LIFEWISE™ multi-component cost-risk optimisation

Fully-quantitative cost-risk optimisation (CRO) is simply an extension of “conventional” risk-based inspection (RBI) planning methods. Conventional RBI involves ranking by qualitative and/or quantitative (but nevertheless relative) procedures (1). CRO involves a financial appraisal of failure costs combined with a rigorous analysis of failure probability, to derive an expected value (EV) of failure consequence (2). The optimum replacement date may be thought of as a point in time when the cost of replacement is equal to the expected value of the failure, Fig.1. The methodology is relevant to all industrial plants and facilities where time-dependent damage mechanisms prevail.

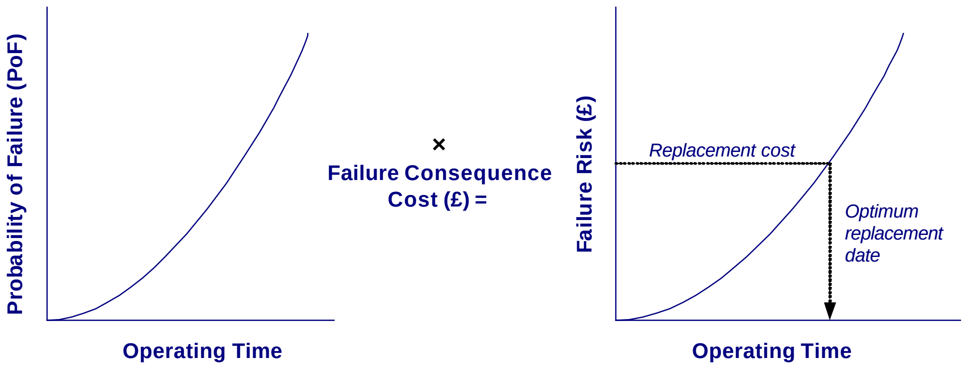

Figure 1. Failure Risk (£) = Failure Probability × Failure Consequence Cost (£)

This case study concerns sub-sea pipelines used for oil production, where the key problem was internal corrosion and limited inspection data. The objective of the study was to assess the replacement dates of 200+ oil production lines with an age in the range 1 to 39 years. The internal damage mechanisms to be addressed included CO_2 and H_2S corrosion. So the work, firstly, involved the evaluation of extent of corrosion in the form of statistical distributions from a combination of theoretical De Waard-Milliams (3) rate predictions and the spread in corrosion rates actually obtained from the limited inspection data. The pipelines were subsequently ranked through conventional RBI analysis, Fig.2.

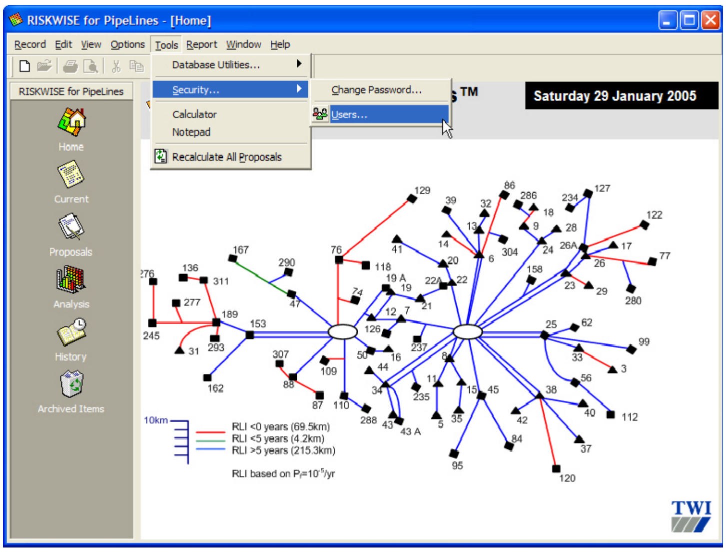

Figure 2. Pipeline remaining life ranking in GIS display, following conventional RBI

The leakage or rupture thickness for each pipeline was subsequently determined using a modified form of ASME B31G (4), taking account of internal pressure, initial wall thickness, material strength and corrosion length. Finally, the probability of the corroded thickness being less than the minimum required thickness was calculated using First Order Reliability Methods (FORM) and Monte Carlo simulation (5). The output consisted of annual failure probabilities as a function of time. From these outputs estimates of the annual expected value of savings, in the event a failure is avoided by replacing the pipeline, were calculated. The costs of failure specifically included oil production losses and environmental clean-up costs.

Money can generate income by earning interest (or lose value through inflation), ie. its present value today is different from its future value. Therefore, the preferred financial measure for CRO is net present value (NPV), which is the equivalent lump sum value now, after summing the present values of all positive and negative cash flows. A fully-quantitative CRO decision model was constructed that calculated the expected value of savings, in the event a failure is avoided by replacement. The model represented a trade-off between forced outage lost production costs and the pipeline replacement costs. The optimum pipeline replacement date corresponds to the maximum value of NPV, Fig.3.

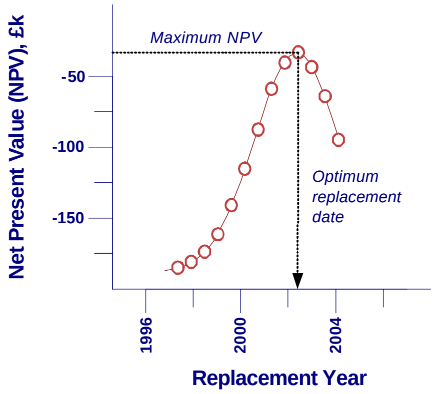

Figure 3. NPV of the cost of replacement versus the year of replacement

The numerous replacements of individual pipelines in the network were simultaneously competing for a limited maintenance budget. The optimum replacement plan (ie. schedule of pipeline replacement years) was therefore one that avoided scheduling more maintenance replacements that the budget limit could handle. In other words, the Actual replacement year of a pipeline ($RY_{A,Pi}$) may not always be it's Optimum replacement year ($RY_{O,Pi}$), ie. where NPV is maximum for that particular pipeline ($NPV_{O,Pi}$).

For the three pipelines illustrated, Fig.4, $NPV_{A,P1} < NPV_{O,P1}$; $NPV_{A,P2} > NPV_{O,P2}$ and $NPV_{A,P3} \neq NPV_{O,P3}$ because only under this condition was $NPV_{A,P1} + NPV_{A,P2} + NPV_{A,P3} \leq$ Maintenance Budget Limit (and $\sum NPV_{Pi}$ had been maximised). Optimisation in this context is the decision analysis process that maximises the total NPV for the many pipeline replacement projects in the network, in a specific strategic planning period.

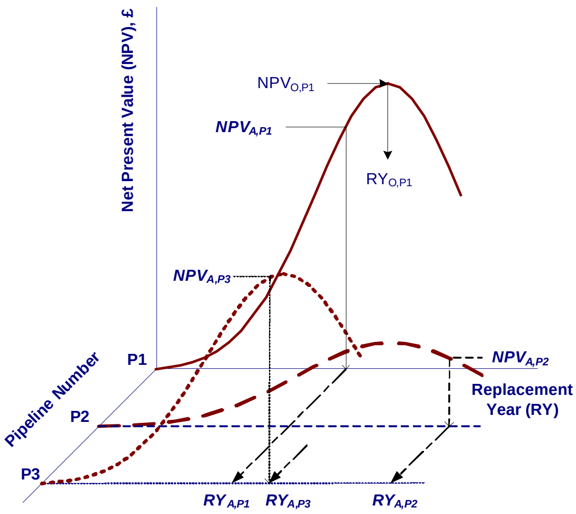

Figure 4. Pipeline replacement schedule is optimised (ie. the date order of RYs) when $\sum NPV_{Pi}$ is maximised, provided $NPV_{A,P1} + NPV_{A,P2} + NPV_{A,P3} \leq$ Budget Limit

The output enabled the operator to formalise a pipeline inspection and replacement plan with associated savings resulting from reduced business interruption, deferred capital spend and minimised liability uncertainties.

It should be noted that the solution to this optimisation problem was beyond the capabilities of linear programming tools. In general, a genetic algorithm non-linear solver will be required for the optimisation if a system contains more than ten components. It should also be noted that had the oil pipeline network been considered a safety critical system, with constraints on failure probability for example, Table 1, fully-quantitative CRO would not have been beneficial (5). The constraints may have been so severe that these overshadowed any potential financial benefits to be gained from applying this tool.

Table 1. Target probability of failure, events/year (6)

Safety consequences	Redundant component	Non-redundant component
Moderate	2.3×10^{-1}	10^{-3}
Severe	10^{-3}	7×10^{-5}
Very severe	7×10^{-5}	10^{-5}

References

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