The relationships between these elements are also clearly depicted, allowing the subject matter experts and decision makers to take a step back from their experiences with respect to the day-to-day process and digest the overall spare parts inventory problem. The analysts and subject matter experts at the case study company may not clearly understand the full ramifications of their decisions and the problem itself, and an influence diagram allows for a pictorial representation of the problem in a format that provides insights into both the details of the problem and its overall effects. The majority of the analysts that we worked with have little decision modeling experience and some also have limited technical backgrounds. The influence diagram allows them to easily understand the problem so that they can initiate process improvement as well as to easily validate or verify the structure of the diagram based on their work experiences and knowledge.

Because an influence diagram has been proven in the literature to be effective at depicting decision problems (see examples noted above), other companies and industries implementing the methodology developed in the overall research project can easily adapt the diagram to fit their inventory modeling process and decision needs. The following is a discussion of the rationale for the influences that were included in this diagram.

3. Influence Diagram Model

The overall structure of the influence diagram for spare parts in nuclear plants places influences in groups based on both categorical and company process characteristics. To develop the diagram, the authors needed to employ the expertise of various work groups at the case study company, including supply chain, planning and scheduling, engineering, equipment reliability, maintenance, work management, outage management, and asset utilization. These experts can also assist with model validation. For a summary of the methodology used to develop the diagram, see Section 4. To aid in the process of collecting the information and expertise of employees, influences were grouped according to work functions that had detailed knowledge of a group of similar items. Figure 1 depicts the high level diagram of the main groups of influences and their effects on determining a part score and subsequent part criticality. Table 1 depicts the sub-influences contained within each overall group. Due to limitations on space, we restrict ourselves to one example of a sub-diagram (for the Timeliness of Work Order group), which can be found in the bottom half of Figure 1.

Such a breakdown of the model into sub-diagrams is common in practice to simplify visual representation without the expense of losing relevant information, while allowing the reader to effectively digest the information presented. An example of the use of sub-diagrams can be found in [13]. In general, items selected as influences are based on

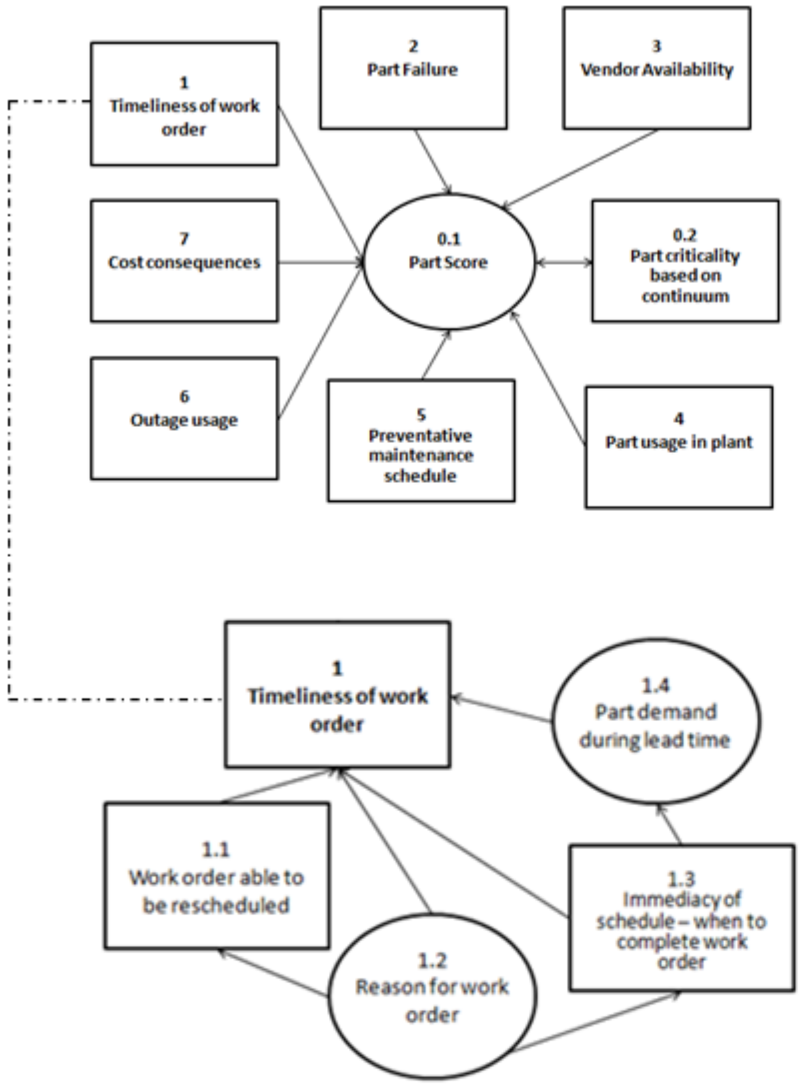

Figure 1: High level influence diagram with sub-level influence diagram for timeliness of work order

studying the spare parts inventory process and interviewing key process stakeholders. Industry experts in the supply chain area reviewed and validated the diagram's influences and relationships. During the review, some influences were reassigned to different groups, based on the industry experts' expertise and knowledge associated with their work function. The items on the diagram are also further supported by various case study company internal documents as well as industry standards, including Nuclear Energy Institute's "AP-908: Materials Services Process Description and Guide" [15]. Each group of influences supports the overall inventory decisions of what to buy, when to buy, what to store, and how much to store. Decisions are typically made after a work order is generated or a reorder point is reached in an effort to maintain plant safety and to comply with federal regulations. Descriptions of the diagram subgroups are detailed below.

Timeliness of work order refers to the influences that are related to when the work order can be completed, and the associated parts that would be required to finish the work order. Each influence supports the work order process and the immediacy of completing the needed plant maintenance as well as associated part demand and work order characteristics, requirements, and criticality.

Table 1: Influences in the spare parts ordering process along with node connections

Item	Description	Connects to		Item	Description	Connects to
0.1	Part score	0.2		4	Part usage in plant	0.1
0.2	Part criticality based on continuum	n/a		4.1	Part is at a single point vulnerability	4
1	Timeliness of work order	0.1		4.2	Installation in a functional location tied to LCO	4
1.1	Work order able to be rescheduled	1		4.3	Usage for equipment train protection and reliability	4
1.2	Reason for work order	1; 1.1; 1.3		4.4	Number of locations in plant where part installed	4
1.3	Immediacy of schedule - when to complete work order	1; 1.4		4.5	Regulatory requirement to keep part on-hand	4
1.4	Part demand during lead time	1		4.6	Usage to prevent equipment forced outage	4
2	Part failure	0.1		4.7	Open work orders and part demand	4; 1.5
2.1	Failure of part leads to LCO or SPV	2		4.8	If the part requested is actually used in the PM work order	4
2.2	Lab testing results in predictive maintenance	2		5	Preventative maintenance schedule	0.1
2.3	Surveillance maintenance results	2		5.1	PM done on the related equipment	5
2.4	Failure history	2		5.2	Frequency of time the actual PM job is more involved than anticipated	5
2.5	System health for related equipment	2		5.3	PM done online or only during outage	5
2.6	Normal part life	2		5.4	Associated maintenance rules for the equipment	5
3	Vendor availability	0.1		6	Outage usage	0.1
3.1	Vendor discontinued or obsolete	3		6.1	Part scheduled for use during outage	6; 6.2
3.2	History of vendor quality issues	3; 3.3		6.2	Actual usage of the part during outage	6
3.3	Vendor reliability	3		6.3	When the part can be used or equipment accessed	6
3.4	Vendor lead time	3; 3.3		7	Cost consequences	0.1
3.5	Availability on RAPID	3		7.1	Cost of expediting the part	7
3.6	Quality testing or hold before installation	3		7.2	Cost of replacement power	7
3.7	Ability to expedite the part	3				

Part failure refers to the influences that are indicators of imminent or future part failure. Such part failures may place the plant in a compromised situation. This includes the possibility of a limited condition of operation (LCO), where the plant personnel have a specified amount of time (usually 72 hours) to remedy the situation or shutdown / de-rate the plant according to regulation. The case study company has internal labs that test plant equipment and chemicals to support proper and safe plant performance along with a system to track failure history. Surveillance maintenance involves visually inspecting components for defects or needed maintenance. System health involves an internal quarterly score given to plant systems based on various operational factors.

Vendor availability refers to the influences that represent the ability of vendors to supply spare parts when needed and the ease with which parts can be procured. In particular, *RAPID* is a database unique to the nuclear industry where nuclear plants can purchase or borrow needed spares from other utilities. Quality testing refers to appraisal testing that must be completed before the part can be installed in the plant.

Part usage in the plant captures the influences that represent the volume and frequency with which a spare part is installed or used in the plant. Functional locations are codes referring to physical locations where parts are installed in the plant. Train protection and equipment forced outage (EFOR) refer to keeping the plant safely running and preventing equipment from being off-lined. Single point vulnerability (SPV) means only one component of a given type is installed in the plant; no backup system exists in the event of failure.

Preventative maintenance refers to influences that represent activities associated with PM, corresponding maintenance rules, and how parts are selected to be included on a PM work order. Each influence is directly related to the PM policies and related plant work.

Outage use refers to influences that capture information related to parts requested for use during a plant outage and when the related work orders can be carried out. Each influence is directly related to work that must be or is typically done during a scheduled plant refueling outage, which occur every eighteen to twenty-four months, depending on the plant.

Cost consequences refers to the influences that represent company-wide costs incurred if the plant has to be off-lined or de-rated, particularly without prior notice, in a forced outage situation. Each influence supports related costs incurred if a part is not available when required causing the work not to be completed leading to off-lining or de-rating of the nuclear plant.

4. Extensions to the Analytic Hierarchy Process (AHP) and Future Research

In order to use the influence diagram and develop a spare parts criticality score, the authors are developing an interview protocol to be used with the Analytic Hierarchy Process (AHP). Subject matter experts (SMEs) from the nuclear industry are being interviewed and asked to make pairwise comparisons of the items in each sub-group that is related to their knowledge base and work function. The priorities from these comparisons will be analyzed, aggregated, and used along with spare parts data to determine evaluative criticality scores for spare parts. A weight or importance for each influence will be found, applying the weights from the AHP. The actual company spare parts data will be combined with the weights to formulate a criticality score for each spare part. The parts can then be placed in large groups based on their criticality score, with the groups reflecting the importance of keeping the part in stock in relation to the company bottom line and plant safety. The overall objective is to minimize plant downtime and subsequent revenue loss while maintaining safety.

The AHP was chosen for this process because it is an accessible decision making tool. Similar to influence diagrams, those with little technical background or knowledge of the AHP theory can still easily make meaningful comparisons. Furthermore, multiple software packages exist, including SuperDecisions, for use in calculating AHP priorities and synthesizing the overall hierarchy. Those in industry can easily access the software and build hierarchies corresponding to the influences that are relevant in their spare parts processes.

Future research involves carrying out the AHP extensions discussed above and analyzing the influence diagram. This includes developing the interview protocol, interviewing the SMEs, and performing the AHP analysis in an effort to determine part criticality with respect to the company bottom line. Once part criticality is obtained, a corresponding spare parts stocking policy will be developed.

5. Conclusions

Overall, the authors are developing a framework for spare parts process management in the electrical utility sector. Although the details presented here are related to the nuclear industry and a specific company, the methodology can be followed and applied in various industries, plants, and companies, adopting and modifying the influence diagram as necessary to incorporate both relevant company and industry influences and process characteristics. This research approaches spare parts management from a decision modeling and engineering management perspective, eliminating the need for theoretical assumptions in mathematical models while incorporating all relevant factors and forces in the process. The results can be immediately applied to the actual industry problem to provide process re-engineering and continuous improvement that supports the competitive business environment of electric generation.

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