Integrating pipe replacement prioritisation **in the master planning process**

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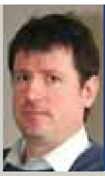

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BACKGROUND

South Africa faces the challenge of operating and maintaining world class-infrastructure, while at the same time experiencing a backlog in services for those living in informal settlements. On-going planning for future growth and development must be performed to ensure acceptable future service levels. As existing infrastructure ages and deteriorates, maintenance and the prioritisation of infrastructure refurbishment become critical. Planning for the future includes planning for infrastructure provision, planning for maintenance and pipe replacements, as well as sound financial planning. Water and sewer master planning has traditionally taken the form of establishing a model of existing infrastructure, followed by compiling the master plan defining future improvements to the system to meet the requirements for expected developments. Infrastructure refurbishment programmes and proactive component replacement actions should be designed to be integrated with the master planning process. With the extensive GIS-based information from the *Wadiso* and *Sewsan* data models available as part of the master planning process, GLS has implemented a pipe replacement prioritisation methodology specifically suited for South African conditions, also taking account of the available information and reliability thereof.

PIPE REPLACEMENT PRIORITISATION

The Pipe Replacement Potential (PRP) analogous to risk for any one modelled pipe in the water distribution model is assessed by the product of two critical indices – the Likelihood of Failure (LF) and the Consequence of Failure (CF):

$$PRP = LF \times CF$$

Independent weighted factors contribute to each of these indices. For LF the following factors pertaining to each pipe are typically identified and contribute to a high factor value:

1. High historic pipe failure frequency
2. Poor assessed condition (if available)

Figure 1: Historic incidents of pipe failures on top of the network layout

Figure 2: Typical rolled-up results showing final weighted PRP score ranked in five categories

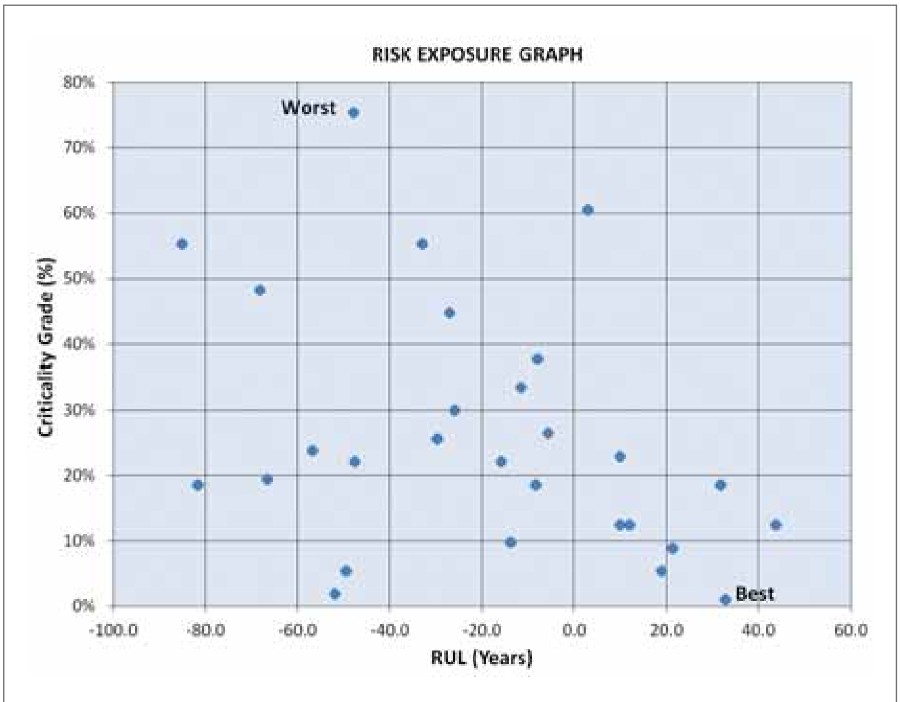

Figure 3: Typical graph of Criticality Grade plotted against Remaining Useful Life (RUL)

3. Short catalogue remaining useful life
4. High reserve pressure ratio (actual static pressure over design pressure rating)
5. Presence of a master plan upgrade item in existing model
6. Undesired pipe material (such as AC pipe material)

For CF the following factors pertaining to each pipe are typically identified and contribute to a high factor value:

1. Cost of damage to consumer due to high water pressure
2. Cost of damage to consumer due to high flow rate
3. High repair cost based on pipe location
4. Cost of outage of strategic location serviced
5. Long outage due to lack of network redundancy

Each factor is scored from 1 to 5, with 1 the best and 5 the worst score. The applicable factors, the mapping to the 1 to 5 score, as well as the weighting of each factor in the index, are discussed and agreed with the client during workshops. As factors are added or removed, each index is therefore customised for every client.

Figure 1 shows how historic incidents of pipe failures from maintenance management systems are related to the network layout, and then in Table 1 mapped to the 1 to 5 score based on the calculated number of failures/km/year.

By calculating the product of the LF and CF indices the compound risk is assessed. Only if a pipe has a high index for likelihood of failure and a high index for consequence of failure will a high potential for replacement result. In addition, the expected replacement cost for every pipe is calculated. The table of pipes in the model can then be sorted in order of decreasing PRP. The pipes with the highest replacement potential can then be visualised graphically.

Table 1 Mapping of historic number of failures to the 1 to 5 score

Criteria	Rating
(failures/km/a)	(1–5)
0.0	1
2.0	2
3.5	3
5.5	4
>5.5	5

ROLL-UP OF RESULTS

In larger towns and cities where replacements are typically not done on an isolated individual basis, the PRP of a set of pipes can be rolled-up to provide the weighted average, maximum or minimum PRP for various areas of replacements, such as:

- Political region
- Reservoir system
- Suburb extension
- Street block

Figure 2 shows typical rolled-up results with the final PRP score ranked in seven categories.

ALIGNMENT WITH ASSET MANAGEMENT PRINCIPLES

The outcome of the PRP analysis is typically a relative PRP score that, when sorted from high to low for all the pipes in a model or for all the pipes in a roll-up area, provides a ranking from worst to best existing pipe. It was proposed to align the PRP methodology with asset management principles such as Remaining Useful Life (RUL) and Criticality Grade (CG). In addition, an absolute measure for requirement of replacement was needed so that the PRP of pipes among different models can be compared with one another.

Typically different failure modes are considered when establishing the RUL of a pipe. The following three failure modes can be considered with the available data from the PRP model: Capacity, Performance and Condition. A model was adopted where various failure modes are considered to increase or decrease the catalogue RUL (the RUL based on a catalogue of pipe materials and their respective standard Expected Useful Life).

Each of the individual LF factors has previously been scored from 1 to 5 as part of the PRP analysis. Weights have also been assigned to each factor within the set of LF parameters. These scores and weights (with the exclusion of catalogue RUL) are reused to calculate a final RUL. The CG factors coincide with the CF factors. In the simplified approach, the CF index is substituted for CG.

Similar to the LF × CF product, a (RUL_{max}−RUL) × CG product can be formed to assess the compound effect. This metric is called the Risk Exposure (RE). The RE value now provides an independent metric for comparing the Pipe Replacement Potential of one pipe to another, even in different models. The RUL and CG can be used as inputs for asset registers and asset management plans.

Figure 3 shows a typical graph of CG (in %) plotted against RUL in years, and also identifies the best and worst pipes in the sample set based on the RE metric.

MULTI-YEAR SIMULATION

A recent development for an international project involved the extension of the PRP analysis to simulate annual pipe replacement actions over a multi-year period. Various annual Capital Expenditure (CAPEX) budgets and Operating Expenditure (OPEX) budgets can be provided as input to the analysis. Pipe replacement programmes form part of the CAPEX budget, while pipe repair and maintenance forms part of the OPEX

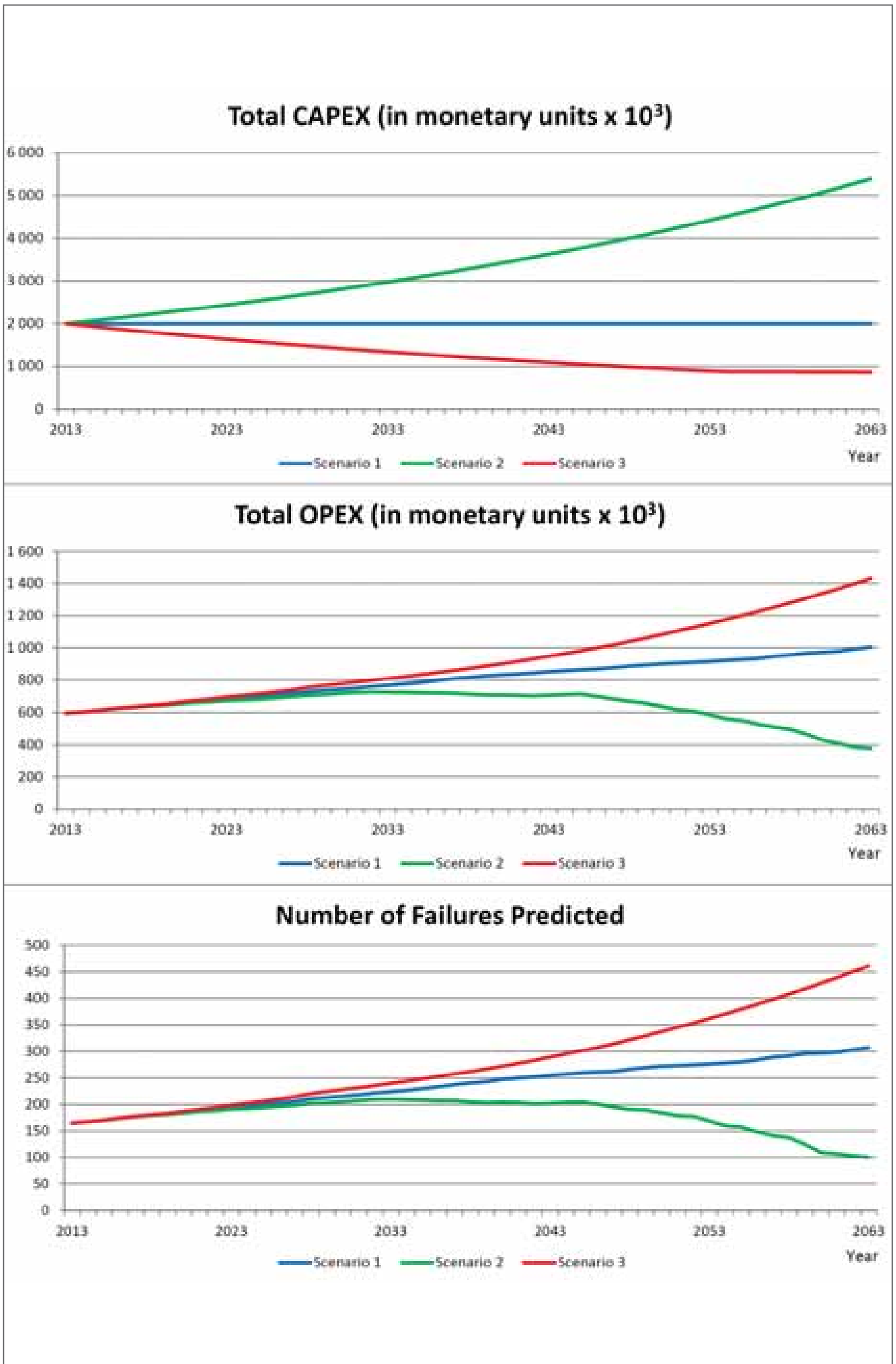

Figure 4: Simulated results for three scenarios

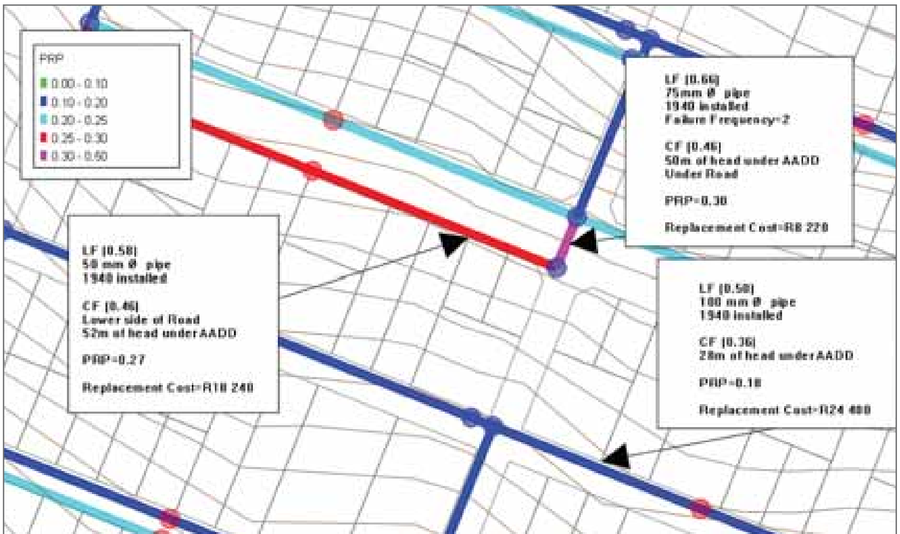

Figure 5: Typical PRP analysis result

budget. One aim of the simulation is to establish what CAPEX budget must be provided for every year in order to prevent the OPEX from increasing annually.

Several parameters are introduced to determine the number of theoretical failures per year (based on statistical information) as well as the total time of service interruption due to failures per year. The aim is to minimise both these parameters by spending the CAPEX budget efficiently on preventative replacement or refurbishment of existing pipes.

In Figure 4 the simulated results for three scenarios are displayed and graphs for CAPEX, OPEX and a theoretical number of failures are presented. It can be seen that only for an increasing CAPEX budget, as per scenario 2, the OPEX decreases as well as the number of failures predicted.

RESULTS AND CONCLUSIONS

The *Wadiso-PRP* software has been developed by GLS Software to perform the required analysis. Results are then reported in the embedded GIS system. In a typical analysis result as shown in Figure 5, it can for example be seen how the pipe highlighted in red has a number of high LF and CF factors contributing to a relative high PRP score of 0.27. The short pipe shown in magenta has a PRP score of 0.30, mainly contributed also by its high failure frequency and location under the tarred road.

Advanced reporting is available from the PRP module in *IMQS*, where results per pipe or roll-up area can be inspected in table or graphical format. PRP analyses have been successfully performed for five municipalities in the Western Cape, two metros in South Africa and a European water utility, and have been extended to sanitation and stormwater infrastructure.

Combining the pipe replacement programme with the required infrastructure programme ensures that upgrades and replacements are planned and implemented in an efficient and cost-effective manner. With the extension of the master planning to include the assessment of infrastructure replacement it is now possible not only to generate a list of costs for infrastructure requirements to accommodate the future scenario, but to also assess the cost to maintain the current infrastructure.

NOTE

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