Institution: University of Southampton

Unit of Assessment: 10 Mathematical Sciences

Title of case study: 10-02 Transforming the efficiency of Ford's engine production line

1. Summary of the impact

Through a close collaboration with Ford Motor Company, simulation modelling software developed at the University of Southampton has streamlined the design of the car giant's engine production lines, increasing efficiency and delivering significant economic benefits in three key areas. Greater productivity across Ford Europe's assembly operations has generated a significant amount [exact figure removed] in direct cost savings since 2010. Automatic analysis of machine data has resulted in both a 20-fold reduction in development time, saving a large sum per year [exact figure removed], and fewer opportunities for human error that could disrupt the performance of production lines costing a large sum [exact amount removed] each to program.

2. Underpinning research

Ford Motor Company's UK production lines produce a quarter of the engines used by Ford worldwide, amounting to a throughput of around £60 million each year. The multinational carmaker relies on simulation modelling to ensure that production lines are designed to maximise efficiency and minimise the use of factory space. Each assembly line comprises 70 machines connected in series; one machine failure can result in the costly suspension of the whole line, denting productivity.

Building upon a long tradition of simulation modelling for industry, our researchers began collaborating with the Process and Simulation Teams at Ford in 2005. Professor Russell Cheng, (retired 2007), and Dr Christine Currie (Lecturer 2004-present), analysed breakdown data for every machine across three engine assembly lines. They created an automated tool that Ford engineers could employ to identify the machines that are particularly vulnerable to failure and to accurately forecast when a particular configuration of the production line would break down **[3.1]**. This work followed on from earlier research projects led by Cheng that revolved around parameter estimation in non-regular statistical problems.

In non-regular problems maximum likelihood estimation, the classical fitting method, is no longer valid due to the presence of irregularities in the likelihood surface. Cheng and Currie developed a practical methodology for fitting finite mixture models using Bayesian statistics **[3.1, 3.2]**, which could combine a variety of factors into a single statistical distribution. Finite mixture models - weighted sums of standard statistical distributions - are ideal for describing multimodal data such as those encountered in machine breakdowns along the Ford assembly line. However, as the number of components in the finite mixture model is unknown, the problem is statistically non-regular. While the theoretical understanding of fitting finite mixture models is well developed, prior to this work little effort had gone into developing robust and efficient fitting methods that enable a good fit to be obtained in a reasonable length of time. The academics were able to apply these sophisticated mathematical models to translate complex, messy data sets into useful inputs for manufacturing simulation models for use by engineers with little specialist mathematical expertise.

Every one of the machines along Ford's assembly lines had its own set of data pertaining to the time it would take to repair them in the event of a breakdown. The Southampton researchers recognised that in order to obtain more accurate parameter estimation and reduce the number of models to be fitted to data, it was necessary to group the machines together, based on the similarity of the data. Currie and PhD student Lanting Lu (2005-2009) developed a new method where each machine is characterised by a dataset of machine breakdown durations: the Arrows Classification Method (ACM) **[3.2, 3.3]**. The method measures the similarity of two sets of data and only groups machines together if their similarity is greater than a user-defined threshold. ACM works as an alternative to better known methods such as cluster analysis, and is particularly appropriate to the situation at Ford because it makes no assumption about the underlying distribution of the data and allows for the comparison of datasets.

This methodology provides a flexible, robust fitting procedure for multimodal data that can be applied to simulation input and output modelling in other sectors, including healthcare. In a project for BUPA Hospitals, the method was used to group medical procedures based on length-of-stay in hospitals following operations in order to devise more efficient timetabling procedures. The techniques used in the automated fitting tool are useful to any business wishing to extract value from their data, particularly for complex systems where relatively detailed simulation models are being implemented that require extensive and repetitive data analysis.

3. References to the research

Publications:

3.1 Lu, L., Currie, C.S.M., Cheng, R.C.H. and Ladbrook. J. (2007) "Classification analysis for simulation of machine breakdowns" in Proceedings of the 2007 Winter Simulation Conference, pp 480 – 487.

3.2 (*) Lu, L., Currie, C.S.M., Cheng, R.C.H. and Ladbrook. J. (2010) "Classification analysis for simulation of the duration of machine breakdowns", Journal of the Operational Research Society, Vol. **62** pp760-767

3.3 Lu, L. and Currie, C.S.M. (2010) "Evaluation of the Arrows Method for Classification of Data", Asia-Pacific Journal of Operational Research, Vol. 27, Issue 1, pp 121-141.

(*) These references best indicate the quality of the underpinning research.

Grants:

G1. October 2005-October 2008: £15,000 support from Ford motor company "Modelling breakdown durations in simulation models of engine assembly lines".

4. Details of the impact

Unique simulation tools created at the University of Southampton have allowed Ford to achieve significant efficiency gains through changes to the design of its engine assembly lines across its European operation. In effect every one of the engines produced by Ford Europe each year has benefitted from Currie and Cheng's modelling research, translating into substantial cost savings **[5.1]**.

The academics' analysis of the machine breakdown data, and the subsequent use of the automated tool by the Process and Simulation Teams at Ford, has enabled Ford engineers to identify machines that are particularly vulnerable to failure. The Process Team works with suppliers to reduce future machine failures on the production lines and reduce the repair time, so limiting the downtime of the production lines. The main measure of throughput on a line is the number of jobs completed per hour (JPH). Ford estimate that, as a result of a greater understanding of machine breakdowns, JPH has increased by 1-2%, which equates to a significant amount of revenue [exact figure removed]. On average, there are three production lines running simultaneously, meaning that there have been significant direct savings [exact figure removed] generated by this tool since 2010 – a strong return on the original £15,000 research grant over three years **[5.1]**.

John Ladbrook **[5.1]**, head of the Simulation Team at Ford's Technical Centre at Dunton, UK confirms: *"We have worked with the University of Southampton for more than ten years on a number of simulation projects. Thanks to their expertise, this project was particularly successful and the tool developed has helped with making significant direct savings [exact figure removed] since 2010."*

Ford engineers use Southampton's automated tool to read raw data detailing the downtime recorded for each of the machines on the production line; fit a distribution to describe the downtime of each of these machines; and generate the specification files that describe the machine downtime on the line, which can then be entered into the simulation model. The tool has a user-friendly interface, allowing the full analysis of the data required for a simulation project to be completed in only two hours. Previously the engineers were unable to distinguish between different machines when recording the downtime of the production lines. Furthermore, they would have spent around five days carrying out the individual analysis of each machine along the production line. The resulting increase in staff productivity means that two additional production line simulations can be developed each year. All current Ford Europe engine production lines have been designed using this tool. For the cost of each simulation [exact figure removed], Ford confirms this has delivered a six-fold return [exact figure removed] since its completion in 2010 and continues to benefit Ford at a significant rate per year [exact amount removed] **[5.1]**.

The greater accuracy of the simulation models has contributed to further economic benefit, albeit one that is harder to quantify. By automating the generation of machine downtimes, thus delivering a more standardised approach to model development, capacity for human error is reduced. Any miscalculation can give rise to expensive consequences, as up to £1m in investment can ride on the correct simulation of a new engine production line. Southampton's input has made these kinds of costly errors less likely **[5.1]**.

The implementation of a new simulation tool requires specialist training and Southampton researchers have been responsible for training Ford engineers in its use **[5.1]**. Much of the computational work for the initial project was carried out by PhD student Lanting Lu (under the close direction of Currie and Cheng), who then went on to spend three months working within Ford's Simulation Team to train employees and embed the analytical tool in their wider approach to simulation. Southampton has continued to work closely with the Ford team in the development of the tool through subsequent supervised MSc and PhD projects.

The techniques developed by Southampton to fit the data, including the Arrows Classification Method which is freely available for public download **[5.2]**, have applications beyond manufacturing, particularly healthcare. Currie's work influenced the strategic thinking of healthcare provider BUPA Hospitals (in 2009) as it trialled the simulation tool to optimise the scheduling of operations in order to maximise the use of hospital beds **[5.3]**. Due to a major restructuring within BUPA, the methods were never implemented on a permanent basis.

5. Sources to corroborate the impact

5.1 Head of the Simulation Team at Ford's Technical Centre, Dunton, UK.

5.2 http://www.southampton.ac.uk/~ccurrie/

5.3 Currie, Christine S.M. and Lu, Lanting (2009) Optimal scheduling using length-of-stay data for diverse routine procedures. In, McClean, Sally, Millard, Peter, El-Darzi, Elia and Nugent, C.D. (eds.) Intelligent Patient Management. Berlin, Springer, 193-205. (Studies in Computational Intelligence 189)