Institution: The University of Edinburgh

Unit of Assessment: 19 Business and Management Studies

Title of case study: Risk Management of Physical Assets: Enhancing Methods for Estimation and Optimisation of Performance of Maintenance Systems

1. Summary of the impact

Physical asset management is a major cost for many organisations and is measured in £billions in the regulated industries within the UK. Methods developed by researchers in the University of Edinburgh Business School have enabled managers to estimate the effectiveness of maintenance interventions, and to build optimal maintenance strategies for large and complex assets, providing a scientific basis for major budgetary allocations. Users have deployed these methods to: achieve optimal asset management (Scottish Water); support regulatory assessments (Yorkshire Water Services); assist Severn Trent Water Company with its regulatory submissions (Cap Gemini); and inform procurement decisions across major platforms in maritime and air environments (Ministry of Defence).

2. Underpinning research

The on-going research started in 1998 and initially involved Professor L.C. Thomas (left Edinburgh 2000), Professor J.I. Ansell (1990-current), Professor T.W. Archibald (1988-current) and Dr J. Dagpunar (1996-2000). Subsequently Dr G. Andreeva (from 2007) joined the project team to contribute to the development of Risk Management Training.

The initial work aimed to provide estimates of the rate of unplanned maintenance actions for large and complex assets whose performance is influenced by environmental and organisational factors. This stage of the research benefited from access to data from Yorkshire Water Services which was regarded at the time as an industry leader in data collection. However, all water companies recognise that existing information on assets is extremely limited in scope. One of the challenges for the research was the relatively short time period during which useful data on maintenance actions had been collected. Data was only available for a period of four years while the typical lifecycle of an asset could be 40 years or more. This required the development of robust methods of analysis capable of producing important management insights from the existing incomplete maintenance records. An innovative approach was developed that integrated a number of advanced statistical modelling techniques. This assumed a time-dependent base rate for unplanned maintenance that is common to all assets of a given type. The base rate is adjusted by a factor that depends on the characteristics of a particular asset. Methods were developed to estimate the common base rate and the adjustment factor from the available data [see 3.1].

The resulting model allowed the investigation and assessment of the effect of various factors on the rate of unplanned maintenance. This knowledge allows decision-makers to improve the performance of an asset. Since the techniques employed were data driven, they provided insight into the underlying process, through improved appreciation of the impact of maintenance actions on the performance of assets, which led to further work on assessing the impact of maintenance actions. This is an insight that would not have been possible from alternative approaches which impose an intuitive, but arbitrary, form on the rate of unplanned maintenance (for example that it is increasing over time) to simplify analysis. This research was published in Ansell *et al* (2003) [3.1].

The realisation that the data could be used to assess the impact of maintenance on the rate of unplanned maintenance motivated follow-on work to develop a general stochastic model to optimise the timing of planned maintenance interventions on an asset. For the purposes of this model, the state of the asset is assumed to consist of three components: (1) the environmental and organisational factors that affect performance of the asset, (2) the age (i.e. time since installation) of the asset, and (3) the “virtual” age of the asset. The virtual age of an asset is an alternative measure of age that allows for the “rejuvenation” effect of maintenance. The extent of the rejuvenation is estimated from the insight provided by the analysis above. The model can

consider a range of maintenance interventions, from minor refurbishment to complete replacement, and is flexible enough to allow characteristics of replacement equipment to differ from those of the original equipment, to take account of technological advancement. The model is based on a discrete-time, stochastic dynamic programming formulation of the problem. Standard solution approaches exist to find optimal management strategies for maintenance. In addition to the novel approach to estimating the impact of maintenance, this research was distinctive because of the concept of virtual age and the range of actions considered. The research was published in Ansell *et al* (2004a) [3.2].

3. References to the research

3.1 Ansell J, Archibald, T, Dagpunar, J, Thomas, L, Abell, P and Duncalf, D (2003), 'Analysing maintenance data to gain insight into systems performance'. *Journal of the Operational Research Society* 54(4):343-349 (DOI: 10.1057/palgrave.jors.2601496).

3.2 Ansell J, Archibald, T and Thomas, L (2004a), 'The elixir of life: using a maintenance, repair and replacement model based on virtual and operating age in the water industry'. *IMA Journal of Management Mathematics* 15(2):151-160 (DOI: 10.1093/imaman/15.2.151).

3.3 Ansell J, Archibald, T and Thomas, L (2004b), 'The stability of an optimal maintenance strategy for repairable assets'. *Journal of Process Mechanical Engineering* 218(E2):77-82, (DOI: 10.1243/095440804774134253).

3.4 Ansell J and Archibald, T (2008), 'Data driven risk based management of assets in the water industry'. *International Journal of Performability Engineering* 4(3):215-224 (Journal article - http://www.ijpe-online.com/p2-data-driven-risk-based-management-of-assets-in-the-water-industry.html#axzz2foYFh3m3).

3.5 Ansell J, Archibald, T, Denning, R and Bain, A (2011), 'Investigating deferment of maintenance actions', In: Prescott and Remenyte-Prescott (Eds.) *Proceedings of the 19th Advances in Risk and Reliability Technology Symposium* (AR2TS), Stratford, 289-296.

4. Details of the impact

The first stage of the research (to estimate the rate of unplanned maintenance [5.1]) produced what became known within Yorkshire Water Services as "Edinburgh curves" for different types of assets [5.2.1 & 5.2.2]. These curves gave a scientific underpinning to the deterioration model which contributed to the assessment of the need for future maintenance activity. This assessment was the basis for the evidence Yorkshire Water Services submitted to the English water regulator (OFWAT) to support the company's price review [5.2.1 & 5.2.2]. Thus within Yorkshire Water Services, the research had an impact on the budget for maintenance projects estimated to be in the order of £1.93bn 2010-2015 based on findings and the prices charged to customers [5.3]. The approach was also taken up by Gap Gemini to underpin work carried out to assist Severn Trent Water Company with its submission to the regulator [5.2.5].

A further consequence of the implementation of the research in Yorkshire Water Services was the development of a Risk Management Training programme [5.1]. The aim of the training was to make employees more aware of the techniques available for the management of risk within the organisation. Between 2008 and 2010, over 100 staff participated in the programme [5.3]. The training was organised at two levels: an awareness level and an understanding level. The aim of the former was to give all technical and managerial staff the ability to assess how their role had an impact upon the efficiency and effectiveness of the organisation. The understanding level allowed individuals to develop their skills in implementing appropriate procedures within Yorkshire Water Services with a view to achieving reductions in both risk and cost within their own work context. The programme is attributed with "improvements in service performance … by reducing the risk of service interruptions to customers and improving the prioritisation of investment needs" [5.3]. Through the programme, the research has had impact on management practices throughout the organisation by "opening the risk management practices up to all" in a way that "embeds a risk

management culture into Yorkshire Water" [5.3]. The Programme was awarded two industry national awards including the People Initiative of the Year at the Water Industry Achievement Awards 2008 [5.4].

The second stage of the research (optimising the timing of planned maintenance) has been applied in two separate contexts: assessing the impact of delay in maintenance actions on the overall cost of managing assets; and developing optimal strategies for repair, refurbishment and replacement of assets. The former work was carried out for the Ministry of Defence Procurement Executive [5.1 & 5.2.3] and the latter for Scottish Water [5.2.4].

Discussion of the research at a meeting of the Water User Statistics Group (a specialist interest group of the Royal Statistical Society) led to a Knowledge Transfer Partnership (KTP) to assist Scottish Water in strategic asset planning (Sept 2010–Sept 2012) [5.1]. The aim of the KTP was to build on the published research by developing models (based on concepts from reliability and stochastic dynamic programming) to inform asset management strategy. The resulting suite of mathematical models allows Scottish Water to predict the optimal timing of asset maintenance over a 25-year period. In this way, "the KTP has provided a clearer understanding of data deficiencies and a much more robust application of new and existing risk management techniques" [5.5 & 5.6], resulting in efficiency savings of £67.5m over three years [Scottish Water estimates 5.6, p10]. Presentation of the modelling techniques to the Water Industry Commission resulted in endorsement and acceptance of the outputs of the models to a critical Scottish Water stakeholder [5.5]. The models have been so successful that they have quickly become a crucial element of the company's overarching strategic projections document (published November 2012 [5.7]) and near-term business plan (due to be published October 2013) [5.5]. Within these documents, the models are providing a credible, evidence based approach for over £1bn of capital investment need [5.5]. Both documents are key elements of the regulatory process and will help to set customer charges and the funding the company requires from 2015 through to 2021. Training sessions on optimisation delivered by the research team have ensured that the knowledge acquired during the project was transferred to the whole of the Analytics Team in Scottish Water so that the models can be developed and progressed now that the KTP has officially finished [5.5].

5. Sources to corroborate the impact

5.1. Contracts totalling over £500k with: Yorkshire Water Services for Development of Assessment Procedures; Yorkshire Water Services for Risk Training; Scottish Water (KTP Award); Ministry of Defence (Demonstrates the value that industry partners placed on the research – details available from HEI.)

5.2. Individual users/beneficiaries who could be contacted by the REF team to corroborate claims:

- 5.2.1. Risk Matters (Will corroborate the contribution to Yorkshire Water in both analytic and training – contact details and statement available from HEI.)
- 5.2.2. Yorkshire Water (Will corroborate the contribution to Yorkshire Water in both analytic and training – contact details and statement available from HEI.)
- 5.2.3. Principal Reliability Engineer, Ministry of Defence (Will corroborate the contribution to MoD in modelling - statement available from HEI.)
- 5.2.4. Analytics Team, Scottish Water (Will corroborate the contribution made to Scottish Water in Optimal Maintenance and outcome of KTP – contact details available from HEI.)
- 5.2.5. Cap Gemini (Will corroborate the impact of the modelling developed at Edinburgh – contact details available from HEI.)

5.3. Yorkshire Water (2009), Final Business Plan 2010-15: Part B3 Sections 2 & 6. (www.yorkshirewater.com/about-us/our-investment-plans/final-business-plan.aspx or http://tinyurl.com/nvtueod) (Corroborates the scale of the investment in maintenance

activities that the research helped to guide in Yorkshire Water and the scale of the risk management programme within Yorkshire Water.)

5.4. The Risk Training Programme within Yorkshire Water Services achieved two industry national awards: Utility Industry Achievement Award for Training 2007 and the People Initiative of the Year at the People Initiative of the Year Awards 2008. (http://tinyurl.com/pbdkodq) (Demonstrates the high regard in which the risk training programme was held within Yorkshire Water and the utility industries.)

5.5. Scottish Water (2012), Knowledge Transfer Partnership, Final Report: Results for the Company Partner (copy available from HEI). (Corroborates the impact of the research on the planning of maintenance activities within Scottish Water and the estimate of the financial savings resulting from the new processes implemented.)

5.6. The KTP project was awarded the highest grade of "Outstanding" by the KTP Grading Panel for its achievement in meeting KTP's Objectives. (http://forms.ktponline.org.uk/repository/cert/KTP007813-130227085126.pdf or http://tinyurl.com/o5lcwyh) (Provides an independent assessment of the impact of the research on maintenance planning within Scottish Water.)

5.7. Scottish Water (2012), Draft Strategic Projections, pp.44-46. (http://www.scottishwater.co.uk/assets/about%20us/files/key%20publications/final_swdraftstrategicprojectionsnov12feb13.pdf or http://tinyurl.com/p4wo3gs). (Provides evidence of the embedding of the processes developed within Scottish Water as a result of the research within strategic planning.)