Development of an Asset Management Decision Support Tool for Hydro-Québec TransÉnergie

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SUMMARY

To meet new needs and to respond to changes in the energy market, Hydro-Québec TransÉnergie (HQT) requires the development of new predictive modeling methods and systems for asset management. A requirements analysis carried out by HQT for an improved asset management and modeling system led to the creation of a robust integration and decision-making support program, PRIAD, conducted in collaboration with Hydro-Québec's research institute, IREQ. The goal of the PRIAD innovation project is to complete a range of initiatives to improve asset management decision simulation techniques.

PRIAD is structured into complementary but interdependent modules: Data Warehouse, Asset Behavior, Reliability Database, Transmission System Reliability Simulator, Risk, and Optimization. The modules described in this article are currently under development. When completed, they will make HQT asset management more efficient and robust and will increase long-term asset value.

KEYWORDS

Asset management, transmission system, simulation, optimization, risk, asset behavior, reliability

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1 INTRODUCTION

Owners of power transmission grids must balance maintenance of aging assets with profitability requirements. Asset management systems based on the ISO 55000 series standards [1] allow electric utilities to achieve and to demonstrate a better value asset management. For asset management to meet new needs and be more responsive to changes in the energy market [2, 3], predictive modeling methods and systems must be developed. HQT has been using this type of modeling system to manage its assets for over ten years. A needs analysis at HQT with the goal of creating a system with improved performance and prediction robustness highlighted the existing system's gaps in the areas of data quality, data collection time, reliability models and information technology (IT) infrastructure.

These findings led HQT to create the PRIAD (*Programme de Robustesse, d'Intégration et d'Aide à la Décision*; EN: robustness integration and decision-making support program) research project conducted in collaboration with the Hydro-Québec research institute (IREQ). The goal of the project is to complete a range of initiatives to improve asset management decision simulation techniques. This article presents the project elements currently underway and potential improvements to the current system.

2 ASSET MANAGEMENT MODELING

HQT's Direction – Gestion des actifs [EN: asset management branch] already has a well-established process for drawing up the financial framework for equipment maintenance and long-term operability. It is illustrated by the boxes outlined in red in Figure 1. The PRIAD project's proposed improvements are related to the other boxes in the figure. This research and development project consists of closely linked interpendent modules: Data Warehouse, Asset Behavior, Reliability Database, System Reliability Simulator, Risk, and Optimization. In order to obtain an efficient system, all modules must be implemented. They are described in the following sections.
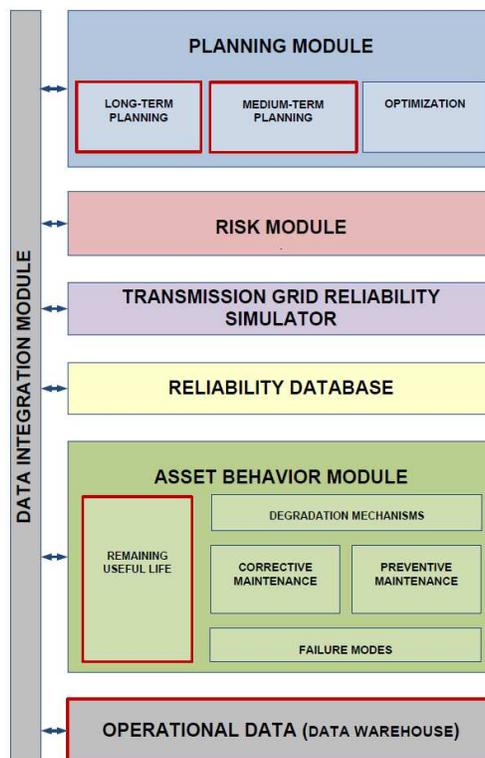

Figure 1   Proposed Asset Management model. The current model is represented by the boxes outlined in red.

2.1 Data Warehouse and Data Integration modules

The data warehouse will be populated by enterprise data used in reliability analyses (e.g., inventories, orders, notices of planned work, maintenance plan and network topology) centralized in a corporate data warehouse, or data lake. This data lake will serve as a repository for both raw and cleansed data. This information storage method allows different schemas and structures of corporate data to cohabitate. It allows us to separate data from treatments and to extract or analyze data for a specific period or date thanks to data historization. This data storage structure makes it possible to create a single authoritative data source in accordance with data governance standards that is available enterprise-wide. Data historization allows us to draw on and analyze the lessons of the past in an attempt to predict the future and thereby create a corporate knowledge base.

The data integration module interacts with all the following modules: Asset Behavior, Reliability Database, System Reliability Simulator, Risk, and Planning. They must support the interaction of other asset management initiatives with the data lake. To achieve this, the latest technology is recommended, for both cloud computing services (Microsoft Azure, Databricks) and local machines (self-hosting). This will allow researchers to adjust distributed computing power to algorithm needs and rapidly respond to queries or needs expressed by the enterprise. An added benefit is access to the latest development tools. Python was selected as the primary development language. However, several modules will be developed in other languages, including Java, MathLab and SparkSQL. Algorithms will be centralized to allow the various modules and systems to use them. IT operations and source code management should be handled by an Azure DevOps service. Detailed results validation will be supported by business intelligence and visualization tools, such as PowerBI, which could be made available to data and operations experts.

2.2 Asset Behavior module

The primary objective of the equipment degradation models is to simulate the effect of systematic maintenance planning on the reliability of critical transmission system equipment. Two methods are used to estimate model parameters: expert interrogation and analysis of historical failure data. Initially, expert knowledge is used to develop a theoretical degradation model for each equipment class. The models are based on the approaches proposed by the Electric Power Research Institute (EPRI) in the Preventive Maintenance Basis Database (PMBD) [4]. They were designed for Hydro-Québec's commercial and operational context (current maintenance standards and enterprise systems). This analysis, based on quantitative Failure Mode and Effects Analysis (FMEA), lists all the degradation mechanisms that could result in each failure mode, their propagation time and the impact of preventive maintenance tasks on that propagation.

The different expert groups held several consultative meetings to develop the model for each equipment class. Their main challenge was to estimate propagation times for degradation mechanisms without taking maintenance effect into account, while maintenance had obviously been performed on the equipment throughout its service life. To account for this potential bias and the other uncertainties in the interrogation process, propagation time was estimated as a confined interval representing the underlying uncertainties. As a result, the theoretical degradation models predict the annual failure rate for a given maintenance program for each equipment class. They can also predict the failure rate of a combination of components and their associated failure mode. These models represent the acquired physics failure knowledge for each equipment class. For an accurate simulation, they must be representative of the past and future behavior of each equipment family.

The theoretical models were calibrated using failure data analysis to estimate the historical failure rate observed for each equipment class under the maintenance programs actually followed. In this analysis, the failure rate was considered constant. As with the expert estimates, the failure rate for each combination of components and associated failure modes was estimated with a confidence interval wherever possible, while taking into account the underlying uncertainties in the failure data.

Reliability parameters estimated by expert consultation and by data analysis both suffer from uncertainties and biases. A better estimate would be obtained by combining the two approaches. Various techniques for combining them were studied, including Bayesian interference methods. A promising approach, currently under development, is to optimize the reliability parameters determined using expert's knowledge in order to obtain an estimated failure rate, and then compare that with the failure rate estimated by data analysis. The final result represents a more robust estimate of the failure model parameters.

2.3 Reliability Database

The heart of the project will be the centralized reliability database, where the asset reliability models will be stored. This database will provide data consistency and traceability for reliability engineers and simulation tools. Its cornerstone will be the asset concept. The database will include tables of historical events for each asset and related information such as: strategies, attributes, statuses, risk profiles, locations, and reliability models. It will be hosted on cloud computing infrastructure to allow enterprise-wide access.

2.4 Reliability Simulator

An event simulator, based on the Monte Carlo simulation and using asset reliability estimates and network topology considerations, is under development to evaluate expected transmission system performance and network reliability characteristics. The simulator can predict the expected performance of a transmission system by calculating indicators such as down time and the energy balance at a given substation. The Monte Carlo approach was selected because it is a powerful and practical tool for analyzing system reliability. It is a well-known alternative to analytic simulation and provides valuable flexibility by combining heterogeneous phenomena. It also makes it possible to break down a complex problem into multiple independent simulations.

The simulator communicates with the PSS/E power flow simulation and uses the simulation of discrete events to easily simulate a wide range of events, including power system overloads, protection mechanisms, power flows, dynamic and thermal stability, simultaneous events and power system reconfigurations. Furthermore, it records partial results for faster processing and improved performance. This simulator will be a complete and powerful tool to help managers, engineers and planners understand the impact of asset management on system reliability.

2.5 Risk module

The Risk module will use relevant data from the modules discussed above. Its purpose is to quantify risks and attach monetary values when possible. The following types of risk will be considered: operational; reliability, availability and maintainability (RAM); environmental; financial; regulatory; occupational health and safety (OHS); corporate reputation; and other relevant risks. To optimize risk management strategies, the interdependence of the various types of risk will be analyzed.

2.6 Optimization module

The components presented above (asset behavior, reliability database, reliability simulator, risk module) will be used to identify optimal long-term replacement and maintenance strategies for the assets being managed. Black box optimization techniques will be used since the complexity of the system prevents the objective function and constraints from being reduced to analytical equations.

A series of operations to quantify strategies' performance is executed. First, the optimizer generates a given vector x, which is submitted for evaluation. That vector is a set of values that fully define the strategy in question. The values of x are injected into the reliability database models to obtain the failure rates. Those rates are used by the Monte Carlo simulator to generate the loss of functionality

scenarios, for which a power flow is obtained and undesirable occurrences are recorded. A monetary value, financial costs and risk exposure estimates can then be associated with strategy x. The calculated values are then returned to the optimizer, which begins evaluating another strategy x'. This is repeated until an optimal strategy is found.

Given the large number of calculations required for a single evaluation, the optimization algorithm must be carefully selected. Typical metaheuristics, such as genetic algorithms (and their derivatives) and particle swarm optimizations (PSO) must be avoided since they are random and rely on populations of candidate solutions. In doing so, they use a great deal of time and effort to evaluate uninteresting strategies. To obtain a local optimization in reasonable time, algorithms that attempt to minimize the number of evaluations to perform must be considered. Pattern search methods, such as GPS, MADS, and HJDS, and trust-region methods such as DFO, NEWUOA and BOOSTERS should be considered [5]. They are currently under study for implementation with the proposed maintenance strategy optimization solution.

3 EXPECTED RESULTS

The implementation of the PRIAD project will help HQT improving its asset management. By providing a number of improved methods and tools for HQT, this project will:
- Help to draw up the financial framework at HQT
- Estimate and quantify risk associated with asset management strategies
- Simulate the effect of asset management strategies on system reliability
- Assist in strategy planning and optimization
- Measure the functional performance of assets
- Provide data quality tracking

In addition, case studies to meet ad hoc needs, such as the study carried by Komljenovic et al. [6], are analyzed using the tools and methods studied and developed within the PRIAD project.

3.1 Optimization example

To illustrate the advantages of this type of asset management modeling system, we look at an important issue in maintenance optimization. The flow between the various modules shown in Figure 1 is illustrated in Figure 2. The starting point is the Asset behavior model based on FMEA, which links asset components, degradation mechanisms, planned systematic maintenance activities and their effectiveness, as well as the failure modes. Using the propagation time of the degradation mechanisms and the impact of maintenance on their propagation, the PRIAD algorithm can predict the failure rate resulting from the maintenance program.

The failure rate is used to define the failure probability distribution used by the reliability simulator for each equipment family. The simulator then generates a large number of failure scenarios and associated outages on a 40-year horizon. Every availability scenario for each piece of equipment is used as an operating topology adapted for the transmission system. The power flow simulator simulates the flow of power generators through the system to the customers for each topology scenario. This makes it possible to see the combined impact of different equipment failures on the power system and on its ability to respond to customers' demand. Using the system simulator results, the Risk module puts a monetary value on the impact of the failures, taking into account other tangible and intangible requirements. In the final analysis, the optimizer can be seen as an orchestra conductor, who identifies the maintenance scenarios to explore in order to determine the optimal scenario that will achieve the objective while respecting the predetermined constraints.
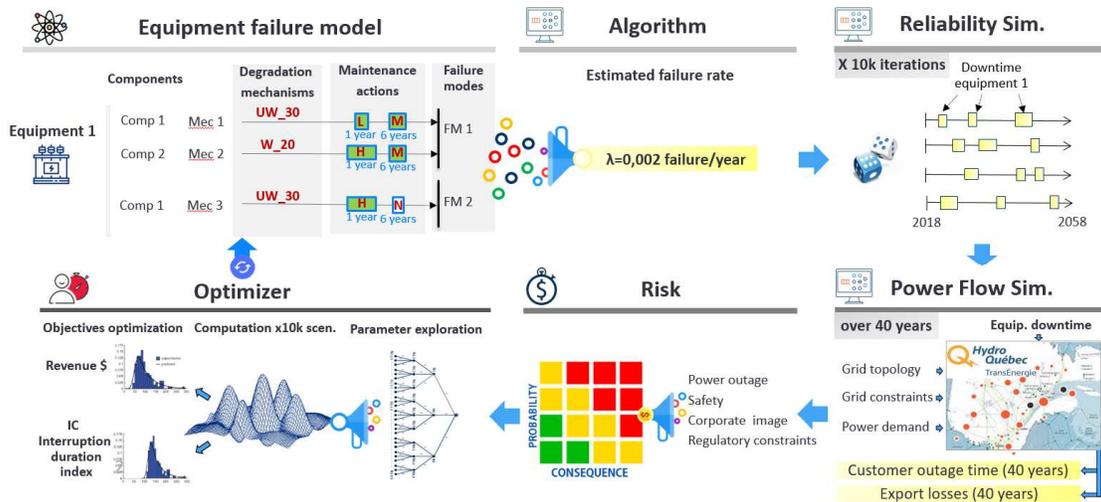
Figure 2   Illustration of the PRIAD process to optimize a maintenance scenario

Predicting the failure rates for equipment families is the bedrock of the process. Consequently, the behavior models are very important. They must represent the best current knowledge for each equipment family, based on expertise and available historical data. These models must evolve as new knowledge (expertise or data) becomes available.

4 CONCLUSIONS

The modules described are currently under development. When completed, they will make HQT asset management planning more efficient and robust. Ultimately, they will increase the long-term value of its assets. New validation and test studies are planned as the project progresses.

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