**Title of case study: Advanced Maintenance Strategy and Tools**

## 1. Summary of the impact

A team at the University of Sunderland has undertaken research into equipment maintenance for over 20 years. This has been undertaken within a series of funded UK and EU projects. The work of the team has resulted in a new model for maintenance strategy, and the development of novel artificial intelligence algorithms to monitor the condition of key factory assets. A series of software tools have been developed in collaboration with industrial partners. These tools and the strategic model have been tested in industrial settings and have had impact in the UK, across the EU, and internationally.

## 2. Underpinning research

The Advanced Maintenance Research Group (AMRG) at the University of Sunderland has undertaken applied research into maintenance over a period of 20 years, establishing itself as a centre of excellence. The AMRG comprises, and has comprised: Prof John MacIntyre (Dean, 1992 - present), Prof Peter Smith (Emeritus Professor, 1981 - present), Prof Chris Cox (Emeritus Professor, 1965 - present), Dr David Baglee (Senior Lecturer, 2000 – present), Dr Mike Knowles (Senior Lecturer, 2007 – present), Dr Odin Taylor (Senior Lecturer, 1996 – 2012), Dr Ken Robson (Senior Lecturer, 2010  present), Dr Adam Adgar (Senior Lecturer, 1992- 2009). Early projects undertaken by the group during the period 1993 to 2005 included:

- An EPSRC CASE Award with National Power (1992 – 1995), which was supervised by Smith and undertaken by MacIntyre. This project explored the cultural aspects of maintenance within a power station, and developed neural network models for monitoring the condition of large plant within the power station (MacIntyre & Smith, 1995).
- VISION (Vibration Interpretation using Simulation and the Intelligence of Networks; 1993 – 1997) funded by the EU BRITE-EURAM programme, resulted in an intelligent vibration monitoring system, linking simulation and neural networks (Adgar et al, 1998). This was one of the first projects undertaken by the group, and formed the basis for future work, which was led by MacIntyre. It was also the start of a long-standing collaboration with VTT, Finland. The Sunderland team and the VTT team have complementary strengths, with Sunderland providing research expertise in the use of artificial intelligence technique for condition monitoring and maintenance strategy and culture, and VTT providing expertise on industrial engineering and machine diagnostics.
- NEURAL-MAINE (EUREKA project 1250; 1993 – 1996) advanced the technology available for complex machine diagnostics by the use of multiple sensor technology, data fusion and neural networks (Zhong, MacIntyre et al, 1999). The project reduced the complex task of monitoring a large machine into smaller subcomponents called local fusion systems.
- ATLAS (funded by the Department of Environment under the Energy Efficiency Best Practice Programme, 1996 – 1999) resulted in an intelligent on-line monitoring system for detecting and locating steam leaks in industrial pipework, producing a low-cost solution to the problem of automated leak detection and location in a variety of industrial situations.
- SENSOIL (an EU funded project, 2002 – 2005) resulted in an on-line sensor to monitor the quality of lubricating oil in compressors integrating new technologies and methodologies in control and monitoring systems.

The above projects had two major themes running through them: (i) the development of novel approaches to maintenance strategy, and embedding that strategy within organisational culture, and (ii) the use of artificial intelligent techniques for the maintenance of specific pieces of equipment, and within specific application areas (Emmanouilidis et al, 2006). Novel work resulted in each of these areas, and has been reported in numerous research papers, six of which are listed in the next section.

The impacts presented in this case study result from the foundations laid by the projects listed above, and are derived directly from the following three more recent projects undertaken by the group:

- DYNAMITE: (Dynamic Decisions in Maintenance, an EU project, 2005 – 2009) resulted in an infrastructure for mobile monitoring technology and created new for decision systems incorporating sensors and algorithms. The key features include wireless telemetry, intelligent local history in smart tags, and on-line instrumentation (Baglee et al, 2011; Emmanouilidis et al, 2006). A novel method AIMMS (Advanced Integrated Manufacturing Maintenance System) has been developed to identify factors which influence the implementation of modern maintenance practices, and enable organisations to devise an overall maintenance strategy.
- OPTFEST (Optimisation of Food and Engineering Supply Chain Technology, DTI funded, 2006 - 2008) redesigned modern maintenance technologies and practices from the aerospace and other industry sectors to improve the profitability of the engineering parts of the food processing sector (Baglee and Knowles, 2013).

**3. References to the research**


1. Baglee, D., and Knowles, M. (2013) “Maintenance strategy development in the UK food and drink industry” *International Journal of Strategic Engineering Asset Management*, 1(3), 289-300. *This recent paper presents the work on maintenance strategy undertaken by the Sunderland team within the OPTFEST project.*
2. Baglee, D., Knowles, M. and Yau, A. (2011) “Development of techniques to manage asset condition using new tools. In: Asset Management: The State of the Art in Europe from a Life Cycle Perspective. Production & Process Engineering” Chapter 9, 143-154.Springer. ISBN 978-94-007-2723-6. *This Chapter presents some of the novel asset management tools developed by the group.*
3. Emmanouilidis, C., Jantunen, E., and MacIntyre, J. (2006) “Flexible software for condition monitoring, incorporating novelty detection and diagnostics” *Computers in Industry*, *57*(6), 516-527. *This paper presents software tools developed by the team, which use novel artificial intelligence algorithms for condition monitoring, novelty identification and machine diagnostics.*
4. Zhong, B., MacIntyre, J., He, Y., and Tait, J. (1999) “High order neural networks for simultaneous diagnosis of multiple faults in rotating machines” *Neural Computing & Applications,* 8(3), 189-195. *This paper presents novel neural network algorithms for the condition monitoring of high value, complex, rotating machinery, developed by the group. This work was undertaken in collaboration with Prof Binglin Zhong, who was a visiting researcher with the group at the time.*
5. Adgar, A., Cox, C., Emmounilades, C., MacIntyre, J., Mattison, P., McGarry, K. and Taylor, O. (1998) “The application of adaptive systems in condition monitoring” *International Journal of COMADEM*, 1, 13-18. *This paper presents the results of three early projects of the group, including VISION, NEURAL-MAINE and ATLAS.*
6. MacIntyre, J., and Smith, P. (1995) “Condition Monitoring with National Power. In Neural Networks: Artificial Intelligence and Industrial Applications” (pp. 287-296). Springer London. *This paper presents early work by the group, which set the foundations for future projects.*


Papers 2, 3 and 4 are representative of the work of the group, and cover work at both the strategic level (new developments in maintenance strategy), and at the operational level (development of novel algorithms and tools for machine monitoring and maintenance).
The research has been supported by many competitively won UK and EU funding streams, with a total budget of several million pounds. Recent funded projects are: DYNAMITE, EU FP6 project IP017498, total project budget 3.7M Euro; OPTFEST, DTI, ICT Carrier

programme; and POSSEIDON, EU FP6 project TST5 031473, total project budget 1.2M Euro.

**4. Details of the impact**

The results of the research of the maintenance team have had impact in several companies with whom we have collaborated and demonstrates international reach.

*DYNAMITE project:* Industrial impact has been on-going throughout and beyond the project. The project has produced an industrial tool: *DynaWeb.* (Evidence 1). Validation activities of the tool were carried out at four different sites: Fiat; Volvo; Goratu; and Martintech. FIAT tested and demonstrated the integration of 25 Dynamite-inspired hardware and software components/services. VOLVO tested an oil sensor system developed within the project (which measures the oil oxidation/degradation level by means of visible light spectroscopy). This was performed in a real industrial hydraulic system within a production line in the foundry. GORATU provided a global demonstration by testing several Dynamite components and their communication with the Mimosa database. MARTINTECH conducted a trial consisting of a simulated application of a stern tube bearing/tail end shaft assembly from an 8000TEU container ship. Cycled lube oil was progressively contaminated with water and particulate matter. The exercise "clearly demonstrated considerable benefits from applying the Dynamite concepts" (Evidence 2). DYNAMITE was selected as one of the top three EU research projects at its conclusion, and has "influenced VTT's strategic research related, to e-engineering and ICT future research directions" (Evidence 2). The Sunderland team and the VTT team have worked together on many EU funded projects and have complementary strengths. In DYNAMITE Sunderland provided research expertise in the use of artificial intelligence technique for condition monitoring. The E-Maintenance book (Holmberg, Adgar et al, 2010) which resulted from the work of the DYNAMITE project is one of the top 25% most downloaded ebooks by Springer in this category (Evidence 3).

The project has also resulted in eMDSS http://www.e-maintenance.se/ "A unique decision-making system for profitable maintenance decisions within manufacturing companies such as paper, shipping, energy and automotive industries, that can estimate future life such as a warehouse and also link the cost of maintenance, with revenue for fewer interruptions and less downtime in production." (Evidence 4).

Lube sensor development within the DYNAMITE project has helped to create a new spin-off company (www.atten2.com) (Evidence 5) which has its first product available for the market, an on-line optical sensor which measures the degree of degradation of lubricating oils.

*OPTFEST and impact at Glenmorangie:* The research undertaken in the OPTFEST project and that which underpins it (Evidence 6) has had significant impact upon the maintenance strategy now pursued by Glenmorangie (Evidence 7). Maintenance has been identified as an integral part of the business, and they now use a web based maintenance system Emaint to control the maintenance of their three sites. The approach taken is based on the AIMMS model developed by Sunderland. Glenmorangie have two distilleries and three production sites. The AIMMS model underlies the approach taken across the sites and has also influenced the design of the production line and the new factory environment. Glenmorangie used the results of the OPTFEST project to implement a new maintenance strategy and embed it within their functional and management structure. During 2012 almost 5000 preventative maintenance tasks were completed, over 650 reactive tasks were recorded and 80 corrective tasks were completed. The impact of this work has been wide ranging, producing a culture change across the three sites. Maintenance is now recognised as key to the business at all levels, including management, engineers and production operatives (Evidence 6).

***Seminars and conference***

Research from the group has also fed into industry seminars (Evidence 8). Comments from delegates include: *"This was a useful opportunity to benchmark and understand current best practices in the industry. The presenters were very knowledgeable and their enthusiasm for the subject was very evident."* **Siemens Industrial Turbomachinery Ltd;** *"Excellent event giving a broad taster into the realm of reliability engineering."* **Busch** GVT **Ltd;** *"An enjoyable presentation on what can be a complicated time/cost consuming subject. Very enjoyable and accessible."* **Sellafield Ltd;** *"M's presentation was well put together, he offered a good range and gave enough information to satisfy."* **Alstom Power Ltd.**

**In 2012 the University hosted MPMM12**, the second international conference of Maintenance, Performance, Measurement and Management, which followed on from the very successful first edition held in Luleå, Sweden in 2011. This highly successful event was attended by 65 delegates from around the world (Evidence 9).

**5. Sources to corroborate the impact**

1. http://dynamite.vtt.fi/ The website of the DYNAMITE project. This website shows all the results of the DYNAMITE project including the Dynaweb tool.
2. Contact details of CEO of VTT (Technical Research Centre of Finland and Project leader of the DYNAMITE project) can be provided for corroboration purposes.
3. Holmberg K, Adgar A et al (Eds): *E-maintenance*; Springer; (2010). ISBN 978-1-84996-204-9; e-ISBN 978-1-84996-205-6; DOI 10.1007/978-1-84996-205-6. Since its online publication on Sep 05, 2010, there has been a total of 3924 chapter downloads for this book on SpringerLink, Springer's online platform. This makes it one of the top 25% most downloaded ebooks by Springer in this category. We have an email from Springer which confirms this.
4. eMDSS http://www.e-maintenance.se/ "A unique decision-making system for profitable maintenance decisions within manufacturing companies such as paper, shipping, energy and automotive industries, that can estimate future life such as a warehouse and also link the cost of maintenance, with revenue for fewer interruptions and less downtime in production." This commercial system includes modules which predict the vibration level of a specific device, and draws directly from the research results developed in the DYNAMITE project.
5. Tekniker (DYNAMITE). Technology which was developed within the DYNAMITE project, has led to the creation of a new spin-off company (www.atten2.com). This product uses online optical sensors for measuring the degree of degradation of lubricating oil.
6. Baglee, D, Knowles, M, Morris, A, O'Hagan, G, Galar, D, (2013) Optimisation of Food and Engineering Supply Chain Technology (OPTFEST): A Case Study, COMADEM 2013. This paper, presented at the COMADEM conference in 2013, is a joint paper between the Sunderland team and staff at Glenmorangie. The paper uses the impact of the OPTFEST project at Glenmorangie as a case study to demonstrate how maintenance strategy and deployment can produce positive results within the drinks industry.
7. Glenmorangie. Contact details can be provided for corroboration purposes.
8. http://wildeanalysis.co.uk/news/2010/reliability-engineering-explained-seminar. Review of a maintenance seminar led by Sunderland in 2010.
9. http://theiam.org/events/listing/maintenance-performance-measurement-management-mpmm-2012 Maintenance, Performance, Measurement & Management (MPMM) 2012 held at University of Sunderland. External publicity.
10. http://centres.sunderland.ac.uk/mpmm/ Maintenance, Performance, Measurement & Management (MPMM) 2012 held at University of Sunderland. Conference website.