Optimum Timing for Equipment Replacement

Optimization Logic for Forecasting Reliability-based Replacements

Costs Evaluated in the Strategy

Equipment Replacement Cost – Forecasted replacement costs were developed for 50 equipment types (turbine runner, transformer, etc.) by the Corps' Hydroelectric Design Center, the organization responsible for developing government estimates for procurement of Corps hydroelectric equipment. For each equipment type, cost estimates include a fixed cost component, which is the same for all equipment of that type, and a variable cost component, which is dependent on parameters related to the size and complexity of the equipment, i.e., shaft diameter, MVa rating, etc.

Incremental Equipment Failure Cost – When equipment fails, costs to repair or replace it are typically incrementally higher due to collateral damage and to planning, procurement and scheduling inefficiencies. Incremental failure costs are specific to each equipment type, expressed as a percentage of replacement cost when done on a planned basis.

Replacement Power Cost – For the asset strategy, Federal Hydro Projects used hydro regulation studies to determine the amount of generation produced by each plant on the system assuming each generating unit is available 90 percent of the time (somewhat high for the FCRPS based on recent history, but in line with industry averages and a reasonable steady-state level for a reliable plant). Generation amounts were calculated for HLH and LLH periods by month for 50 water years. Next, hydro regulation studies were run at lower levels of unit availability to determine the amount of generation that would be produced if the plants were less reliable. The difference between modeling runs produces the incremental generation from an increment of plant availability. For the strategy, the incremental generation produced by the "least used" unit (marginal unit) was calculated for each plant on the system. This is the amount of generation that is deemed to be at risk in the event of equipment failure. Although a distinct possibility, particularly for plants with many generating units or low reliability, no consideration was given to multiple and simultaneous equipment failures that would take more than one unit out of service and have increasingly higher lost generation consequences.

When equipment fails and takes a generating unit out of service, repairing and replacing the equipment typically takes longer than if work is done on a proactive, planned basis. For instance, a transformer can take three or more years to procure and, absent having a spare available, a failure would take a generating unit (or multiple units) out of service for

Costs Evaluated in the Strategy

three years or longer. Replacing a transformer on a planned basis typically requires an outage of three months or less. So, the incremental outage duration for a failed transformer can be 2.75 years if no spare is available (we assumed 1.5 years in the strategy). Other equipment types have much shorter incremental outage durations.

The annual generation at risk for the marginal unit at each plant is then multiplied by the expected additional outage in years for each equipment type to determine the amount of lost generation if that equipment fails. The lost generation is valued at BPA's rate case long-term forward price forecast to determine a replacement power cost (or lost secondary market opportunity) for the equipment failure.

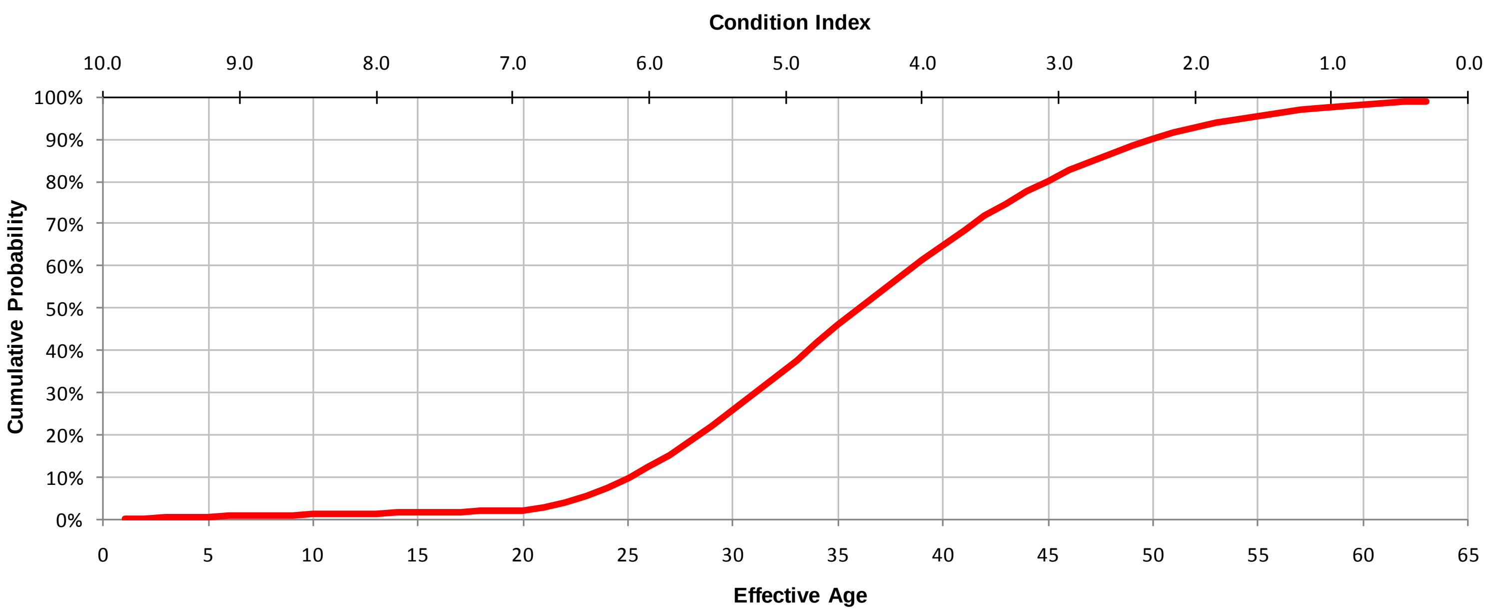
CO2 Cost – BPA's Climate Change Action Plan requires hydro investment decisions to include greenhouse gas avoidance benefits in asset planning analyses and business cases for proposed capital and major expense sub-agreements. Guidance from BPA Corporate Strategy is to use CO2 costs from the Power Council's 6th Power Plan for determining that value. The plan's 20-year levelized cost of CO2 emissions is $41 per ton (2012 dollars). This cost is multiplied by the CO2 emissions generated by a combined cycle natural gas plant (0.37 tons per MWh) – the resource that would be used to offset losses in hydro generation – to determined the avoided CO2 cost for maintaining hydro plant reliability.

For the strategy analysis, only equipment replacement costs are deterministic. Other costs are probability-based, derived from information about equipment condition that is correlated to a likelihood of failure.

Equipment Condition and its Relationship to Risk

The strategy analysis uses hydroAMP to assess condition of power train and some other hydro equipment. Developed by the Corps, Reclamation, BPA and Hydro Quebec, hydroAMP uses a set of condition indicators describing operational performance, maintenance history, physical inspection, age, and specialized testing results to derive a condition index for equipment. The condition index scale ranges from zero (Poor condition) to 10 (Good condition). For equipment not covered by hydroAMP, a simplified condition assessment tool was built based on the hydroAMP methodology.

A regression analysis was performed on the hydroAMP database to establish a correlation between a condition index and equipment "effective age". The results were then used to map the hydroAMP condition index and effective age to a survivor curve for that equipment. Survivor curves are derived from industry data and show the relationship between equipment age and the percentage of the equipment population that has failed or been retired. Mapping the hydroAMP results to the survivor curve yields a failure probability for equipment with a certain condition index and effective age.



Equipment Condition and its Relationship to Risk

Risk is a function of the probability of failure as condition degrades over time. For the strategy, four types of risk were calculated in incremental time steps:

Safety Risk, where equipment failure has a relatively high probability of causing permanent disabilities or multiple fatalities;

Environmental Risk, where equipment failure has a relatively high probability of causing detrimental or catastrophic environmental impacts;

Direct Cost Risk, which is the Incremental Equipment Failure Cost identified above multiplied by the incremental probability of failure over time; and,

Lost Generation Risk, which is the sum of Replacement Power Cost and CO2 Cost multiplied by the incremental probability of failure.

The sum of Direct Cost Risk and Lost Generation Risk are hereafter described as financial risk.

Optimum Timing for Equipment Replacement

To determine the optimum timing for replacement, each equipment component is evaluated in yearly time steps over 20 years. In each year, the present value of accumulated financial risk cost is added to the present value cost of replacing the equipment in that year. The sum of these present value costs is the Total Cost related to a decision to delay equipment replacement until that year. This algorithm is described graphically on the next page.

Total Cost of Replacement at Different Points in Time

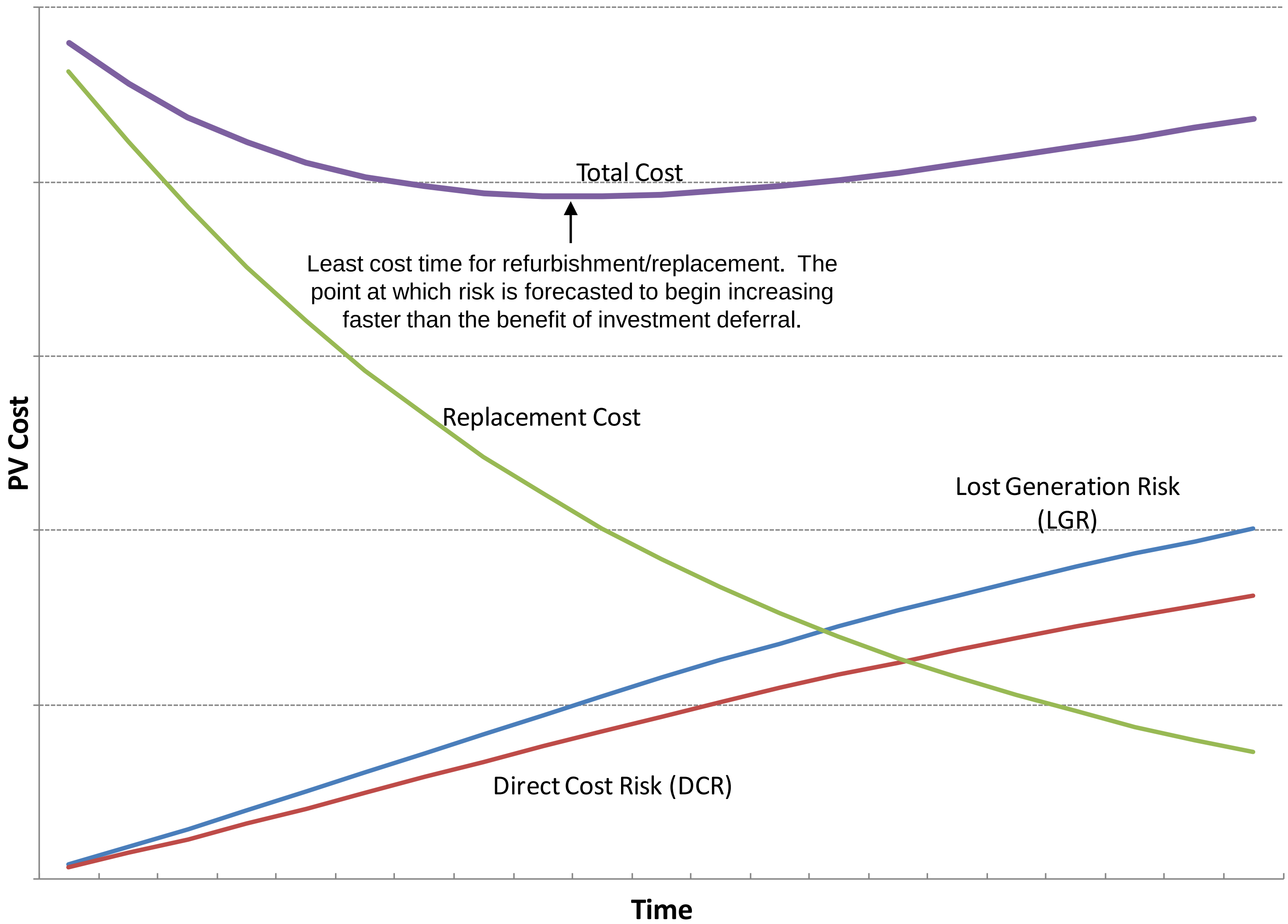
The optimum time to plan on equipment replacement is at the low point (cost minimum) of the Total Cost curve. The cost minimum is the point in time at which financial risk costs begin growing faster than the benefit of deferring the investment. Up until that time the value of investment deferral is greater than the expected increase in financial risk costs, so it makes financial sense to continue deferring equipment replacement. This objective function is applied to each of the 5,500 equipment components included in the strategy to derive an investment plan.

Running the model without funding constraints generates the “least-cost plan”. Under this scenario, equipment replacements for projects that are already underway are funded as planned. Potential new investments are then selected for refurbishment/replacement if they meet either of the following criteria:

- First, if condition places the equipment into a safety or environmental high risk category; or,
- Secondly, if financial risk costs are increasing faster than the investment deferral benefit, i.e., the equipment has reached the cost minimum.

The model can also be run to limit annual funding availability to any level desired. For these cases, once an annual funding limitation is reached, investment in equipment in which financial risk is increasing the least is deferred until the following year, where it is then re-evaluated using the same prioritization logic. As funding levels are increasingly constrained, more new investments are deferred past their cost minimum which causes the Total Cost to increase accordingly.

Optimum Timing for Equipment Replacement

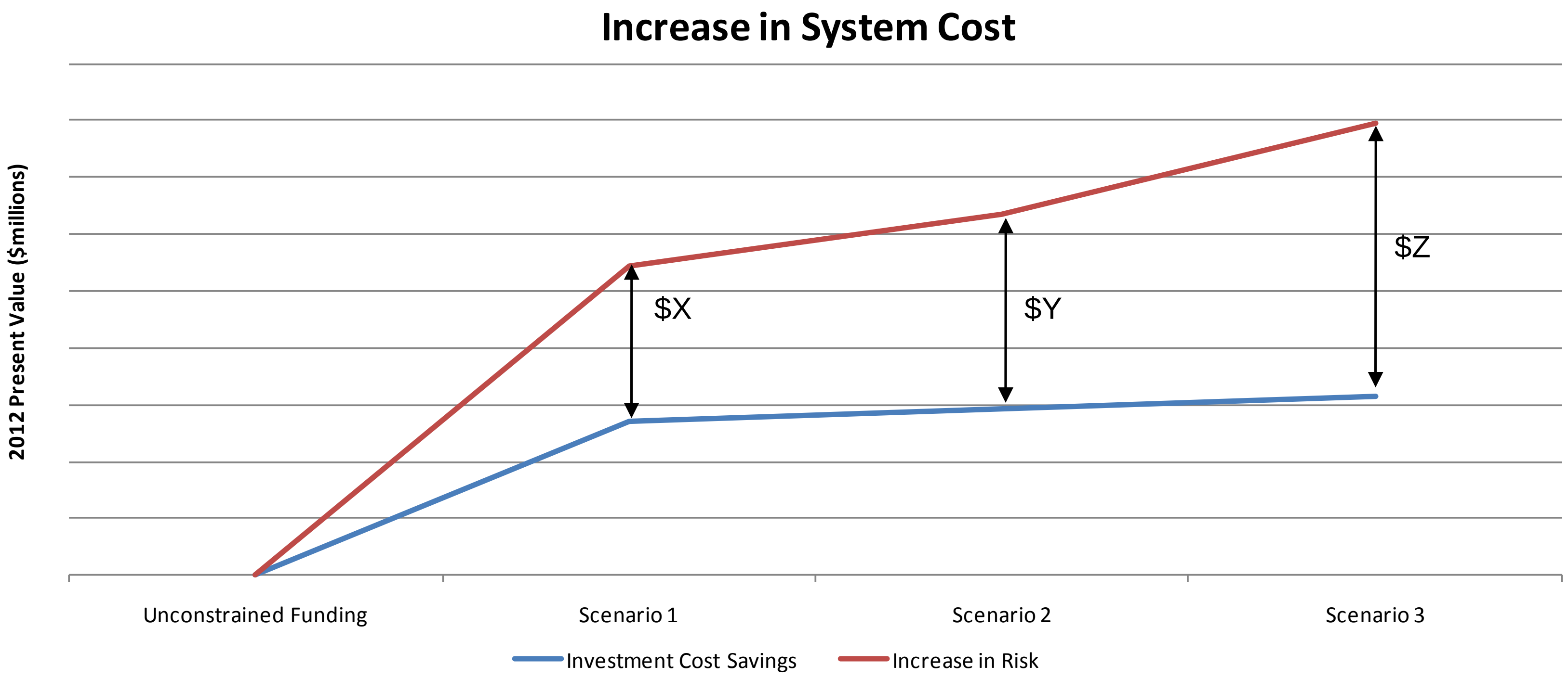


Net Present Value

Calculation of Net Present Value

The Total Cost for the system increases when a funding constraint causes new investments to be pushed out past the cost minima. The present value of investment costs is reduced, but risk increases by a larger amount. The Total Cost difference between various funding availability scenarios and an unconstrained funding alternative yields the increase in system cost.

The net present value of each scenario is the negative of the increase in system cost, i.e., the Total Cost of unconstrained funding minus the Total Cost of a constrained funding scenario.



Assumptions Used in Modeling

2014 Hydro Asset Strategy for the 2012 IPR

Assumption	Value	Source	Comment
Discount rate	12.0 percent	BPA Finance	Applies to all generation investments
Inflation rate	1.7 percent	BPA Finance	Average annual rate based on 20-yr forecast
Forward energy price curve	20-yr, by month, HLH, LLH, flat	BPA Power Services Resource Program	Includes spot prices and a component for long-term firm capacity consistent with rate case demand rate.
Equipment cost	Varies by equipment type	FCRPS hydro program	Based on industry cost data
Real cost escalation	0 percent	BPA Finance	Global Insight
Failure curves	Varies by equipment type	BPA Federal Hydro	Based on industry data for certain equipment
Outage duration for LGR	Varies by equipment type	FCRPS hydro program	Based on industry experience
Environment and safety	Risk	BPA Federal Hydro	Treats all high risk items as “must do”
Value of avoided CO2	$41/ton	BPA Corporate Strategy	Based on Council’s 6th power plan
Alternative resource for hydro lost generation	Natural gas-fired Combined-Cycle Combustion Turbine	BPA Power Services Resource Program	0.37 tons of CO2 per MWh of generation

Criticality of Assets

FCRPS Hydro Plant Classification

Relative Cost of Unavailability (RCU)	Local Support	Area Support	Headwater/ Lower Snake	Main Stem Columbia
Severe >$40m/yr				CHJ GCL MCN
Extreme $10 - $40m/yr			DWR	JDA
Major <$10m/yr	AND, BCD BDD, MIN, ROZ, CDR, GSP	BCL, DEX, LOS, DET, GPR, LOP, HCR, CGR, FOS, ALF, PAL	LIB, HGH, IHR, LGS, LWG, LMN	BON TDA