

Institution: University of Manchester		
Unit of Assessment: 12 (Engineering)		
Title of case study: Financial and environmental benefits through the development and transfer of control and monitoring technology in the process industries		
Period when the underpinning research was undertaken: 2000 – 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
David Sandoz	Professor	2000 – 2006
Barry Lennox	Professor (2008 – present) Reader (2004 – 2008)	2000 – present
Ognjen Marjanovic	Senior Lecturer (2019 – present) Lecturer (2006 – 2019) Research Associate (2002 – 2006)	2002 – present
Matt Desforges	PDRA	1998 – 2003
Matt McEwan	PDRA	2000 – 2003
Marie O'Brien	PDRA	2006 – 2008
Period when the claimed impact occurred: August 2013 – November 2020		
Is this case study continued from a case study submitted in 2014? Y		
1. Summary of the impact		
<p>Perceptive Engineering Limited (PEL) formed in 2003 to exclusively exploit novel model predictive control and monitoring systems that were developed at the University of Manchester. These control and monitoring systems maintained product quality and detected faults within operational processes with sufficient robustness for them to be integrated into industrial plant safety systems. Since 2013, PEL's annual turnover has increased [text removed for publication] in 2020. It employs 30 full time staff across its business in four countries. The developed technology is benefitting manufacturing and utility companies, providing financial savings [text removed for publication] worldwide, as well as delivering considerable environmental benefits in the form of reduced CO₂.</p>		
2. Underpinning research		
<p>The impact is based on research undertaken at The University of Manchester (UoM) in the Department of Electrical and Electronic Engineering. The research aim was (and continues to be) to develop algorithms and techniques that enable large-scale industrial processes to be both monitored and controlled in real-time. Sandoz and Lennox pioneered research by integrating condition-monitoring capabilities offered by multivariate statistical techniques with model predictive control. This integration enabled control systems to be developed and applied to processes that previously operated inefficiently in open-loop. When operating in open-loop, a plant is unable to respond to abnormalities, such as disturbances and equipment faults, thus considerably reducing plant efficiency. The UoM research led to a series of mathematical techniques and algorithms capable of simultaneously regulating and monitoring processes where sensors are unreliable and/or operate in batch mode.</p> <p>The key results were:</p> <ol style="list-style-type: none"> 1. Novel multivariate statistical algorithms were developed that can be used in real-time to detect faults with sufficient robustness for them to be integrated into plant safety systems and automatically shut down equipment when necessary [1, 2]. Prior to this work, multivariate fault detection techniques were not sufficiently robust to be applied automatically and in real-time, and therefore were not delivering their potential benefits. 2. Multivariate statistical models were shown to provide an integrated approach to monitoring and control. This research enabled system controllers to be developed 		

that were able to monitor their own performance and determine when re-modelling or re-tuning was required [3]. Furthermore, it enabled the development of controllers that can cope seamlessly with poor-quality sensor measurements [4]. For the first time, this meant that these system controllers were appropriate for use in areas such as wastewater treatment where sensor measurements can be unreliable.

3. A series of algorithms, able to provide simple and accurate control and monitoring of processes that operate in a batch manner, were developed. These algorithms were tested in case studies involving the manufacturing of pharmaceuticals and food, and were found to be suitable even in situations where the length of each batch varied considerably [5]. This proved that this technology could be used to improve the efficiency of batch processes, most notably those in the pharmaceutical industry.

This research remains highly productive and continues to generate impact. Joint research projects between PEL and UoM focus on enabling state-of-the-art control technology to be applied to solve manufacturing problems in the UK and overseas [4].

3. References to the research

The research is published in internationally leading journals, including top journals in the field of applied process control such as *Control Engineering Practice* and the *Journal of Process Control*. Output [5] won the Outstanding Paper award at the Chemical Process Control conference in Canada in 2006. Citations from Scopus (30 Sept 2020).

Key publications (Manchester researchers shown in **bold**):

- [1] Wang, X., Kruger, U. and **Lennox, B.**, (2003), Recursive partial least squares algorithms for monitoring complex industrial processes, *Control Engineering Practice*, 11 (6), 613-632 [DOI:10.1016/S0967-0661\(02\)000965](https://doi.org/10.1016/S0967-0661(02)000965) [Citations: 162; ranked 63/4140 in CEP all time citation list]
- [2] **Marjanovic, O, Lennox, B., Sandoz, D** and Smith, K. (2006), Real-time monitoring of an industrial batch process, *Computers and Chemical Engineering*, 30 (10-12), 1476-1481 [DOI:10.1016/j.compchemeng.2006.05.040](https://doi.org/10.1016/j.compchemeng.2006.05.040) [Citations: 42]
- [3] Al-Ghazzawi, A and **Lennox, B.**, (2008), Monitoring of a complex refining process using multivariate statistical process control methods, *Control Engineering Practice*, 16 (3), 294-307 [DOI:10.1016/j.conengprac.2007.04.014](https://doi.org/10.1016/j.conengprac.2007.04.014) [Citations: 95; ranked 186/4140 in CEP all time citation list]
- [4] **O'Brien, M, Mack, J., Lennox, B, Lovett, D** and Wall, A, (2011), Model predictive control of an activated sludge process: a case study, *Control Engineering Practice*, 19 (1), 54-61 [DOI:10.1016/j.conengprac.2010.09.001](https://doi.org/10.1016/j.conengprac.2010.09.001) [Citations: 70; ranked 349/4140 in CEP all time citation list]
- [5] **Lennox, B.**, Hiden, H.G., Montague, G.A., Kornfeld, G. and Goulding, P.R., (2001), Process monitoring of an industrial fed-batch fermentation, *Biotechnology and Bioengineering*, 74 (2), 125-135 [DOI:10.1002/bit.1102](https://doi.org/10.1002/bit.1102) [Citations: 137; ranked 599/14762 in B&B all time citation list]

Research grants that supported this work include:

- 2000 – 2003, GBP57,000, EPSRC (GR/N25329), 'Multi-sensor Fusion Enhancements';
- 2001 – 2002, GBP423,000, Invensys, 'Development of Perceptor';
- 2001 – 2002, GBP50,000, Swedish Steel, 'Condition Monitoring Application';
- 2001 – 2002, GBP50,000, Falconbridge, 'Condition Monitoring Application';
- 2001 – 2004, GBP57,000, EPSRC (GR/N24858), 'Batch Performance Monitoring';
- 2003 – 2005, GBP104,000, PEL/TSB (KTP), 'Development of BatchMV';
- 2005 – 2006, GBP45,000, Pfizer, 'Multivariate Analysis of Manufacturing Data';
- 2006 – 2008, GBP106,000, PEL/TSB (KTP), 'Control Loop Monitoring'.

4. Details of the impact

Context

The use of multivariate statistical techniques for detecting faults on process plants is well documented. However, before this UoM research by Sandoz and Lennox, industrial uptake of this technology was slow and virtually non-existent in real-time applications. Sandoz and Lennox introduced novel methods that were shown to be robust and implementable within model predictive control structures. This enabled the research team to apply multivariate techniques in real-time and allowed them to apply model predictive control systems to processes where prior technology could not be applied.

Pathway to impact

The research was presented at leading academic and industry-facing conferences, including the International Federation of Automatic Control World Congress [2002, 2005, 2008, 2011], Computer Applications in Biotechnology [2001], and the SAFEPROCESS symposium [2006]. This exposure led to interest from several companies, including Swedish Steel, Pfizer and North West Water who engaged in application studies with the researchers. In addition to these case studies, the global technology company Invensys provided approximately GBP500,000 to develop a generic condition monitoring software system.

In 2003, with support [text removed for publication] from The University of Manchester's Technology Fund, the spin-out company Perceptive Engineering Ltd (PEL) was formed to exploit the process control and process monitoring research that had been conducted at UoM [A].

Reach and significance of the impact since 2013

[Text removed for publication]. The control and monitoring technologies marketed by PEL, developed as a result of the UoM research [1-5], have benefited a wide range of industrial sectors through improved plant efficiency, reduced operating costs, increased productivity and reduced energy usage. This has resulted in combined financial savings (described below) [text removed for publication].

As a result of the work that has developed out of UoM, PEL has won a range of awards since 2013, including the 2016/17 Rushlight Award (sector excellence for clean technologies), the 2015 Water Industry Achievement Award for "Most innovative use of an existing technology", and the 2016 Merseyside Innovation Award for wastewater treatment. In 2019, PEL was awarded Business of the Year in the Cheshire Business Awards, and was shortlisted in two categories in the Water and Energy Exchange Global Awards 2020 [A].

Water and wastewater – improving process efficiency

PEL has completed installations of their control systems for [text removed for publication] major water and sewerage companies in the UK, including United Utilities, Welsh Water and Northumbrian Water.

United Utilities is the largest operator of clean and wastewater networks in the UK. They use sensors to ensure activated sludge plants operate at maximum efficiency: over or under efficient aeration of these plants can result in unnecessary energy use (over aeration) or loss of compliance (under aeration) [B]. Drawing on the UoM research, PEL used the control and monitoring technologies to construct a control system for United Utilities. The project, initially intended as 'proof of concept', was so successful that it resulted in a full installation at Lancaster Wastewater Treatment Works. As confirmed by the Asset Standards and Innovation team at United Utilities "average energy savings over 12 months has been 26% when compared with previous best performance....United Utilities calculates an annual reduction in equivalent CO₂ of more than 250 tonnes for this plant alone" [B]. [Text removed for publication].

Pulp and paper – increasing yield and reducing energy costs

PEL designed control systems are currently operating in five pulp and paper plants in Europe, Australia, Asia and the USA owned by companies such as Smurfit-Kappa and Aylesford Newsprint Limited. These control systems have been independently assessed and found to have reduced steam usage [text removed for publication], reduced CO₂ emissions [text removed for publication] and overall have reduced product costs [text removed for publication].

Smurfit-Kappa operate paper production plants in over 30 countries, with their UK Birmingham mill producing fluting and test liner paper from 100% recycled packaging waste [C]. A particular challenge with recycled paper is variability in its quality and hence drainability. This leads to variations in the production machine's stability, increases in steam consumption, and overall reduced efficiency of the machine. To address this, PEL provided an Advanced Process Control solution based on the UoM research [C]. This model provided closed loop control of the system to manage paper weight and moisture in the machine, and adjust the production rate accordingly. This reduced the variability of the quality of the final product, and specifically resulted in a reduction in steam consumption of 3%, which corresponds to a reduction in CO₂ emissions of 1,600te/year (*tonnes equivalent*) [C].

Aylesford Newsprint Limited operate two paper machine plants at their Aylesford site in the UK, producing an average of 400,000t of recycled newsprint per year [D]. This process involves a series of pulping, cleaning, screening, ink-floatation, bleaching and thickening stages depending on the specific requirement of the final quality specification. Using the UoM process and control research, PEL delivered an Advanced Process Control system on Aylesford's De-Inking plant to provide coordinated control of product quality, production rate, and process constraints [D]. This system enables Aylesford staff to enter costs of the source materials and chemicals as they change, which the optimiser can then balance. Aylesford's Full Package Production Manager has confirmed "*The Perceptive APC system installed on our process has provided significant improvements in quality and process stability. The system has reduced the standard deviation of final brightness by 60% while optimising production rate, chemical dosages and yield in real-time*" [D].

Benefiting the nutritional powders and pharmaceuticals sector

[Text removed for publication]. In November 2020, PEL was purchased (for an undisclosed amount) by Applied Materials, a USD17,000,000,000 US company, as part of their strategic plan to build a stronger presence in the pharmaceutical sector. PEL's PharmaMV® advanced process control (APC) platform is to supplement Applied Materials' SmartFactory Rx® portfolio [F]. The Managing Director of Applied Materials Pharma has stated that this acquisition enables Applied Materials' clients "*to bring powerful new therapies to market with assured quality, higher yields, reduced costs and all with optimised productivity*" [F].

5. Sources to corroborate the impact

[A] Letter of Support from Managing Director of Perceptive Engineering, July 2020

[B] United Utilities Wastewater Treatment Case Study. Available at:

https://www.perceptiveapc.com/industries/water/activated_sludge_plant/

[C] Smurfit Kappa Board Machine Case Study. Available at:

https://www.perceptiveapc.com/industries/pulp_and_paper/smurfit_kappa/

[D] Aylesford Newsprint Ltd Case Study. Available at:

https://www.perceptiveapc.com/industries/pulp_and_paper/rcf_plant/

[E] Abbots Nutritionals Case Study. Available at

https://www.perceptiveapc.com/industries/powders/nutritional_evaps_and_dryer/

[F] Press Release – Purchase of PEL by Applied Materials, November 2020, Available at:

https://www.perceptiveapc.com/news/latest_news/appliedmaterialsperceptive/