4. The Development of a Risk Based Maintenance and Rehabilitation Budgeting Model for the City of Tshwane

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INTRODUCTION

The City of Tshwane (CoT) commissioned a study to develop an Integrated Maintenance Framework (IMF) to address several asset management challenges. The City is focused on developing new infrastructure to address service availability challenges, which is increasing both the asset base and the associated asset maintenance burden.

While developing new infrastructure is a priority for the City, there is an awareness that the existing asset base is aging and the risk of service delivery failure on existing assets is increasing. The implementation of asset management practices is seen as a necessity to reduce the risk of service delivery failures and to minimize avoidable maintenance expenditure due to the premature failure of assets.

The CoT prepared terms of reference for the development of the IMF, which had the main purpose of establishing uniformity in planning and budgeting between the different departments of CoT and providing an overall picture of the status of infrastructure in the City and how this would change over time.

The IMF was required to prioritise expenditure to ensure that resources are allocated in a manner that sustains service delivery and to quantify the maintenance funds needed and the risks of deferred maintenance.

In addition, the IMF was also required to be responsive to the legislative requirements in the Municipal Financial Management Act requiring Accounting Officers to be responsible for the safeguarding and maintenance of the assets under their control. Aurecon was appointed to develop the IMF in a staged approach:

- Stage 1: Assessment of the status quo of asset registers and maintenance systems currently used in the various departments of the CoT.
- Stage 2: Development of the IMF, including the review of international maintenance benchmarks, development of the model concept, and the derivation of theoretical models.
- Stage 3: Finalization and verification of the IMF using a sample data set and approval of the model by all technical departments.
- Stage 4: Implementation of the IMF using currently available data from all departments in the CoT. Importantly, this stage did not involve any field data collection.

This paper deals with the developmental aspects of the IMF model and does not address all the technical tasks that were undertaken on the project. The infrastructure types that formed part of this study include: water, sanitation, electricity, roads, roadside furniture, parks and cemeteries, buildings, solid waste, storm water, and public transport assets.

DESIGN OF THE INTEGRATED MAINTENANCE FRAMEWORK

Review of International Maintenance Benchmarks

A review of international maintenance benchmarks was undertaken to gain insight into their relevance to quantify maintenance funding needs. These maintenance benchmarks express maintenance funding needs as a percentage of asset replacement cost, with a typical range being in the order of 1% to 4%.

The review indicated several difficulties in estimating funding needs using these benchmarks. The literature review and consultation with organisations in New Zealand and Australia highlighted the poor transferability of these benchmarks between organisations and across country borders.

There are several factors that cause a high variance in the results including the problem of inconsistent definition of what constitutes maintenance and which costs are included in the benchmark figures e.g. labour, material, plant, management, finance costs.

Further factors that result in poor transferability are major differences in the types of assets in the asset portfolio, the age profile of the assets, the magnitude of the asset base, and the past maintenance effort. Given the high variance, it was concluded that benchmarks of this nature should be used with caution.

For the development of the IMF, it was recommended that a zero-based approach to maintenance budget estimation be developed i.e. using actual asset data of individual assets including the asset replacement value, age, remaining life and condition data.

The estimates from the zero based approach were expected to provide a higher level of confidence in the budgeting estimates and would enable the CoT to model how the performance of the asset and the associated budgeting needs would change as its asset portfolio ages.

DESIGN OF THE INTEGRATED MAINTENANCE FRAMEWORK

Conceptual Design

The conceptual design of the IMF was based on several key design considerations:

- to ensure uniformity between the different departments, a generalised model was required;
- to quantify the impact on service delivery, asset performance measures needed to be defined;
- to address the challenge of asset stripping and intergenerational equity, it was necessary to predict asset deterioration and failure for a time period of at least 20 years;
- to quantify the risk of action or inaction, a risk based performance measure was required;
- to test different maintenance strategies and funding scenarios, asset deterioration modelling functionality was required; and
- to determine the trade-off in allocating funds between different services, optimisation functionality and a funding allocation model was required.

The key design considerations described above lead to the development of the conceptual model of the IMF. The IMF concept is based on available existing data, which is used to determine long term funding needs to minimise the risk exposure of the CoT.

Given the reality of limited funding, a fund allocation model is then used to distribute funds between the different departments based on their risk sensitivity.

The limited funding is in this way allocated to the assets with the highest risk within each department so that the risk to the organisation as a whole is minimised. The conceptual model is shown in Figure 1 below.

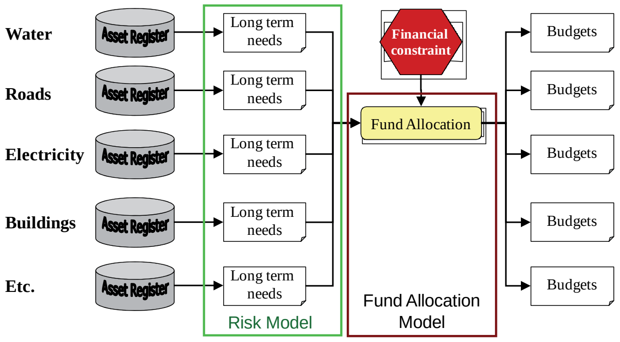

Figure 1: Conceptual design of the IMF

The IMF has a few key components that make up the technical working of the model. These components include:

- a risk model, consisting of probability and consequence of failure components, to predict the risk exposure that the City is subjected to as owner of the asset;
- a condition model that indicates the change of physical state of the asset over time;
- an operations and maintenance model that estimates the planned maintenance, unplanned maintenance, and operations cost over the life of the asset; and
- an allocation model used to distribute funds between the departments.

Development of the Risk Model

The risk model consists of two components: a probability of failure model and a consequence of failure model. A Weibull distribution derived probability of failure frequency model was used to approximate the "bathtub" curve often used in maintenance management and reliability engineering. The early life failure portion of the bathtub curve was ignored in the model as the effect of aging assets was the main concern in the IMF. The Weibull probability density function that forms the basis of the model is shown below.

$$f(x,\alpha,\beta) = \frac{\alpha}{\beta^{\alpha}} x^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}$$

$$f(x,\alpha,\beta) = \frac{\alpha}{\beta^{\alpha}} x^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}$$

,with x as the Age of the asset in years

The expected useful life for each asset type, as defined by the technical managers, was used as the centrality parameter (□) of the Weibull function. Since insufficient failure data is currently available to calibrate the models for each asset type, an initial spread parameter (□) was estimated. The difference in the bathtub curve and the adopted curve is shown in Figure 2 below:

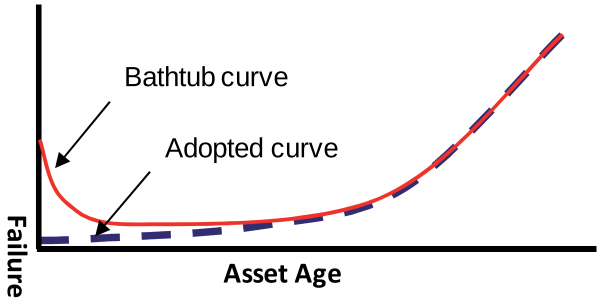

Figure 2: Bathtub curve and adopted probability of failure curve

The development of the consequence of failure model is based on a triple-bottom-line approach of defining economic, social and environment consequences and with each of these transcribed into monetary values. The economic consequence is defined as a function of the asset repair cost to keep the model simple.

The environmental consequence is related to the cost of the impact on the environment using a five point scale with associated monetary values. The social impact considers both the impact on service delivery and the impact on community health and safety. Both factors are sensitive to the type of service supplied and the associated land use to which the service was supplied. In this manner, commercial, industrial and high density land uses have higher impacts than low density land uses. Electricity and water services also have greater impact than sanitation and storm water services.

There is not an accurate method to ascribe monetary values to these consequences of failure, so there is a greater emphasis placed on simplicity, relative value, and consistency in the design of the consequences in this study.

DEVELOPMENT OF THE CONDITION MODEL

A condition model was developed to model the expected change in physical state of the assets. The basis of this model is a 100 point condition index with a decay curve from 100 to the minimum condition value that represents the minimum acceptable condition state. Since there was little existing available condition data for the CoT assets, with the exception of roads, a relationship between condition and the remaining useful life of the asset was developed i.e. it is assumed that as the remaining life diminishes, the condition deteriorates. Since the remaining life diminishes one year at a time until it reaches zero, the associated condition can be modelled into the future. Complex condition deterioration models using individual distresses and other asset performance measures can be developed in future. More complex deterioration modelling will require more complex data, hence the costs and benefits of this should be considered for each asset type in future. The typical relationship between condition and the percentage of remaining life is shown in Figure 3 below.

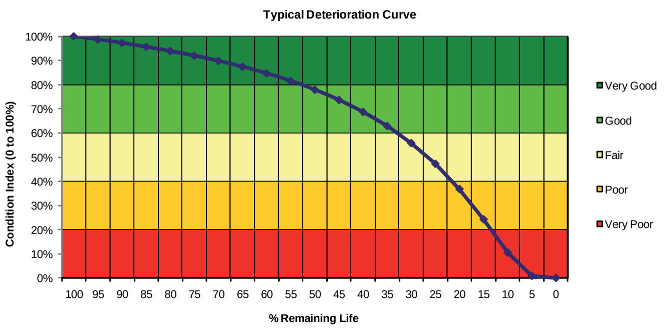

Figure 3: Assumed relationship between condition and remaining life %

The condition model was used to trigger capital rehabilitation (CAPEX) treatments when the assets dropped below their defined minimum condition thresholds. The CAPEX expenditure is required for refurbishment and renewal of assets to extend their lives beyond the initial design life. The timing of the treatments is dependent on the life-cycle of the asset type. The asset types followed one of three basic life-cycle scenarios: run to failure, renewable, and perpetual asset. The associated cost of each triggered treatment provides a cash flow of CAPEX for each individual asset into the future, given that adequate funding is available.

When the funding is limited, the assets with the best treatment benefit/cost ratios are selected for funding, while funding is deferred on assets with lower benefit/cost ratios.

The benefit function is defined as the area under the risk curve between the asset strategy and the do nothing strategy i.e. the strategies with the greatest risk reduction get selected for funding. The costs are the present value of the actual treatment costs. This is shown in Figure 4 below.

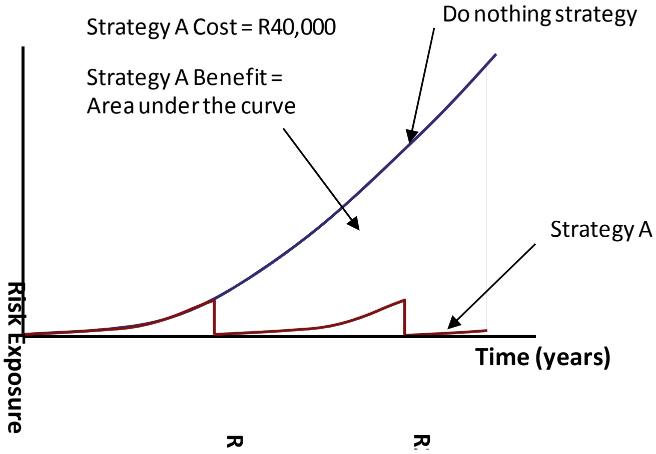

Figure 4: Life-cycle model and benefit function

DEVELOPMENT OF THE OPERATIONS AND MAINTENANCE (OPEX) MODEL

The operations and maintenance (OPEX) budget is required for planned maintenance activities, unplanned maintenance activities and operations costs to ensure that the assets provide a service to the end of their design lives.

These costs include the labour, materials, consumables, plant usage, and contract work for the maintenance or operational activity and the administrative overheads to ensure that the activities can be done. Planned maintenance refers to preventative maintenance activities prior to failure that is typically cyclical and pre-programmable e.g. lubrication of parts, cleaning out gutters, cutting grass verges, programmed light bulb replacement, and programmed inspections.

Unplanned maintenance refers to corrective maintenance after failure e.g. emergency repair, ad hoc repairs, and responding to consumer complaints.

Operating costs refers to all costs to keep an asset operational that is not maintenance e.g. electricity cost, fuel cost, chemicals cost, and operations staff. The planned maintenance, unplanned maintenance, and operations models were developed as a function of the age of the asset i.e. for some assets, as the asset age increases, the maintenance need and associated cost increases.

Each asset type has its own model parameters that define the relationship between asset age and maintenance cost. Planned maintenance, on those assets that require it, also has the effect of reducing the unplanned maintenance. The nature of these relationships is shown schematically in Figure 5 below.

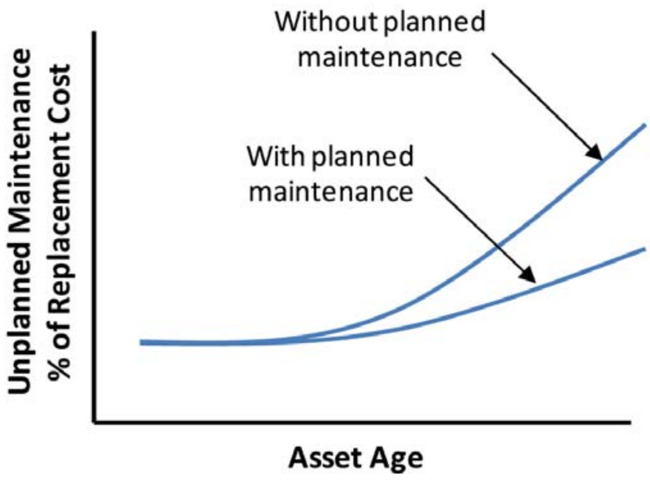

Figure 5: Relationship between maintenance and asset age

Configuration of the IMF Models into a life-cycle analysis software

The dTIMS-CT™ life-cycle analysis software was used to configure the various models of the IMF.

The software has the functionality to configure asset deterioration curves and to model asset performance into the future. A conceptual framework of the dTIMS-CT™ software is shown in Figure 6 below.

Figure 6: dTIMS-CT™ life-cycle analysis software conceptual framework

It should be noted that the dTIMS-CT™ is not a maintenance management software, but a life-cycle analysis software used for quantifying and optimising maintenance and rehabilitation budgets.

The models described above are configured within the software to reflect the life-cycle of each asset as realistically as possible.

DATA COLLECTION

This study relied heavily on available data. The most comprehensive data was generally obtained from the GIS and technical systems within each department. No field assessments were undertaken in the study and it is expected that the data set was incomplete.

The data quality varied from high quality pavement management system data to very limited parks, cemeteries and buildings data. The key asset data required for the modelling was:

- an inventory of assets;
- location data in a GIS or coordinates;
- size of each asset and unit of measure;
- age;
- remaining useful life; and
- condition, if available.

The available data was gathered and processed into the required format for import into the dTIMS-CT™ software. Where asset age data was missing for network assets such as pipe networks, the township proclamation dates were used as a proxy.

The age and remaining life distributions of the available data are shown in Figures 7 and 8 below.

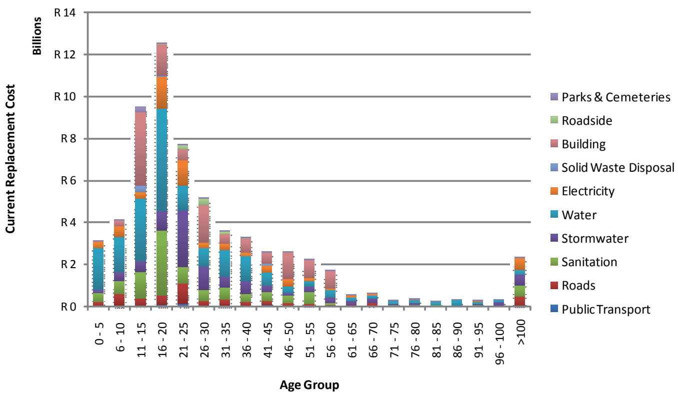

Figure 7: Asset age distribution

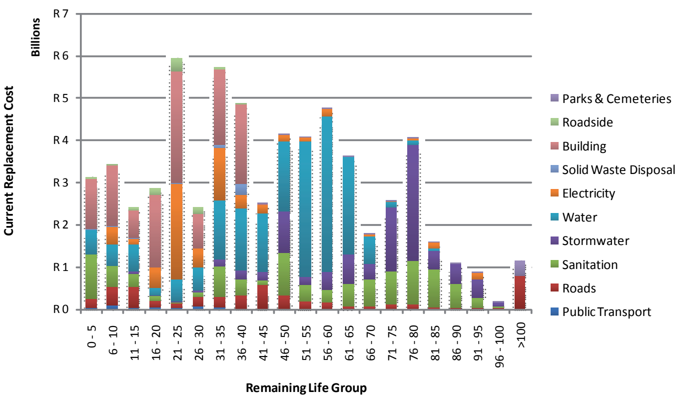

Figure 8: Asset remaining life distribution

ANALYSIS RESULTS

The analysis results are based on the available data and should therefore be interpreted with caution. Should the quality of the data inputs increase through the implementation of a data improvement program, the confidence of results is expected to improve.

In addition, as more detailed data becomes available, the complexity of the deterioration models can be increased. Given the robustness of the model, the analysis results have proven useful and informative to the CoT. Figure 9 shows the average asset condition index for the entire asset portfolio over the next 40 years for different annual CAPEX budgets.

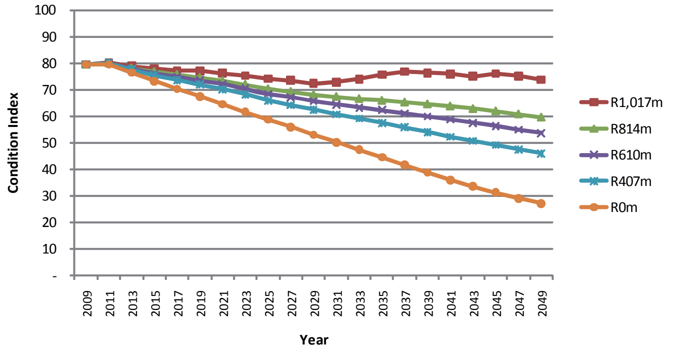

Figure 9: Average asset condition index over the next 40 years for different annual CAPEX budgets

The figure above shows that in order to maintain the current average asset condition, a CAPEX reinvestment rate in the order of R1b per year is required over the next 40 years. If this level of funding is not affordable, the impact of reducing the annual CAPEX funding level is shown in the graph. The impact on the risk exposure of the CoT is shown in a similar manner in Figure 10 below.

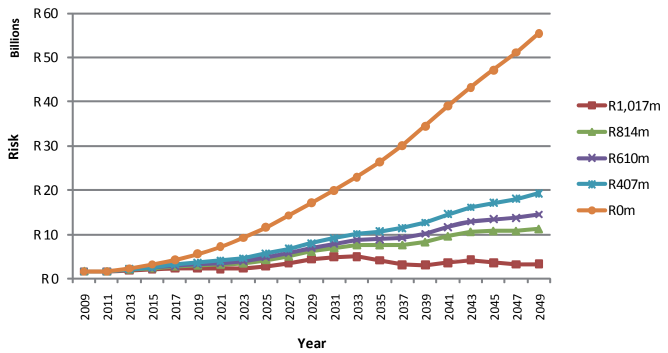

Figure 10: Total business risk exposure over the next 40 years for different annual CAPEX budgets

From the figure above, it is clear that it will be difficult to maintain the current business risk exposure profile with an aging asset portfolio. Even with a high CAPEX budget for asset renewal and replacement, risk exposure is expected to increase considerably over the next 20 years.

The total required CAPEX and OPEX to fund the required asset rehabilitation, replacement and operations and maintenance needs are shown in Figure 11 below. The budgets are expressed as a percentage of asset replacement value.

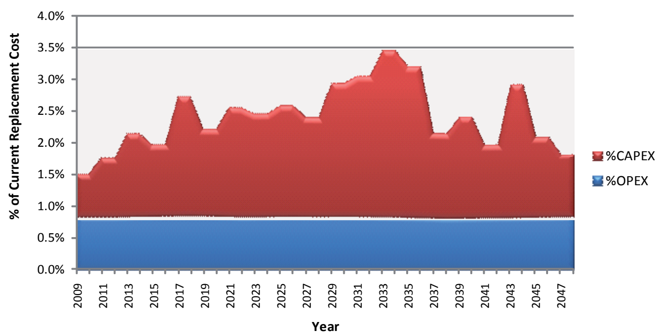

Figure 11: Total business risk exposure over the next 40 years for different annual CAPEX budgets

Figure 11 illustrates that should the required CAPEX be funded, the OPEX budgets are expected to remain fairly constant at approximately 0.9% of replacement value in the long term.

The required CAPEX is expected to increase from an immediate value of approximately 0.7% of replacement value to a peak of around 2.5% of replacement value over the next 25 years. This represents a substantial increase in required CAPEX reinvestment in the medium term.

The average CAPEX and OPEX results for the different services over the 40 year analysis period are shown in Tables 1 and 2 respectively. It should be borne in mind that the OPEX values assume that the CAPEX is fully funded. Should this not be the case, the OPEX value will increase over the analysis period.

Table 1: Average CAPEX over the 40 year analysis period for each service

Service	Current Replacement Cost	O&M	O&M as % CRC	Split of O&M
Buildings	R 7,955,319,813	R 57,592,653	0.72%	10.36%
Electricity	R 6,312,130,724	R 113,057,435	1.79%	20.33%
Parks & Cemeteries	R 3,620,436,269	R 11,648,683	0.32%	2.09%
Public Transport	R 468,872,352	R 31,547,017	6.73%	5.67%
Roads	R 8,748,958,624	R 150,127,189	1.72%	27.00%
Roadside	R 1,277,605,887	R 5,717,423	0.45%	1.03%
Sanitation	R 10,444,267,320	R 7,919,627	0.08%	1.42%
Solid Waste	R 704,728,112	R 2,677,575	0.38%	0.48%
Stormwater	R 4,597,839,735	R 63,490,220	1.38%	11.42%
Water	R 20,207,172,580	R 112,317,748	0.56%	20.20%
Total	R 64,337,331,415	R 556,095,571	0.86%	100.00%

Table 2: Average OPEX over the 40 year analysis period for each service

Service	Current Replacement Cost	Unconstrained CAPEX	CAPEX as % of CRC	Split of CAPEX
Buildings	R 7,955,319,813	R 212,354,704	2.67%	20.88%
Electricity	R 6,312,130,724	R 137,642,580	2.18%	13.53%
Parks & Cemeteries	R 3,620,436,269	R 151,765	0.00%	0.01%
Public Transport	R 468,872,352	R 12,724,444	2.71%	1.25%
Roads	R 8,748,958,624	R 121,782,421	1.39%	11.97%
Roadside	R 1,277,605,887	R 24,140,455	1.89%	2.37%
Sanitation	R 10,444,267,320	R 191,201,659	1.83%	18.80%
Solid Waste	R 704,728,112	R 11,114,175	1.58%	1.09%
Stormwater	R 4,597,839,735	R 14,712,870	0.32%	1.45%
Water	R 20,207,172,580	R 291,196,558	1.44%	28.63%
Total	R 64,337,331,415	R 1,017,021,632	1.58%	100.00%

CONCLUSION

The development of the IMF is a significant advance for the CoT in providing a uniform manner to budget for maintenance and rehabilitation of existing assets, and to assist the City with meeting its service delivery challenges. The IMF provides a framework to test the impact of different funding scenarios and a means for each department to prioritise their maintenance and refurbishment in a manner that minimises total risk exposure to the organisation.

The IMF is a tool that can be used to determine the impact of maintenance strategy, and funding variations at both the portfolio level and the specific asset level. The zero-based design of the model allows technical asset managers to determine the life-cycle asset needs and budgets for any subset of data e.g. a specific maintenance area, a specific facility such as an airport, or a specific political ward.

By adopting a uniform approach, the specific results are rolled up into portfolio results. The step-wise modelling approach over a long term planning horizon of at least 20 years has utility in quantifying the long term impact and the impact on intergenerational equity.

However, the prioritisation method used is as relevant in the short term and a key attribute of the IMF is the ability to produce 5 year maintenance and rehabilitation construction programs to address the prioritised assets. Lastly, the IMF is a significant investment and is expected to take a few years to mature with improved input data and model calibration to provide a higher level of confidence in the results.

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