ROAM WITH RISK RESILINCE CAN NOT BE BUILT IN A DAY

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ABSTRACT

ROAM (Risk Oriented Asset Management) cannot be built in a day. A risk-based and transparent methodology is to be used to assess the criticality of infrastructure in a consistent manner in all facets of asset life from cradle to grave or concept to decommissioning. ‘Criticality’ is usually defined as a measure of the consequences associated with the loss or degradation of the infrastructure or the service it provides. In particular, an assessment of criticality must be based on the scope and gravity of the potential damage to the level of service/function. The best protection is achieved by improving the resilience of critical infrastructure to all potential hazards, whether natural or human induced. Resilience includes resistance, reliability, redundancy, response and recovery.

At the heart of the risk resilience approach is recognition that “…comprehensive protection of all critical infrastructures, equipment … against all threats and risks is impossible, not only for technical and practical reasons, but also because of costs”. Instead of focusing on the type and likelihood of specific threats, a risk resilience approach focuses on the likely consequences of a failure of a specific asset, network or other infrastructure component and seeks to mitigate them. Although some residual risk will always be present, risk management strategies can help build capacity for assets to become more resilient to disasters, disruptions, accidents, faults, failures and crises.

This paper describes various steps involved in the development of a risk oriented asset management (ROAM), with specific examples from a case study (Black & Veatch’s Risk Resilience project on a transmission and distribution (T&D) of electricity & gas utility). There are eight Steps involved in a ROAM approach. In essence the risk resilience approach is an informed tradeoff between risk, cost and performance.

RISK ORIENTED ASSET MANAGEMENT (ROAM)

*As the adage goes Rome is not built in a day****, ROAM also cannot be built in a day*****.** In all facets of life from concept to decommissioning or cradle to grave, the risk resilience approach is to be adopted. Resilience encompasses resistance, reliability, redundancy, response and recovery. At the heart of the risk resilience approach is the informed tradeoff between risk, cost and performance.

There are eight Steps involved in a ROAM approach as depicted in the figure-1 below.

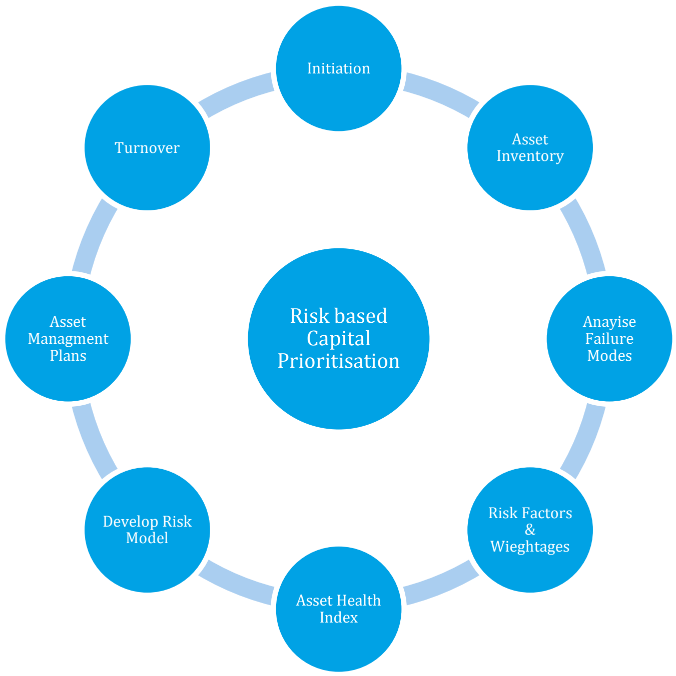

Figure 1 Steps involved in a Risk Oriented Asset Management approach

Let us navigate through the steps one by one with examples from the case study. After the project initiation with set objectives aligning all the stakeholders to a common orientation, an asset inventory is conducted as explained in the following paragraph.

ASSET DATA INVENTORY

The use of "good" asset data is key aspect to asset classification in terms of their existing fitness for use. Table-1 below provides an example of asset data.

Table 1 Asset Data Table: Electric

ASSET CLASS	AVAILABLE DATA	APPROACH	POTENTIAL RECOMMENDATIONS FOR ADDITIONAL DATA COLLECTION	DATA TO DETERMINE CONSEQUENCE OF FAILURE
CLIENT Electric Distribution Substations				
Transformers	DGA (1 year cycle) Physical (4 year cycle) Doble (10	PoF from failure curve via failure mode analysis	Varies depending on Doble tests performed	May include customer impact, Peak load / connected load (MVA), replacement availability, load switching / backup

ASSET CLASS	AVAILABLE DATA	APPROACH	POTENTIAL RECOMMENDATIONS FOR ADDITIONAL DATA COLLECTION	DATA TO DETERMINE CONSEQUENCE OF FAILURE
	year cycle) Meggar (10 year cycle)	Modified PoF from AHI based on DGA, Physical, Doble and Megger results		capability, safety impact, environmental impact
Circuit Breakers	Megger (6 year cycle) Ductor (6 year cycle) Timer (6 year cycle)	PoF from failure curve via failure mode analysis Modified PoF from AHI based on Megger, Ductor and Trip Timer results	Varies depending on circuit breaker type	May include customer impact, Peak load / connected load (MVA), replacement availability, load switching / backup capability, safety impact, environmental impact

Buried assets present a specific set of challenges because, by their nature, data on their condition and performance is more difficult, and therefore costly, to obtain. As the condition of buried infrastructure assets and their environment change, so does the likelihood of failure, presenting a unique problem in the development of an asset risk model.

When considering the performance or condition of gas pipelines for estimating remaining life, it is essential to group the data to allow the unique deterioration rates of different sub sections of the population to be established. If it is found that a particular group or 'cohort' of pipes is particularly critical or the subsequent remaining life analysis shows it to be particularly vulnerable, then the assessment may be focused or 'stratified' towards these assets.

In undertaking the cohort analysis, the following key asset performance characteristics will be considered 1) material type; 2) pipe diameter; 3) pipe age; 4) operating pressure; 5) asset location and 6) leak and repair data.

FAILURE MODES ANALYSIS

Understanding Failure Modes is more than simply making a list of the processes by which assets fail. A List of Failure Modes and Consequences by Asset Class is developed. The table-2 below is a snapshot from a Failure Mode Library document developed by Black & Veatch.

Table 2 Failure Mode Library

FAILURE LOCATION	FUNCTIONAL FAILURE	FAILURE MODE	STRATEGY
Buckholtz Gas Volume Relay	Misoperation	Binding or broken linkage	Functional test (i.e. drain oil from Tfr)
		Installation or maintenance error	
Conservator Tank	Bladder failure	Aging	DGA | Inspection
	Fittings and connection	Installation error	Inspection

FAILURE LOCATION	FUNCTIONAL FAILURE	FAILURE MODE	STRATEGY
	leaks	Vibration	
Core	Loose	Assembly or shipping error	DGA | Vibration | Sound level
		Vibration	
	Loss of core ground	Assembly or shipping error	Core ground testing
		Vibration	
	Multiple core grounds	Assembly or shipping error	DGA, Core ground testing
	Shorted laminations	Over excitation or arcing	DGA
		Poor manufacturing	
		Shipping or handling error	

DEVELOPING RISK FACTORS AND WEIGHTINGS

Asset failures create risk in many areas. These may include simple "Reliability Risk," often quantified as Customer Average Interruption Duration Index (CAIDI) in the electrical industry, performance and safety issues such as "Leaks per Mile," in the gas industry, and other risks that are more difficult to quantify such as those associated with customer service or complaints. Also included are such critical, though more difficult to measure, areas as environmental and safety risks. In this step Black & Veatch worked with the client to understand its tolerance for risk in these different areas and assemble a "Value Function" with weightings that reflect these tolerances so that projects can be weighed against one another. Figure-2 below is an example from a Risk Resilience study carried out by Black & Veatch.

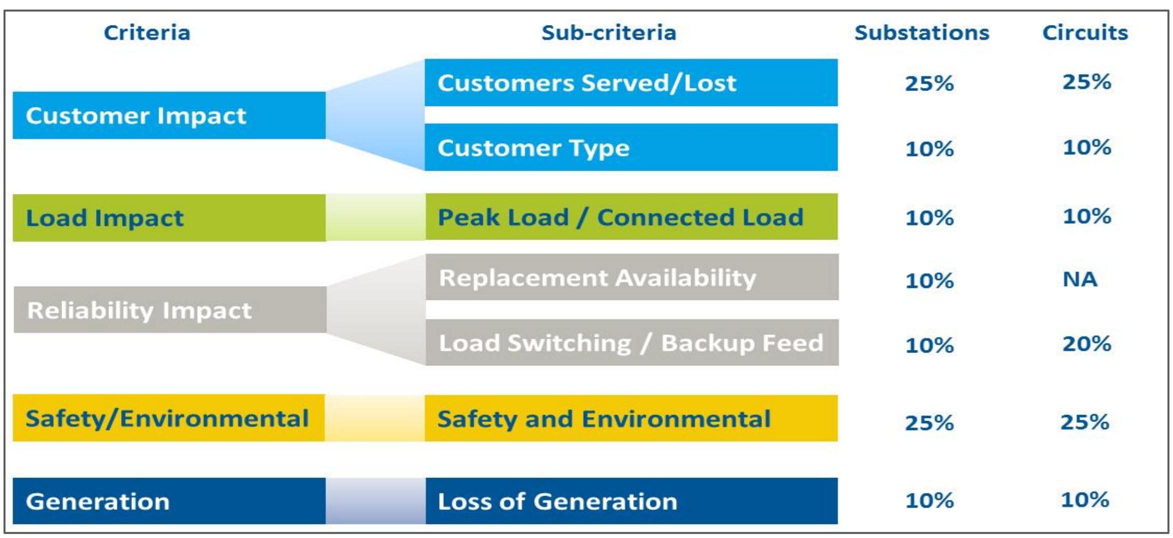

Figure 2 Example Risk Factors and Weightings

DEVELOPING ASSET HEALTH INDEX AND EFFECTIVE AGE ALGORITHMS AND RESULTS

The various data elements are integrated and an in-depth assessment of risk is performed. With the asset registry, and consequence of failure and likelihood of failure defined and evaluated, the asset risk is assessed where:

Risk score = (consequence of failure) x (likelihood of failure)

Using the risk framework definitions developed in the previous step, risk scores for assets can be then plotted on the risk matrix to identify the highest risk assets in comparison to the entire portfolio of assets. All risk elements will be stated developed in reference to the risk categories developed in the previous step. The figure-3 (Heat Map) below provides an example of a 5x5 risk matrix and risk severity ratings.

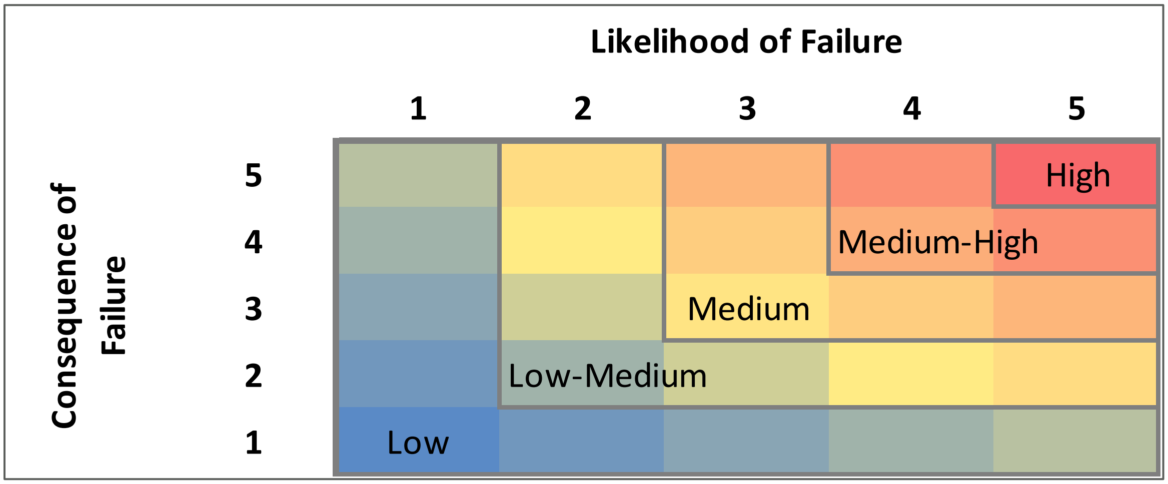

Figure 3 Example 5x5 Risk Matrix and Risk Severity Ratings

Black & Veatch began by selecting an appropriate age-based failure curve for each asset by failure mode, such as one of those shown below in figure-4.

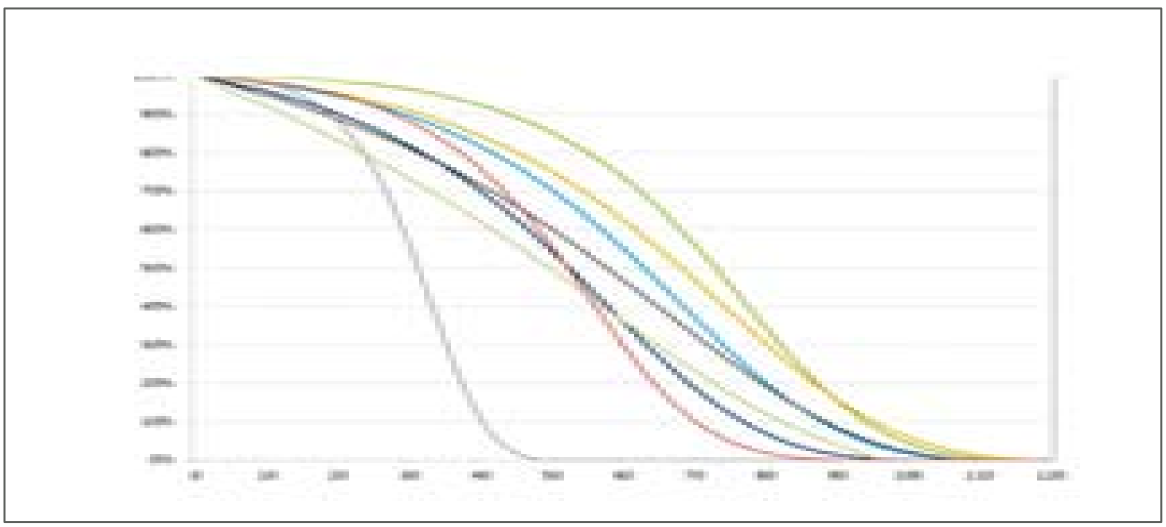

Figure 4 Select Appropriate Age-Based Curve

Then, an “Asset Health Index” to adjust the positioning of the asset on the failure curve by developing an algorithm for each failure mode that yields an “Effective Age” for the asset is developed. This is especially important for critical assets such as transformers, that typically have testing and maintenance data available. Black & Veatch approach to Asset Health Index development is shown in Figure 5 below and entails the combination of asset condition and performance data from monitoring and testing with subject matter expert knowledge.

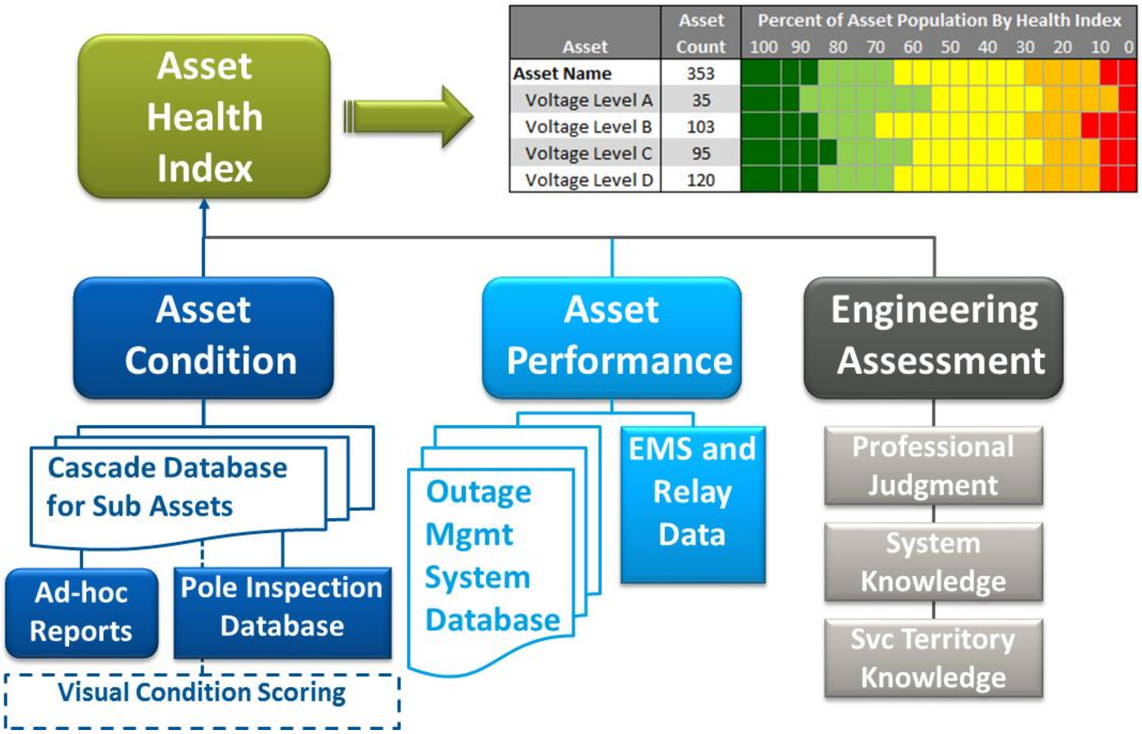

Figure 5 Establishing Asset Health Indices

For assets with insufficient condition data to perform an effective age calculation, Black & Veatch will develop and age-based failure curve and recommend data to be collected in the future. Figure-6 depicts an example of risk matrix based on criteria like: Financial, Operational, Reliability, Compliance, Environmental, Safety, Political, Economical, Sociological, Technological impacts. Discussions also may identify additional criteria to the above, which can be integrated easily into the risk model.

Consequence of Failure	Probability of Failure 1	2	3	4	5
5	33	195	196	99	167
4	491	103	432	41	268
3	442	467	33	460	19
2	85	171	296	456	226
1	117	188	88	2	416

Consequence of Failure	Probability of Failure 1	2	3	4	5
5	$ 106	$ 624	$ 627	$ 317	$ 534
4	$ 1,571	$ 330	$ 1,382	$ 131	$ 858
3	$ 1,414	$ 1,494	$ 106	$ 1,472	$ 61
2	$ 272	$ 547	$ 947	$ 1,459	$ 723
1	$ 374	$ 602	$ 282	$ 6	$ 1,331

Figure 6 Example Risk Matrices showing Numbers of Assets (top) and Replacement Costs (bottom)

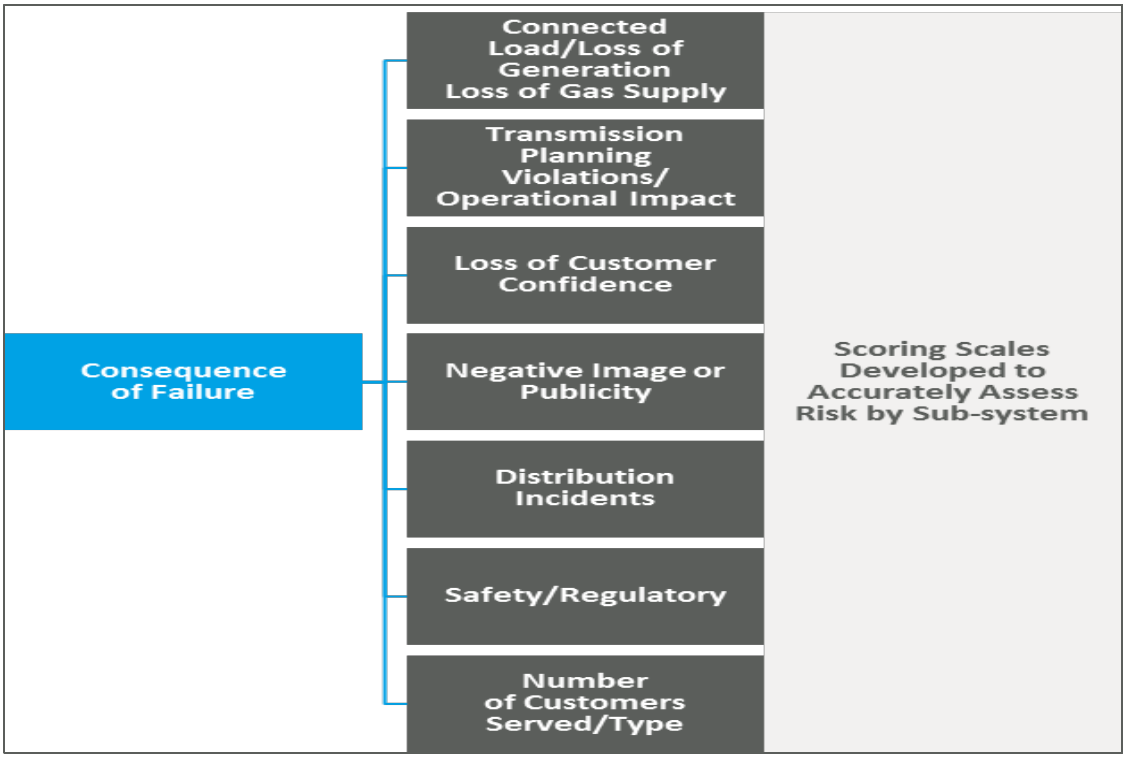

Figure 7 Example of Consequence of Failure Factors

One of the approaches used to estimate the likelihood of failure is through survival analysis,Survival analysis defines a way to assign probabilities to the time of occurrence of an event of any kind, including physical asset failures. Black & Veatch used Weibull analysis in its survival analysis approach. Weibull analysis is a statistical survival analysis that involves fitting a Weibull function to observed event history so that a variety of analysis can be applied including the definition of survival curves like the one below. The Weibull function is commonly used for its ease of use and its ability to describe failure processes defined by infant mortality, constant failure rates, or wear-out. Figure 8 is an illustration of an example of a survival curve developed through Weibull analysis. R software platform is used to develop the Weibull analysis.

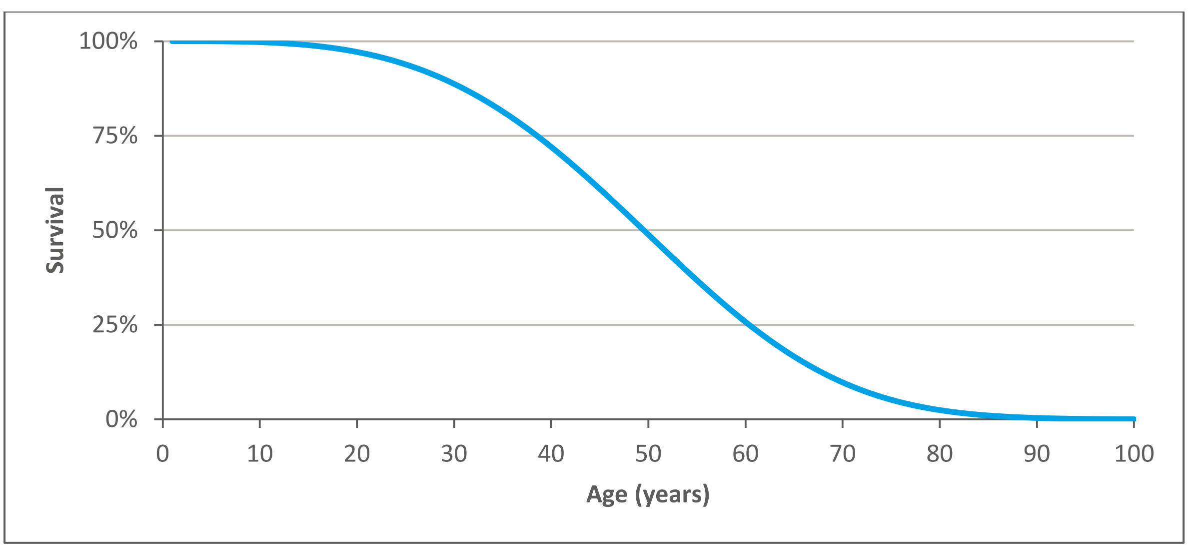

Figure 8 Example Survival Curve from Weibull Analysis

If no failure data is available, Black & Veatch has successfully developed and applied survivor curves for failure estimation for numerous clients and has therefore built up a 'library' of curves for many distribution asset classes. Survivor curves are widely used by utilities as part of depreciation studies to estimate the probable average service life of different assets and set depreciation rates in line with those lives. Service life is defined as the period in years from the initial purchase to the retirement date from service as recorded in the continuing property records (CPR) of the utility. A plot of the retirement dispersions calculated from the CPR data for each FERC account is used to determine "best fit" Iowa survivor (mortality) curves and probable life. Referred to as 'Iowa' curves, the Iowa Type Curves are a codified system commonly used in utility depreciation analyses. An example survivor curve for 138kV power transformers is shown in Figure 9.

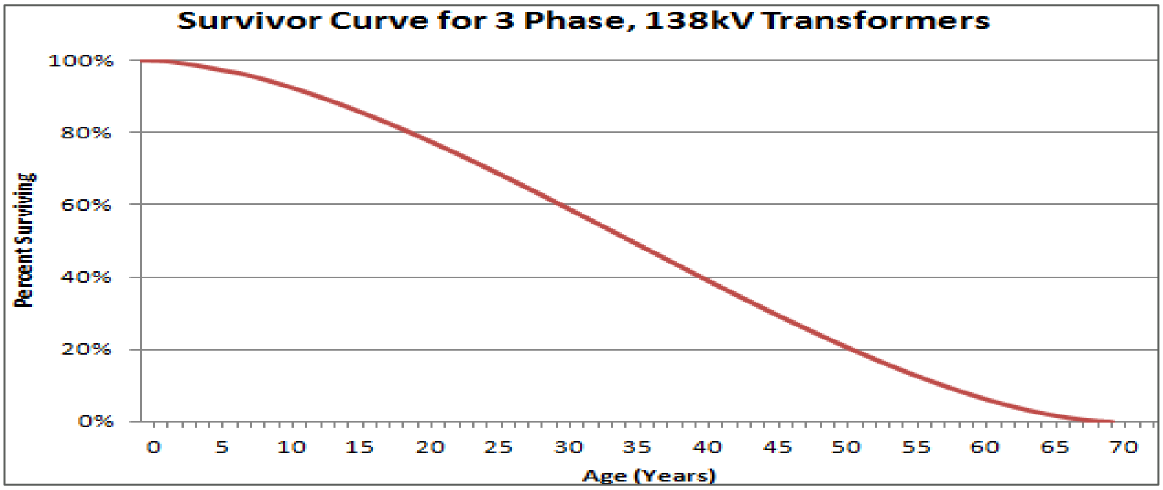

Figure 9 Sample Survivor Curve for a 3 Phase, 138kV Transformer

Once the failure curves or survivor curves have been determined for each asset class, the likelihood of failure of any asset can be estimated based on its age as illustrated in figure 10 below.

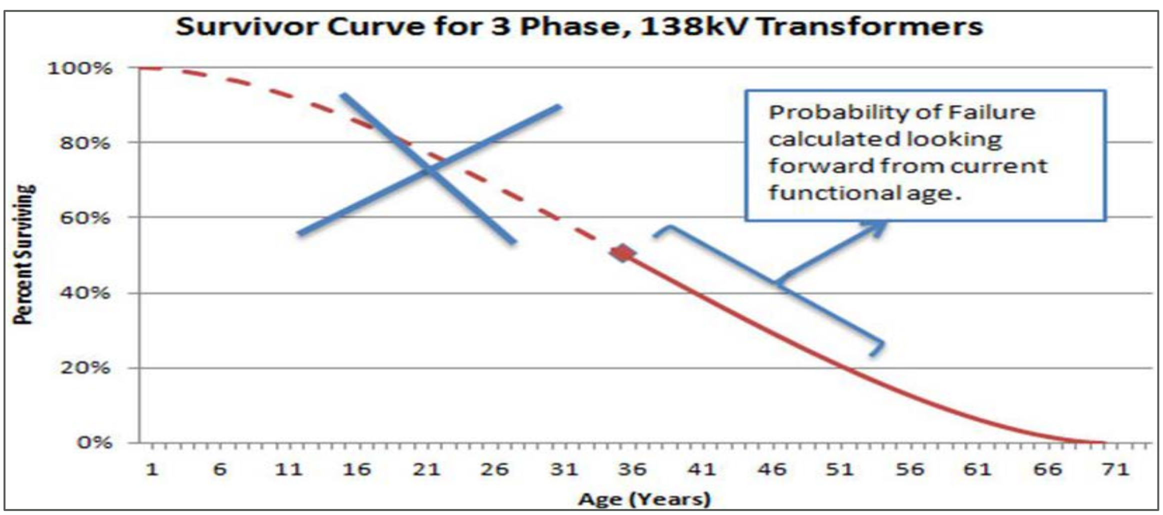

Figure 10 Use of Survivor Curve to Predict Future Likelihood of Failure

The same basic process for both gas and electric assets are used ,however, many gas assets are buried and unavailable for frequent inspection, and in addition, are prey to failures that are difficult to predict from available data. The approach typically taken is to look at "Cohorts", sometimes called "Zones", of asset groups by type, age, or location, that seem to behave similarly.

The focus of the assessment for gas facilities is on risks to public safety, system reliability environmental, financial and customer perception. Grouping of the pipeline assets will be done in a way that acknowledges the most probable failure mechanism(s). The most likely factors include pipe material, pressure, cathodic protection and testing records, pipe coating, diameter, depth, soil type, soil composition, potential, age, installation technique, traffic load potential, and its geographical proximity to people and places.

The relative importance of these attributes will be assessed in conjunction with client's SME staff to select an appropriate set of attributes to evaluate for the cohort analysis. Data sources are expected to include GIS data, and leakage repair data. Based on our expertise we recognize two major types of threats to pipeline integrity:

- Time dependent failure mechanism (failure rate typically increases with time)
  - Corrosion
  - Material degradation
- Random failures (independent of time)
  - Vary only with changing environmental conditions
    - Third party damage- depends on building activity
    - Coating defects
    - Earth movement
    - Material defects
    - Operator error
    - Design issues

For gas pipeline assets the data will be grouped in cohorts or zones of influence which display similar performance characteristics (Figure 11).

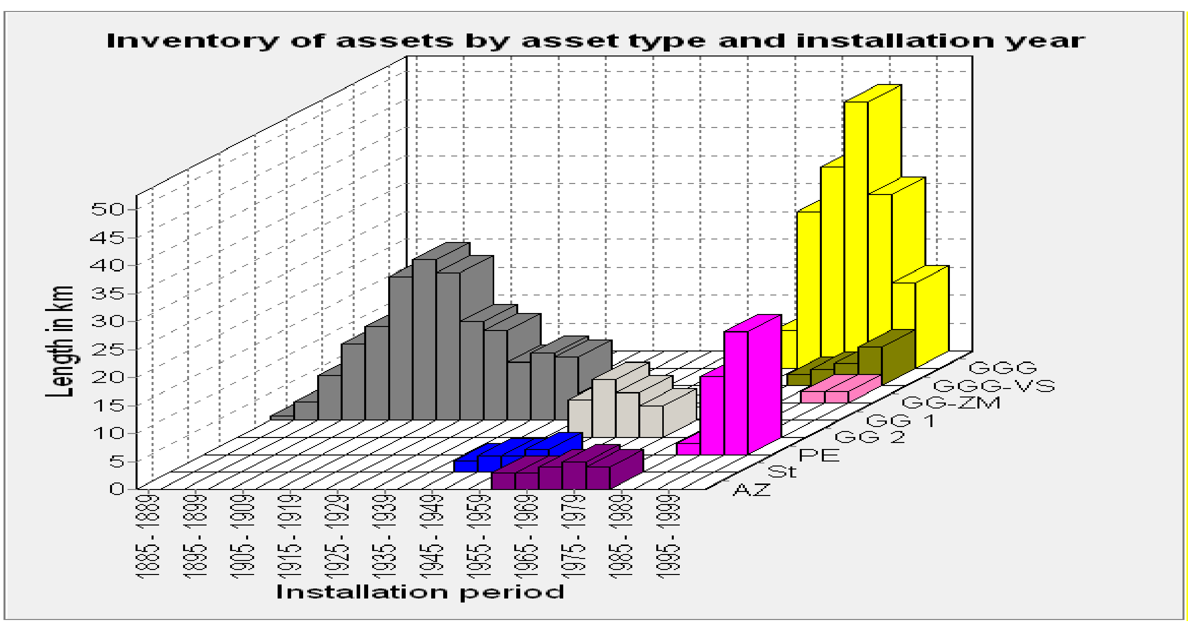

Figure 11 Asset Inventory by Cohort Group

Having analyzed the available inventory and leakage data, the Weibull analysis is used to develop survival curves for each cohort of pipes identified. Weibull involves fitting a Weibull function to observed event history so that a variety of analysis can be applied including the definition of survival curves like the one in figure-12 below. The Weibull function is commonly used for its friendly mathematic properties and its ability to describe failure processes defined by infant mortality, constant failure rates, or wear-out and is therefore ideally suited to the assessment of pipe cohort expected life.

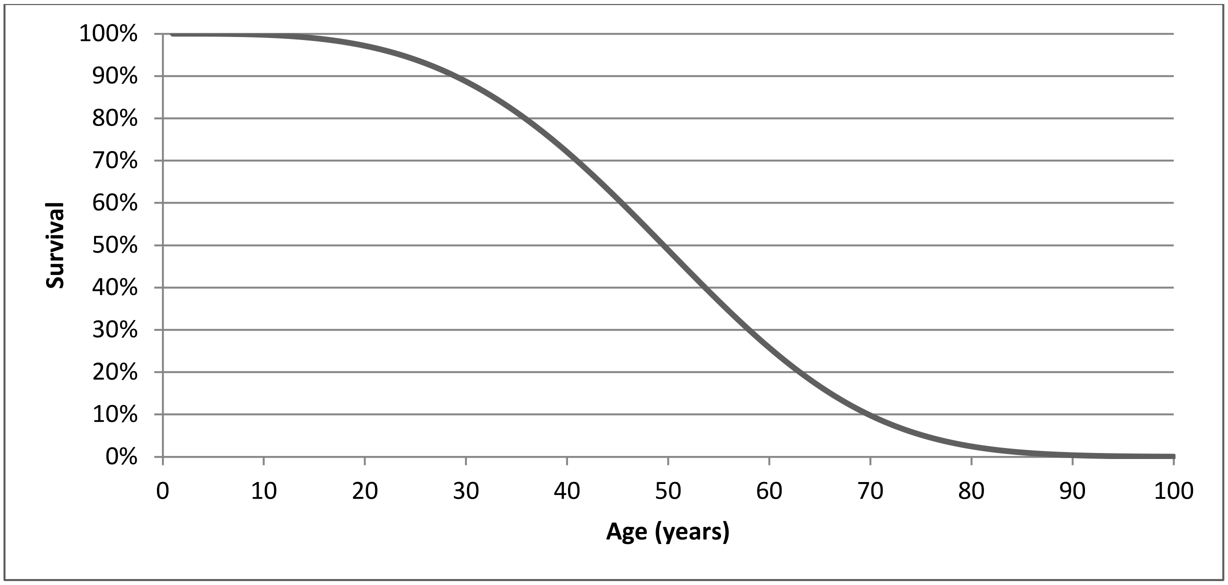

Figure 12 Example of Weibull-based Survivor Curve for Single Asset Class

The resultant cohort level survival curves are shown in Figure 13 below. When evaluating likelihood of failure in the risk model, the appropriate cohort will be utilized and the age of an individual pipe segment will be used to assess the current position on this curve and its remaining life.

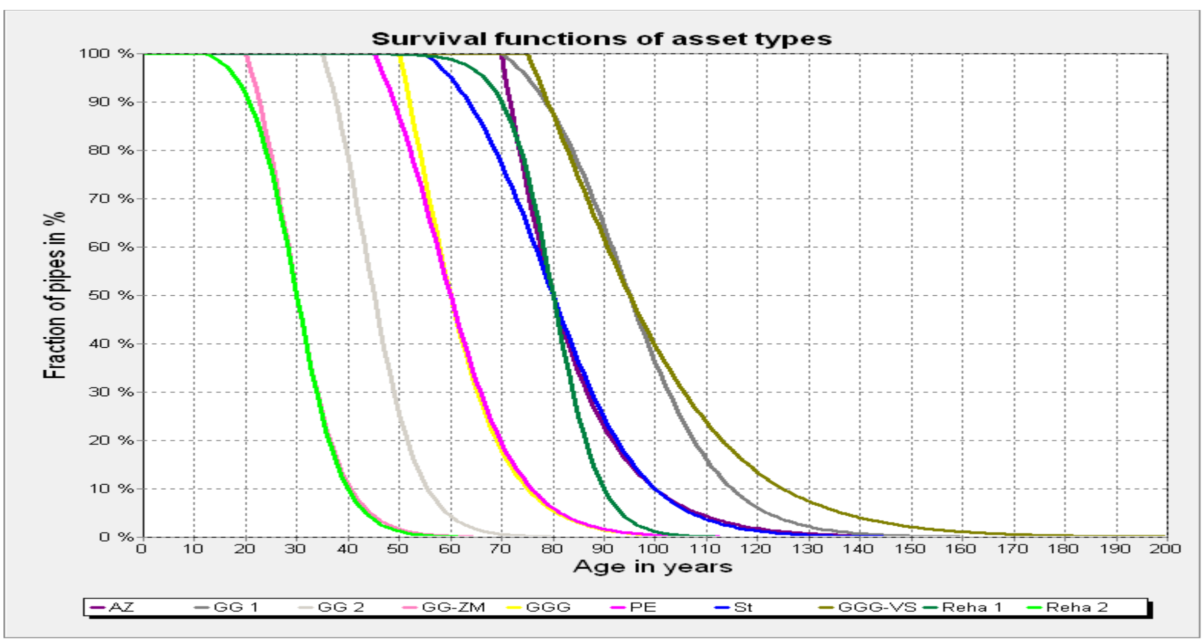

Figure 131 Weibull-based Survival Curves Developed for Identified Pipe Cohorts

This approach predicts the remaining life for each pipe cohort based on failure history and knowledge of the pipe such as installation year, pipe material etc.

The results of this analysis will provide CLIENT with an initial assessment of the useful remaining life of the system based on physical attributes and past performance.

DEVELOPING THE RISK MODEL

The model will:

- Forecast probability of failure in the future and failure mode at a cohort level;
- Quantify risk in terms of utility relatable metrics (CAIDI/ System Average Interruption Frequency Index (SAIFI), Leaks/Mile, O&M Dollars, Replacement Costs, Environmental Remediation, etc.) where possible; it should be noted that many individual assets have a negligible effect on system level metrics such as CAIDI and many clients opt for metrics that lend themselves to a more granular presentation;
- Identify the contribution of each risk factor and asset class failures to impact categories;
- Identify risk indicators.

In establishing the optimal level of expenditure, it is essential that the best balance of cost and risk is achieved. Model outputs such as Figure 14 below serve to illustrate to company boards or regulators the link between expenditure and risk reduction over time.

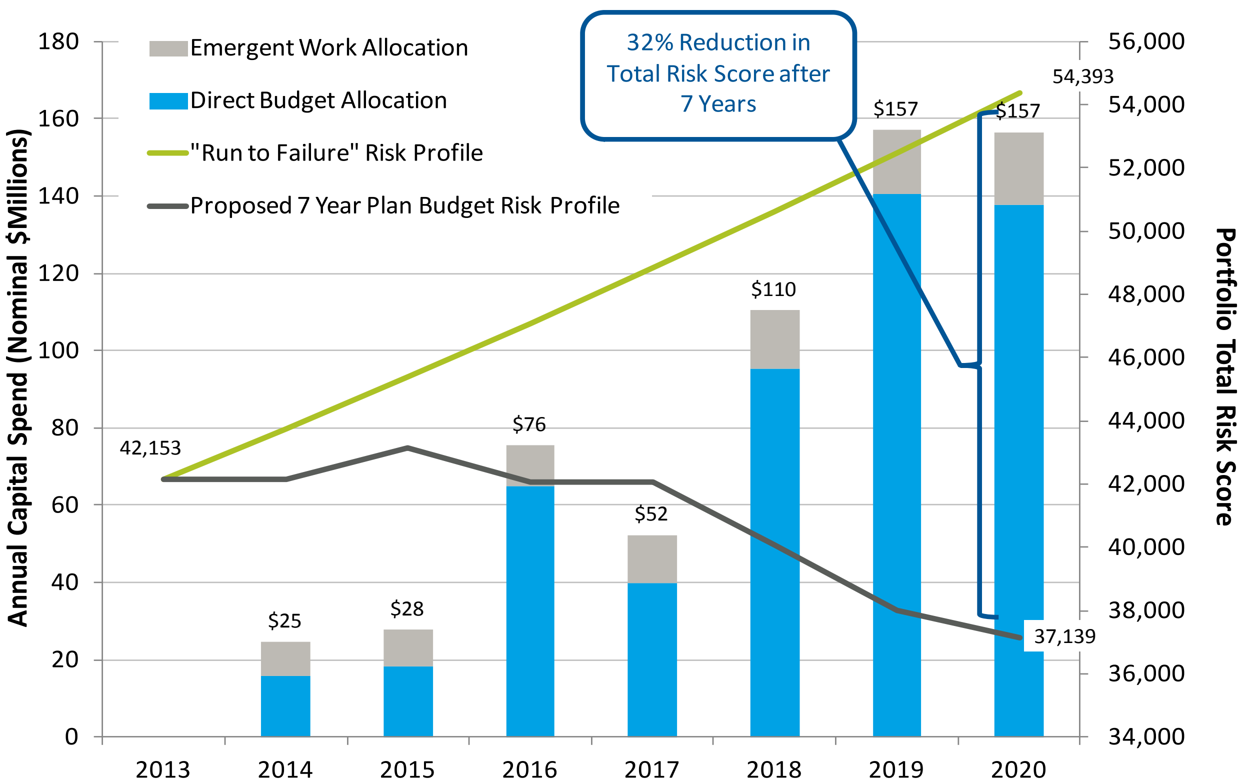

Figure 14 Quantifying the Relationship between Expenditure and Risk Reduction for a 7-Yr Plan

In addition, corporate or regulatory decisions on expenditure levels can be informed by sensitivity testing of the key parameters and assumptions in the model. As an example, Figure 15 below shows the cost and risk reduction achieved by three different assumptions about the timing of investment – P80 (replace when asset is at 80% of its expected life), P90 and the preferred scenario. In this case, the model was used to identify preferred scenario, beyond which costs went up disproportionately compared to the risk reduction achieved. Black & Veatch experience shows that this is a powerful tool for demonstrating the prudence of levels of expenditure.

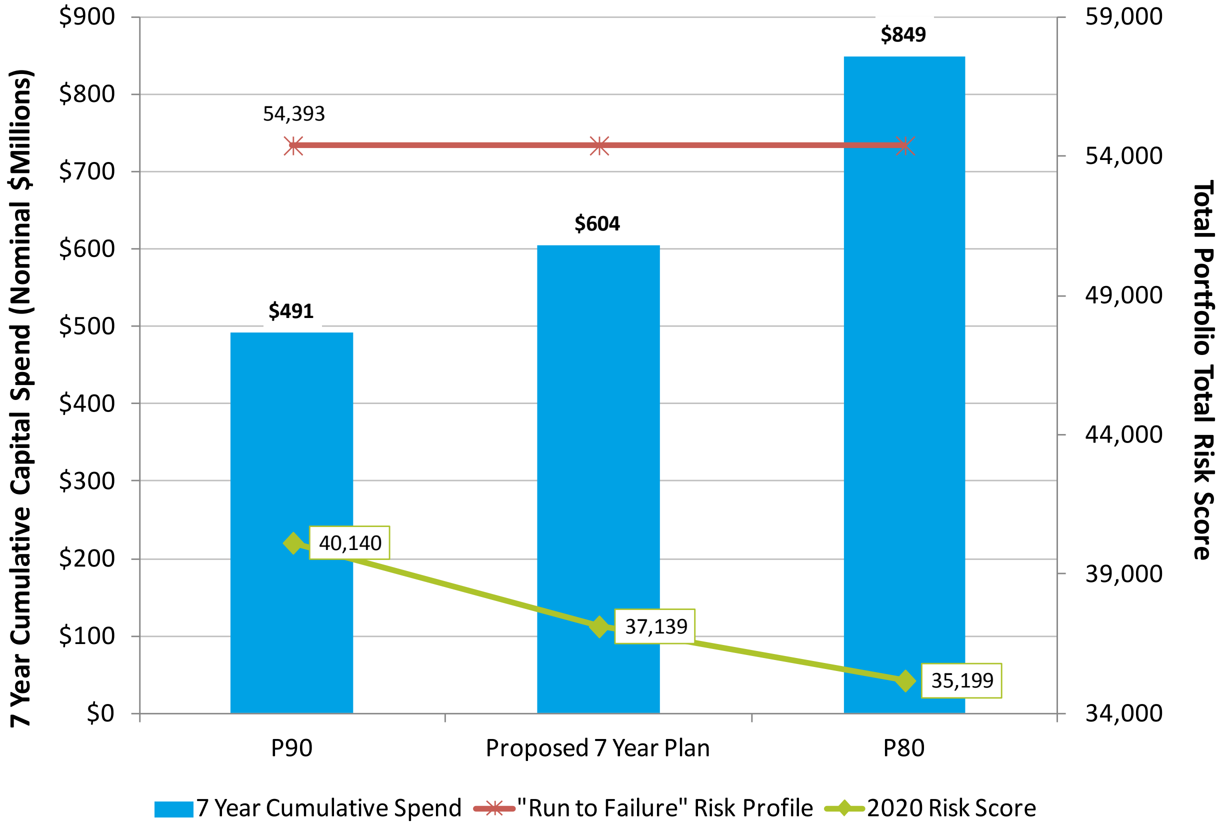

Figure 15 Sensitivity Test on Assumptions Relating to Timing of Replacement

DEVELOPING THE ASSET MANAGEMENT PLAN

The results developed above are compiled into an asset management plan (AMP) for each asset class. The structure of the standard AMP is based on that suggested in the International Infrastructure Management Manual (IIMM) and is as follows;

1. Introduction—Scope and purpose of the plan, key elements;
2. Levels of service—Asset-specific objectives and KPIs; targets and performance against them; regulatory and legislative requirements;
3. Risk assessment—Risk register with results of risk assessments, identified critical assets;
4. Life cycle management plan—Includes maintenance strategy, renewal/ replacement strategy,
5. Financial plan—Budget forecasts
6. Plan monitoring and improvement—Performance measures, improvement plan, monitoring and review procedures.

Part of the AMP will be an assessment of economic life. The physical probabilistic failure models will allow determination of the expected time to first failure for the assets along with the upper and lower limits which define the time period over which the net present value analysis is conducted. Assessment of maintenance frequencies and costs will allow us to identify trends for asset classes in terms of the economic viability of different types and levels of maintenance activity. Using this analysis will enable the 'economic level of maintenance' to be identified and the most cost effective balance between maintenance and rehabilitation/replacement to be defined'.

Costs associated with an asset are then expressed in terms of the discounted failure risk up to the time of intervention and the discounted cost of asset inspection and replacement. Benefits are expressed as the "avoided" failure risk estimated between the intervention time and the upper limit of time to first failure. The net present value (NPV) of intervention is then expressed as the difference between these discounted benefits and costs, with the time of maximum NPV corresponding to the most cost effective time for intervention.

The plot below shows an example of an NPV analysis conducted on a cast-iron pipeline**.**

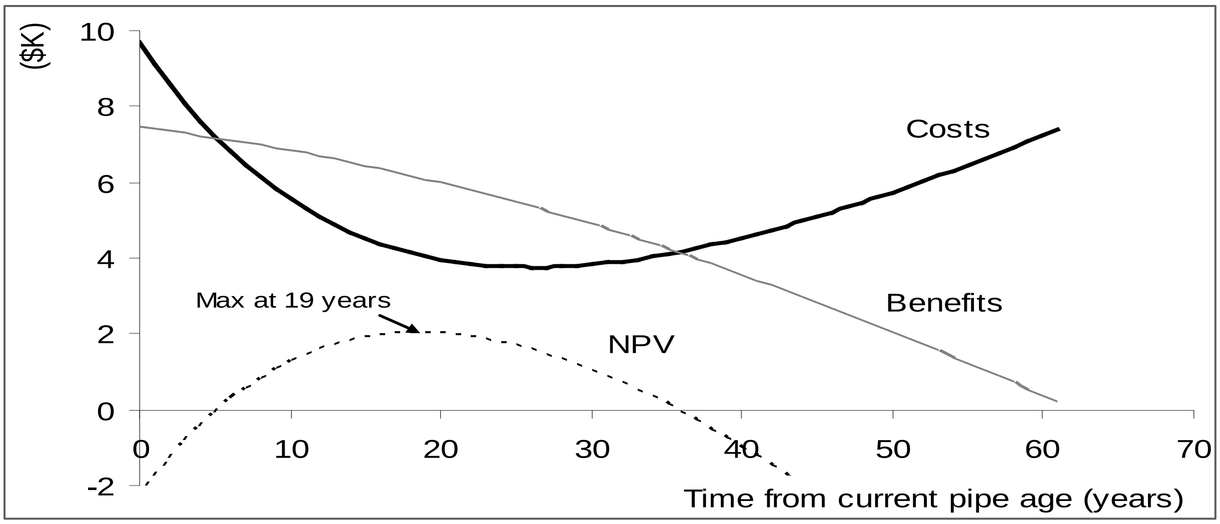

Figure 162 Cost-benefit Analysis of a Cast Iron Pipeline. The time of maximum NPV indicates most cost effective replacement schedule. (Taken from Davis, 2006)

TURNOVER

The project culminated with training of client's Asset Management practitioners on methodologies and approaches used, as well as the modeling tool.

CONCLUSION

The risk oriented asset management (ROAM) approach thus helps in informed tradeoff between risk, cost and performance improving the resilience of critical infrastructure to all potential hazards through resistance, reliability, redundancy, response and recovery.