Institution:	**University of Manchester (UoM)**
Unit of Assessment (UoA):	**B10 (Mathematical Sciences)**

Title of case study:
Novel Statistical Methods for Optimising Production of Disc Brake Pads

1. Summary of the impact

Novel statistical methods were developed in order to address the needs of Federal-Mogul Corporation (FM), an innovative and diversified $6.9bn global component supplier to vehicle manufacturers, with a broad range of customers in the industrial sector. During 2012, the research underpinned the production of new disc brake pad products for Audi, BMW, Ford, GM, Mercedes Benz and VW. The research has already resulted in significant benefits for the company by improving the manufacturing process, allowing it to be optimised to a mean specification, and by reducing the production cycle time by 30%.

2. Underpinning research

The impact is based on research that has been conducted at The University of Manchester since 2008 and was carried out by

Dr. Alexander Donev (Senior Lecturer, September 2007 – present)
Mr. Liam Brown (PhD student 2010 – present) [fully funded by FM],
Mr. Sergio Loeza-Serrano (PhD student 2009 – present), [undertook sKTP with FM in 2011]

The principal outcomes of the research were:

- the development of novel statistical methodology to inform the design of physical experiments used in product testing. The key insights were to take prior information into account when evaluating sources of variability in the manufacturing process; and to develop a novel graphical representation of the results to aid decision making [1]. The new methods allow the design of experiments in the most efficient and economical way [2].

- the development of new statistical models for studies of products constructed from different mixtures of materials, as well as methods for designing experiments to collect the data required by such models. The key insight was to use models that are nonlinear in parameters, formulated in terms of estimable flexible regressors. These can describe fast changing and localized effects which had not been possible with standard statistical models for mixture experiments**.** Nonlinear models of this kind had never been proposed before and are potentially applicable to a huge range of other industrial processes.

3. References to the research

The research has been published in a leading journal in computation and statistics, the official journal of the International Association of Statistical Computing [1].

[1] Loeza-Serrano, S. and Donev, A. N. (2012). Construction of Experimental Designs for Estimating Variance Components. *Computational Statistics and Data Analysis*, http://dx.doi.org/10.1016/j.csda.2012.10.008.

[2] Technical Report prepared for Federal-Mogul.

4. Details of the impact

Context

Federal-Mogul Corporation (FM) is a leading global supplier of products and services to the world's manufacturers and servicers of vehicles and equipment in the automotive, light, medium and heavy-duty commercial, marine, rail, aerospace, power generation and industrial markets. The company's products and services enable improved fuel economy, reduced emissions and enhanced vehicle safety.

In 2008 FM approached Dr. Alexander Donev for help in reviewing statistical issues in their experimental practices both in R&D and in the manufacture of friction materials for use in disc brakes. Poor repeatability and prediction from experiments using different material compositions had led them to suspect that there could be something missing in the existing statistical methodology.

Prior to the work described in this case study, FM had used open source and commercial software (e.g. R, JMP) to design and analyse their experimental studies. However, there is no such software that can be used to construct designs for studying variability, and therefore the company was using only the so-called six–sigma methods. The benefits that such methods can bring were already exhausted, and more advanced statistical methods were required to achieve the necessary reduction in manufacturing variability.

Pathways to the Impact

Since approaching Dr Donev in 2008, Federal-Mogul has funded the PhD studentship of Liam Brown, as well as an sKTP project with Sergio Loeza-Serrano. The very nature of the projects provided a natural pathway to implementing the results in the company's technological processes. The novel models have been reported directly to Federal-Mogul [2] along with computer codes that implement the new statistical methods. Consequently, the new experimental designs have become standard procedures within the company. The collaboration remains active and an EPSRC grant application, with financial commitment of £250k from Federal-Mogul, has been submitted.
An additional pathway to broader impact is provided via open source versions of the computer codes that implement the new statistical methods, which have been made available for other academic and non-academic users.

Reach and Significance of the Impact

The research has had a significant influence on the practices within FM. Comparative analysis of variation data from a recent production study and the methodology proposed [1] showed that statistically the same conclusions could have been reached with only 12% of the experimental trials originally used by the company, leading to considerable savings in R&D and in manufacturing [S1]. As a result, the new experimental designs have been adopted as standard procedures within Federal-Mogul [S1].

The first commercial application of the research was for modelling and optimising the production of a new design of the disc pad for Ford P415 SUV vehicles (typical US sales of 40,000 per year since 2010 [S2]). Response surface models based on the design were verified experimentally and found to be highly accurate. Disc brake pad production costs are due to combination of raw material costs and manufacture. The manufacturing costs are particularly sensitive to process cycle times, which determine the production rates on the allocated presses. Application of the new

statistical methodology identified optimal process conditions that lead to a 30% reduction in overall cycle time compared to that previously obtained with a conventional production engineering approach. This reduction in cycle time was critical to the economic viability of the product and lead to substantial cost savings for the company [S1].

Further analysis of the new model identified multiple solutions that made it possible to select production process conditions to yield the desired specification with minimum inherent variation. To combine these aspects of maximising production efficiency with maximizing product quality requires accurate and detailed process models, which the company had been unable to achieve without such an effective experimental design [S1].

Following the outstanding success of this Ford project, the use of same basic design has become a standard procedure within Federal Mogul for introducing new friction products into production. During 2012, based on this experimental design, new disc brake pad products for Audi, BMW, Ford, GM, Mercedes Benz and VW have been optimised for production [S1].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Letter from Federal Mogul supporting claim that FM have adopted the new experimental designs; that cost savings have been made; production cycle times reduced; and that the designs have been used in brake pad production for the vehicle manufacturers listed in the case.

[S2] http://www.goodcarbadcar.net/2011/01/ford-expedition-sales-figures.html
(Gives yearly US sales figures for the Ford Expedition (P415 SUV))