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A Case Study of a Criticality Model to Recalibrate the Unfunded Liability Forecasts in a Standardized Capital Needs Assessment

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ABSTRACT

Many asset intensive organizations face the perennial challenge of working with constrained budgets to achieve their asset management objectives. Quantification of the funding requirements for sustainment of their asset portfolios is often determined by a Capital Needs Assessment (CNA) that forecasts the unfunded liabilities facing the organization. The size of the gap between the organization's means and its needs depends on several factors, including: the age of the assets; the quality of maintenance; the local exposure conditions; and historical funding levels. Responsible stewardship of the organization's funding gap requires a two-pronged strategy: the development of a compelling business case to advocate for additional funding; and a prioritization scheme to defensibly support the annual cycles of appropriation of the limited resources to certain projects on certain assets.

This paper presents a criticality model and a case study of a Canadian University that implemented the model. The model draws upon a hybrid of statistical (quantitative) and empirical (qualitative) methods to achieve the means-and-needs analysis by evaluating the pre-existing estimate of the unfunded liabilities, determining whether a recalibration is required and providing a prioritization schema to optimize distribution of the available funds. The statistical elements of the model reference a library of asset survivor curves to evaluate the local and global maxima for forecasting asset service life. This is coupled with facilitated workshops with the organization's domain experts to elicit qualitative information to align the model to the institutions' objectives, such as on decision-making criteria and weightings for certain variables in the model. The output of the model is a recalibrated forecast of the unfunded liabilities that optimize the inevitable trade-offs that must be made in the face of a funding gap.

KEY WORDS. Criticality; priority; proximity; survivor curve; functional failure; modal year; global maxima; local maxima; case study.

1 INTRODUCTION

The Canadian Infrastructure Report Card of January 2016[7] contained as one of its key messages that "(i)ncreasing reinvestment rates will stop the deterioration of municipal infrastructure". Many asset-intensive organizations share a common challenge of insufficient funds for sustainable stewardship of their asset portfolio. When organization's grapple with this challenge they find that it decomposes into two interconnected problems:

- *The Criticality Problem* – How much money will the organization realistically need over period 'x'?
- *The Priority Problem* – How should the organization optimize the distribution of its limited budget?

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These problems are interconnected in that *priority* cannot be properly ascertained without a clear understanding of *criticality*, as the latter sets the framework for understanding the relationship between what is urgent and what is important. In turn, *criticality* is meaningless if the quantification of the costs is inaccurate.

This paper advances a criticality model that has been applied within the MUSH Sector (Municipalities, Universities, Schools and Hospitals) and a case study is used to demonstrate its efficacy at a leading Canadian public university facing similar challenges. Regardless of the sector an organization operates in, the *criticality* and *priority* concerns are the same.

2 THE O_2 MODEL

The model, where the O's represent *oversight* and *optimization*, is intended to help an organization determine the right work, to be performed on the right assets, at the right time, and for the right cost (Figure I).

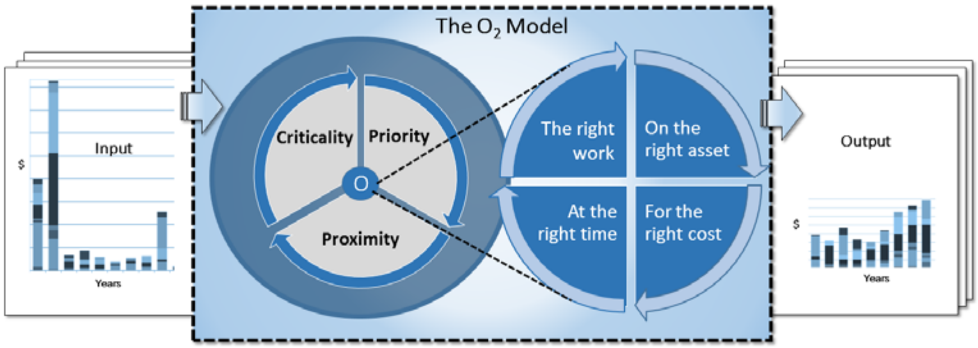

Figure I. The conceptual model

The model contains ten elements (Table I) that interact algorithmically. These are organized into a back-end that contains the quantitative (statistical) elements, and a front-end to receive the qualitative (empirical) elements from the organization's internal and external stakeholders.

	Element of the O_2 Model	*Objective*
A	Back-end	
	1. Five core concepts	To articulate the relationship between criticality and priority
	2. The source data	To serve as the baseline data to be imported into the model
	3. The 12 data filters	To establish criticality rankings for the assets
	4. A scoring mechanism	To rank the assets
	5. A library of risk profiles	To visualize risk
	6. A library of survivor curves	To convert criticality into priority
	7. The algorithm	To calculate the next event year
B	Front-End	
	8. A series of workshops	To elicit input from domain experts / knowledge resources
	9. A weighting mechanism	To translate the input into the model
	10. A suite of visual analytics	To translate a business case to top management

Table I. Elements of the *O_2* model

While space does not permit a full exploration of all the elements of the model – some of which are proprietary – the paper provides sufficient information to evaluate the value proposition so that other organizations can build upon this foundation.

2.1 The Five Core Concepts

The following key terms are used to articulate the intended outcomes of the *0_2 Model:*

- *Oversight* – the processes an organization uses to establish its objectives and the continual improvement through monitoring and evaluation. Oversight provides the criteria for determining what is considered to be of value to the organization.

- *Criticality* – the importance of something relative to the stakeholders' objectives and applies to objects with intrinsic value, such as a building (vertical asset) or infrastructure (linear asset). Criticality is determined by the oversight process.
- *Proximity* – the changing circumstances and conditions that occur to an asset over time, such as physical degradation and functional obsolescence, which result in an emerging priority. Proximity is the bridge linking criticality to priority.
- *Priority* – the level of deemed urgency, at a given point in time, in accordance with stakeholders' needs and changing circumstances. Priority is the emergent property of the intersection of criticality and proximity.
- *Optimization* – the balance in the trade-offs that occurs when satisfying the correlation of importance and urgency, particularly with limited budgets and in alignment with the organization's objectives (such as risk and sustainability).

The outputs from the model are a suite of graphs and financial tables that facilitate risk-based and whole-life decision-making as contemplated by the ISO 55000 standard of asset management [8].

2.2 The Source Data

The source data comes from a variety of studies, including condition assessments, maintenance assessments and capital needs assessments. If the data is not captured in a structured, tabular format, such as an SQL database or spreadsheet, then additional steps are required to convert the narrative so that it can be migrated into the model. At a minimum, the source data must include an inventory of the assets and estimate of the asset replacement costs.

2.3 The Criticality Filters

Every asset in an organization's inventory is evaluated against a suite of filters that are utilized to derive a series of criticality profiles and composite criticality rankings.

Name of Filter	*Objective of Filter*
1. Bounding status	Are there regulatory requirements on operations and replacement?
2. Consequences of Failure (CoF)	What is the risk associated with failure of the asset?
3. Probability of Failure (PoF)	How long is the interval between a potential failure ("P") and functional failure ("F")?
4. Knowledge of "F"	How easy is it to determine when functional failure ("F") will occur?
5. Intervention Opportunities	Can an asset be maintained to extend its life?
6. PdM diagnostics	Are there diagnostic tools to identify concealed conditions?
7. Empirical Confidence	Is there more detailed information on an asset's condition?
8. Phasing Opportunities	Can the asset renewal cost be spread out?
9. Bundling Opportunities	Should the asset's renewal be grouped with something else?
10. Adaptation Opportunities	Will changes be required to the asset to address obsolescence?
11. Replacement policy	What is the institution's policy for this type of asset?
12. Mission Dependency Index	How important is the building (asset) to the organization?

Table II. The twelve criticality filters

If some data is absent, the corresponding filter(s) are deactivated and the criticality profiles and aggregated scores are derived from a smaller suite. Missing data can be added at a later date – such as during an asset re-assessment cycle.

2.4 The Scoring Mechanism

The twelve filters provide a means for an organization to derive a statement on the relative criticality of the assets within the overall asset portfolio or a designated group of in-scope assets. This is achieved by applying a series of scores across each of the filters, which are further developed into an aggregated score (for each asset or asset class) and a composite score that blend the results of a group of assets, either at the level of a system or a single facility. For example, the relative criticality of one system (say, mechanical equipment) over another system (say, electrical equipment) is derived from the composite scores of all the assets that belong to those respective systems.

2.5 The Criticality Profiles

The multivariate criticality data is represented visually on radar charts where each spoke represents one filter (single, aggregated, or composited). The data length of a spoke is proportional to the magnitude of the subject filter and the resultant polygonal shape represents the overall criticality profile. Some of the attributes of the multivariate criticality profile are shown in Figure II.

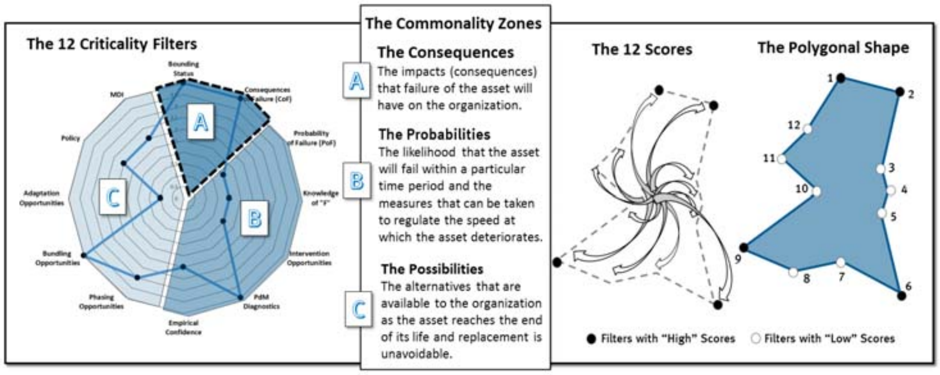

Figure II. Some of the key analytical elements of the criticality profiles

Figure III provides an example of three profiles of different assets with their respective polygonal shapes.

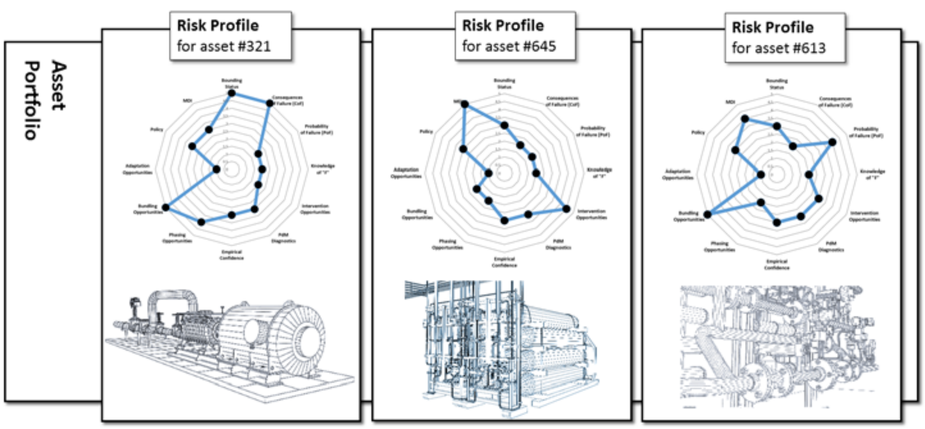

Figure III. Three radar charts illustrating the variability in asset criticality scores and profile polygons

Radar charts are susceptible to occlusion – the obscuring of data if too many profiles are overlaid on top of one another. Therefore, the model produces these charts primarily for assisting in pairwise analysis for the direct comparison of two assets, two systems or two facilities. The individual scores, however, that yield the polygons are essential in a subsequent step in the algorithm for establishing proximity along a planning horizon, which allow for multivariate analysis of larger asset groups. Figure IV illustrates how a capital project in a planning horizon has a corresponding criticality profile that can be used for strategic and tactical purposes in the process of planning, evaluating and implementing individual projects.

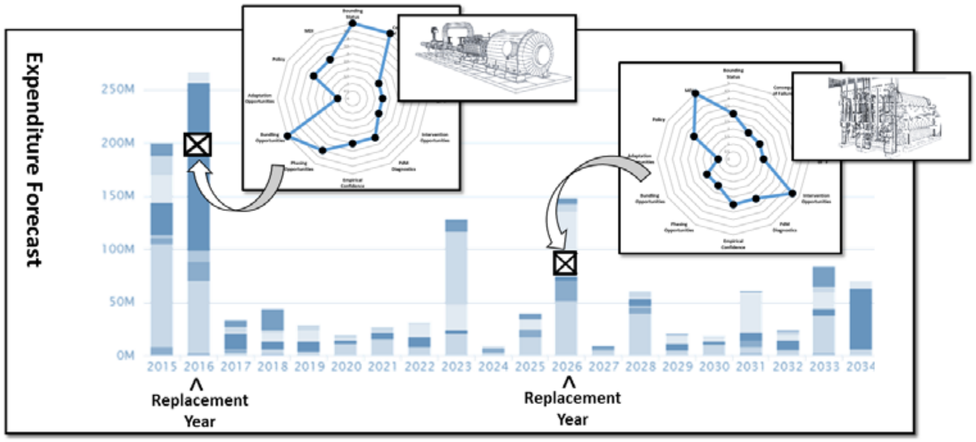

Figure IV. The criticality profiles of two assets relative to the baseline expenditure forecast

While the criticality profiles are a necessary element for establishing the urgency of individual projects, they are not sufficient in themselves. Criticality is a static picture of asset value to the organization (i.e. importance) that needs to be mapped to a dynamic context of changing circumstances (i.e. urgency).

2.6 The Survivor Curves

In order to advance from criticality to priority, the *O_2 Model* draws upon a library of asset survivor curves that are being generated through a longitudinal study of tens of thousands of MUSH-sector assets, administered through the Canadian Scientific Research and Experimental Development (SR&ED) Program[6].

Survivor curves, also referred to as probability distribution curves, are used to ascertain the probability of failure (PoF) of an asset during any particular calendar year and are derived from the statistical data on the functional failures ('F') of all the assets within a statistical population[3]. The *O_2 Model* references five key stages on the survivor curves as follows:

- *The Modal Year* – the year in which most asset retirements occur. This is typically derived from industry guides such as RSMeans[10], Whitestone[12] and BOMA standards[5].
- *The Global Maxima* – the longest observed service life for the subject asset in all observed contexts internationally or wherever the asset has been in service.
- *The Local Maxima* – the longest observed life for the asset in its particular geographical context recognizing factors such as climate zones, geology, topography, regulations, space-user behaviour.
- *Global Minima* – the shortest observed service life for the subject asset in the all observed contexts internationally or wherever the asset has been in service
- *Local Minima* – the shortest observed service life for the subject asset in its geographical context

Once survivor curves have been matched with assets, the global maxima and global minima are used to set parameters for the prioritization of each asset (Figure V).

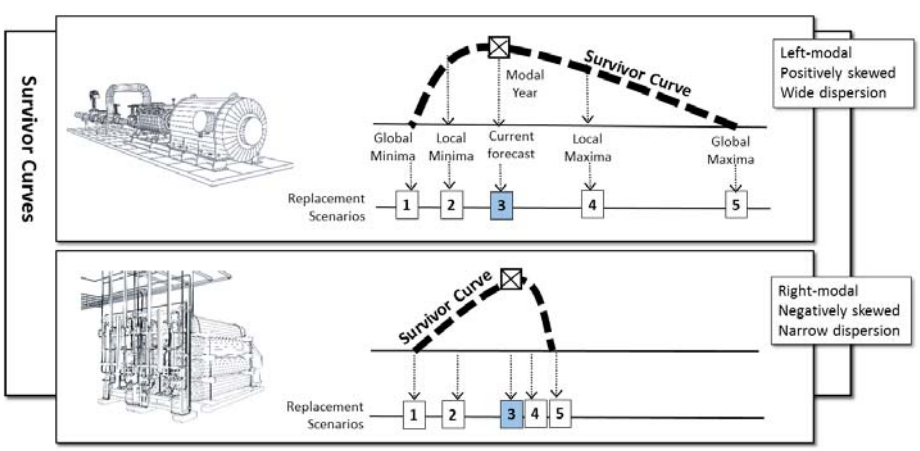

Figure V. Examples of the survivor profiles of two assets

The matching of survivor curves to assets is then extended by overlaying those curves onto the baseline expenditure forecast. This reveals the relationship between the modal year and the furthest point of dispersion on the survivor curve. Figure VI illustrates this relationship with a left-modal survivor curve.

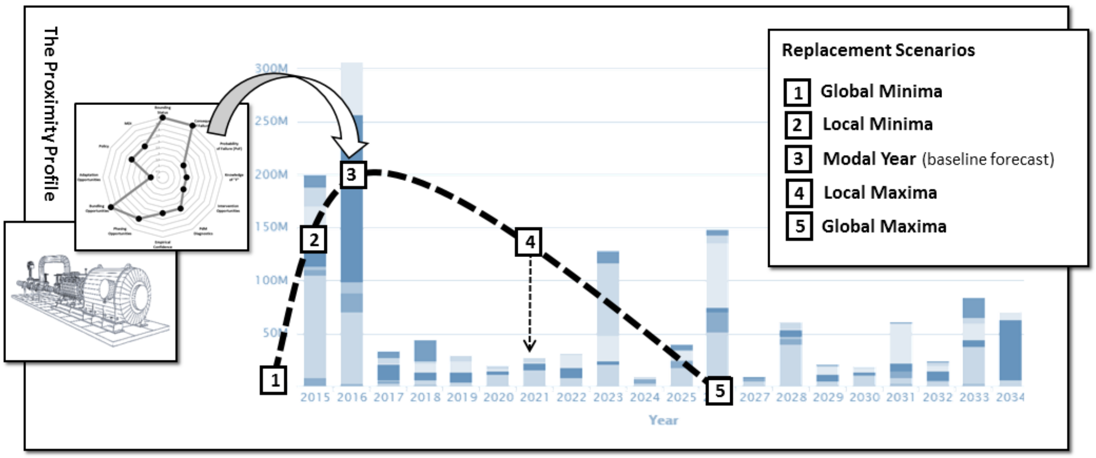

Figure VI. The survivor profile of an asset is mapped onto the expenditure forecast

While the global maxima provides an organization with the best possible scenario, this is not necessarily a realistic target for many assets in their local context. Where the local minima correlates with the earliest potential date for functional failure the local maxima represents the likely last date for functional failure of a single asset within its population group [3] .

2.7 The Algorithm

The application of the algorithm entails four key steps:

Step A: Match the survivor curve to each asset and overlay them individually onto the expenditure forecast

Step B: Identify where the global maxima falls on the forecast

Step C: Apply the scores from the 12 criticality filters against the global maxima

Step D: Determine the local maxima yielded by the calculation (including application of the organization's weightings)

Figure VII illustrates how these steps are applied against the global maxima of two assets that share the same survivor curve but occupy different facilities.

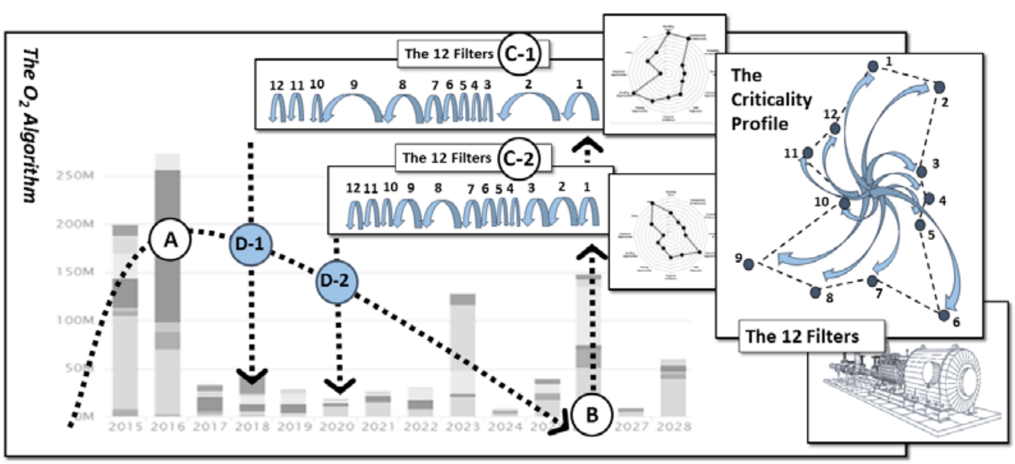

Figure VII. The four key steps of the algorithm (A, B, C and D)

Figure VII illustrates the impact of different score series on the resultant proximity profile. The first asset received a higher aggregate score (C-1) than second asset (C-2) and this translates into a higher prioritization ranking (D1 on the survivor curve).

Given the variety of assets in a typical portfolio of an asset-intensive organization, and their variability in performance, the algorithm needs to accommodate a wide range of scores. The resulting analytics provide an opportunity for the organization's stakeholders to conduct sensitivity analyses to test against organizational objectives and scenario development for risk management and planning purposes. Table III summarizes some of the different scoring scenarios and their respective outcomes returned by the model.

	Scoring Parameters	*Result/Outcome*
	Normal Cases	
1	If the asset receives a zero score on all 12 of the filters	Then the asset renewal year defaults to global maxima on its survivor curve
2	If the asset receives the maximum score on all 12 filters	Then the asset renewal year defaults to the modal year on its survivor curve
3	If the asset achieves a score that falls between zero and maximum on any combination of the 12 filters	Then asset renewal year falls between modal year and global maxima
	Special Cases	
4	If the asset achieves a full score on the bounding filter (#1) but variable scores on the other filters	Then the asset renewal year falls between the modal year and local maxima (or a year defined by local regulations)
5	If the asset is turned off in the model	Then the asset renewal year falls to the modal year on its survivor curve
6	If an excessive number of filters are suspended due to a lack of data	Then the asset renewal year falls to the modal year on its survivor curve
7	If the facility is turned off in the model	All asset renewals (of the subject facility) fall to the modal year on their respective survivor curves

Table III. Alternative score results and outcomes

Depending on the quality of the published observed life data in any particular geographical area where the model is applied, the scoring range in the model can be set so that the survivor curves are bounded between one of the following ranges: a) between local minima and local maxima or b) between modal year and global maxima.

2.8 The Recalibrated Expenditure Forecast

The final step in the model is the recalibration of the baseline expenditure forecast presented as a series of stacked bar charts that show the redistributed projects. Figure VIII shows how a single asset's expenditure forecast is recalibrated after applying the 12 criticality filters and survivor curve analysis.

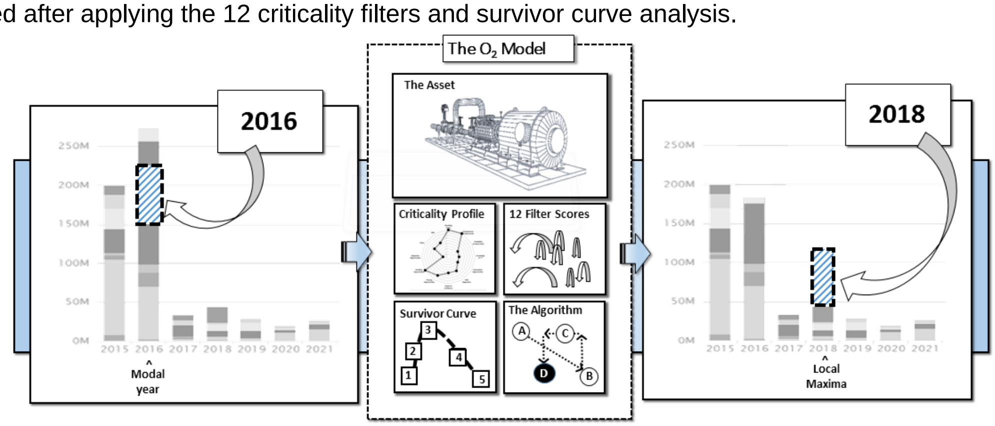

Figure VIII. The recalibrated expenditure forecast of a single asset

In order to make informed decisions at different levels of an organization, stakeholders require the disclosure of the assumptions and a synopsis of the results in both tabular and graphical format supported by data tables. Fiscal cycles and annual cycles require the model to be refreshed periodically.

3 THE CASE STUDY

3.1 The Context of the Organization

Established in 1965, Simon Fraser University (SFU), one of Canada's top teaching and research universities, extends across three campuses with 30,000 students and 130,000 alumni [11]. In 2009, the Province of British Columbia's Ministry of Advanced Education deployed protocols for standardized capital needs assessments at all post-secondary institutions in the province [4]. SFU participated in the provincial assessment program and referenced this information as its baseline database of ongoing funding requirements.

The master register of physical assets at SFU contemplates tens of thousands of elements that can be organized into three broad classes:

- *Vertical Assets* – buildings, such as teaching facilities, research facilities, and support buildings.
- *Linear Assets* – support infrastructure, such as campus roadways, a district heat generating plant and main electrical vault.
- *Portable Assets* – smaller assets like teaching equipment, laboratory equipment (wet and dry), library equipment, and commercial kitchen equipment.

On the largest, and oldest, of the three campuses, the organization has a complex configuration of linear assets that traverse multiple vertical assets on an integrated campus. This is coupled with a plethora of portable assets that are located within the different facilities and are the responsibility of the varied stakeholder groups, including the teaching and research departments.

3.2 The Organization's Challenge

As with most asset-intensive organizations, SFU wrestled with its own unique version of the criticality problem (*How much money is realistically required?*) and the prioritization problem (*How to distribute the constrained budget resources?*).

Since 2009 the facilities management team had relied upon the baseline database in order to ascertain the expenditure forecasts for certain classes of assets. With each successive fiscal cycle, the baseline database automatically aggregated an accumulated backlog of deferred maintenance.

After some cycles of strategic planning with the data that had been generated under the Ministry's assessment mandate, the SFU team found challenges in prioritization of the reinvestment alternatives, particularly within a constrained funding envelope. The heavy front-end loading of the expenditure forecast, coupled with a burgeoning backlog calculation, presented an extremely onerous funding requirement that far exceeded the available funding level.

The estimated funding gap was approximately 10 times the size of the available funding level and increasing with each fiscal cycle.

3.3 The Root Cause Analysis

In discussions with internal and external stakeholders, several factors were determined to be at play in causing the heavily skewed front-end loading of the expenditure forecasts. Figure IX provides a summary of the root cause analysis.

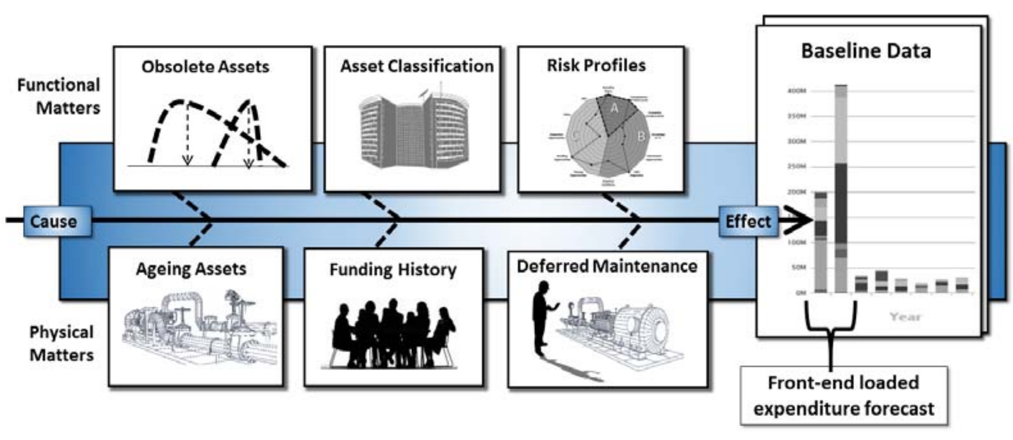

Figure IX. Primary cause-and-effect relationships from the Root Cause Analysis (RCA)

The cause-and-effect relationships were wound together in a complex knot of technical, financial and functional issues.

- *Ageing Assets* – the 50-year old organization had an asset portfolio that had sustained decades of physical degradation that required continual reinvestment to ensure the ongoing performance of the assets, many of which were still original.
- *Historical Funding Levels* – the organization had not received adequate funding for all the necessary and sufficient major maintenance for preservation of the assets and also for capital renewal projects at the end of life of certain assets.
- *Deferred Maintenance* – as a result of the increasing care required of the ageing assets and the inadequate funding levels, a backlog of deferred maintenance had accumulated incrementally over several years.
- *Obsolete Assets* – over time, some of the assets were unable to meet the increasing demands of changing programmatic needs of the space users and other stakeholders (functional obsolescence). Other forms of obsolescence arose due to factors such as seismic protection and asbestos containing materials (legal obsolescence), energy efficiency measures (economic obsolescence), and new products and materials (technological obsolescence).
- *Asset Classification* – the boundary definitions of the asset classes and their respective assignment within the asset hierarchy had not been fully articulated. In some cases, the capital needs assessment had attached the unfunded liability estimates of portable assets to certain buildings rather than to the respective institutional department.
- *Asset Lifecycles* – the baseline database had derived the useful service lives of the assets from a third party publication that provided the modal years without the full probability distribution. The baseline database automatically deemed that many of the assets were beyond their useful service life, although many were still functioning.

The baseline forecast, albeit helpful for order of magnitude estimating, was considered inadequate to develop more nuanced business cases for the planning and funding of capital projects on annual fiscal cycles.

3.4 The Solution

In the absence of a more sophisticated asset deterioration model that could accommodate the complexities of the varied assets in the portfolio, the asset management team decided that it would be prudent to add a criticality layer to the baseline dataset in order to derive a meaningful prioritization and optimization strategy for each class of assets.

Recognizing the value of the standardized protocol that had been applied across the post-secondary sector, the model employed a hybrid of methods (statistical/quantitative and empirical/qualitative) to leverage the existing data and the knowledge resources within the organization without having to undertake a financially onerous new baseline assessment.

Statistical/Quantitative Methods	*Empirical/Qualitative Methods*
Correlation of the baseline data with asset survivor curves that provide more information than modal year of retirements	Facilitated workshops with domain experts (operational staff) in each of the institution's departments to provide decision criteria, weightings and other factors
Application of a suite of criticality filters to establish how each asset may be considered an "average", "poor" or "high" performer relative to the statistical population of its class.	Interviews with consultants familiar with the assets to elicit their insight on asset performance relative to industry standards

Table IV. The hybrid sources of data for the model

The data on thousands of assets were filtered through the *O_2 Model* and tested at different sensitivity levels. This resulted in a rank score for each asset that could be used to make defensible resource allocation decisions.

3.5 Alignment with Organizational Objectives

In addition to the statistical principles for quantitative analysis, the *O_2 Model* provided four qualitative means to achieve alignment with SFU's organizational objectives: 1) workshops with the organization's teams, 2) interviews with stakeholders; 3) weightings for the criticality filters; and 4) scenarios for testing sensitivity. Figure X illustrates the two parallel streams of quantitative and qualitative methods.

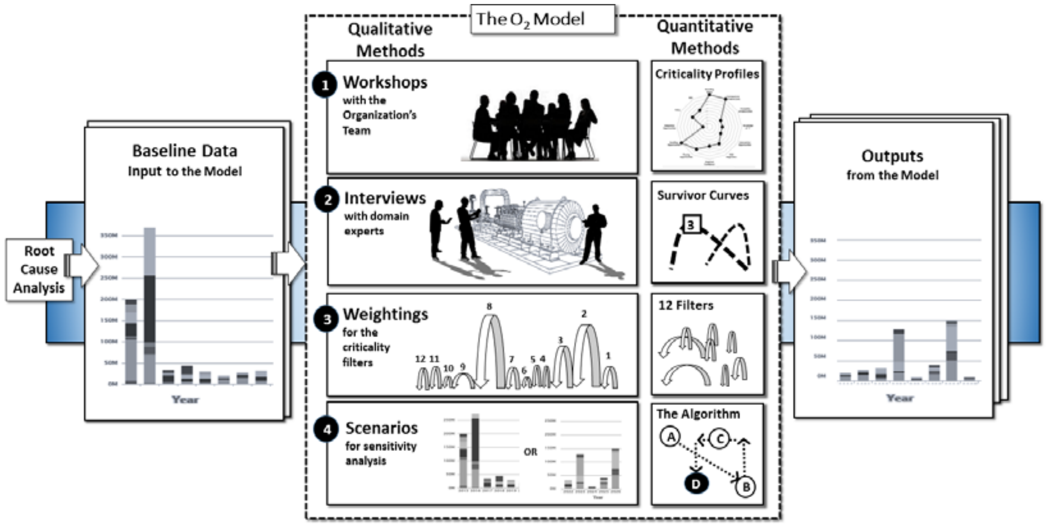

Figure X. Alignment of the model with organizational objectives

The following data collection methods were employed:

1. *Internal Stakeholder Workshops* – SFU arranged for its top management and line staff in different functional groups to meet as a single group and as separate groups enabling the consulting team to obtain the following inputs:
   - the asset register, asset classification and departmental costs
   - scores to be applied to the quantitative filters for establishing asset criticality
   - knowledge of local maxima and minima for certain assets based on *in situ* performance rather than theoretical service lives
   - whether to switch off certain filters, assets and/or facilities from the model due to extraneous factors such as decisions to replace a building rather than reinvest
   - confirmation of any ongoing studies that may provide quantitative data for the model
   - review of the sensitivity outputs

2. *External Consultant Walkabouts* – SFU arranged for a group of its multi-disciplinary external consultants, who had extensive prior knowledge of certain assets, to conduct a walkabout of the facilities to share their system insights and to identify their recommended high priority projects.

SFU's organizational culture was one of transparency and cooperation between the different levels of the organization and between internal and external stakeholders. As such, this contributed to the efficient facilitation of the qualitative factors in the model.

3.6 The Outcomes

The outcomes were evaluated in terms of how they addressed the interconnected problems of *criticality* and *priority*. With reference to the criticality problem, the *O_2 Model* yielded the following outputs:

- The heavily skewed front-end loading of the tactical plan was redistributed more evenly over the different years of the planning horizon.
- Some of the original baseline expenses were removed entirely, such as departmental costs that had been misclassified
- The quantification of the unfunded liability was lowered by approximately 50%. It was recognized, however, that the asset management team still had a significant funding shortfall that needed to be addressed through prioritization.
- A suite of visual analytic tools were used to develop a compelling business case to bring to the institution's top management and to support a funding advocacy program with the Ministry of Advanced Education.

Figure XI demonstrates how the input and output data were plotted in a Geographical Information System (GIS). This was another tool used by SFU's Facilities Team and Campus Planning Team to visualize the spatial distribution of the priorities across a campus of highly integrated assets.

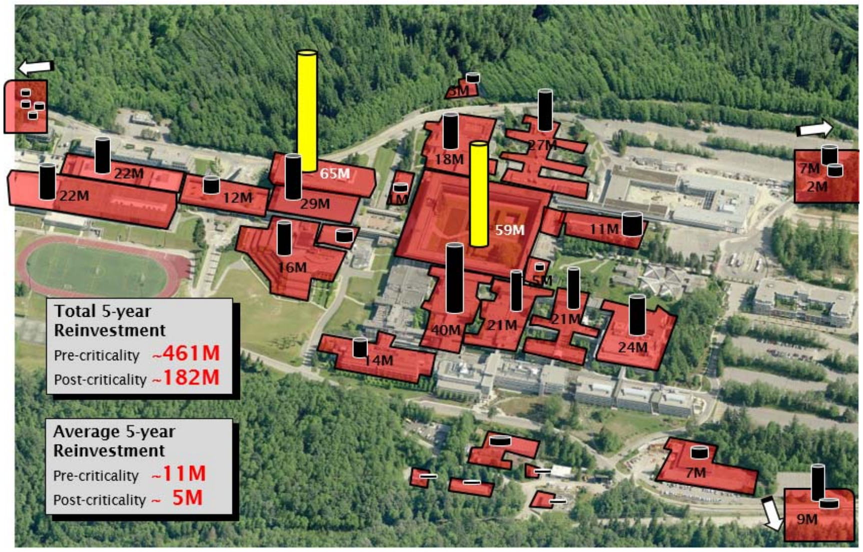

Figure XI. Illustration of model outputs represented on a geographical information system (GIS)

With regards to prioritization, the Province of British Columbia's Ministry of Advanced Education provided an additional appropriation of funds to reduce the size of the funding gap. The outputs of the model provided SFU with a ranked list of projects for implementation in fiscal 2016, 2017 and 2018. This prioritized work was thus able to move into the detailed planning phase.

4 CLOSING REMARKS

Organizations operate in different contexts with varying structures and cultures. This variability may impact the optimal mix of quantitative and qualitative inputs into the *O_2 Model*.

It is therefore important that the team tasked with implementing and administering the model be sensitive to the impact of organizational behaviour on the outcomes. In order for an organization to leverage the full potential of the model, its top management must provide a commitment to ensuring that the organization's policies and objectives are clearly communicated and are reflected in the qualitative inputs.

Continual improvement of the quantitative elements of the model can be further enhanced through industry cooperation in sharing the data of longitudinal studies on the observed lives of an ever-expanding population of assets in different exposure conditions and regulatory environments (i.e. multiple sets of local minima and local maxima). Despite proprietary constraints that prevent the articulation of a truly universal suite of survivor curves with global minima and maxima, the methodology in the *O_2 Model* allows for defensible decision-making and the ability to revisit assumptions as additional information about asset performance becomes available.

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