**Institution: Loughborough University**

**Unit of Assessment: B12 Aeronautical, Mechanical, Chemical and Manufacturing Engineering**

**Title of case study: The commercial and economic benefits of research at Loughborough into the process simulation, monitoring and control of industrial electronic soldering**

**1. Summary of the impact** (100 words)

Publically and industrially funded research at Loughborough University into the simulation, monitoring and control of electronics soldering has had significant impact in the development of new software and hardware technologies, which have delivered substantial commercial and economic benefits, with examples cited for at least two leading companies. One key commercial product is a modelling tool that optimizes reflow oven settings quickly, easily and accurately. It optimises oven settings each time a new product or solder paste is introduced, reducing set up times and scrap levels. More than 700 systems per year continue to be sold, with 90% exported.

**2. Underpinning research** (indicative maximum 500 words)

The research originated in 1993 within the Interconnection Research Group at Loughborough University and was initially focused on the modelling and experimental investigation of reflow soldering **[G3.1]**. Funded by the EPSRC, the research achieved the highest rating of Alpha 5-Excellent (a letter to this effect can be provided if required).

Subsequent research and commercial activities focused on process simulation for product and process optimization, including the following insights.

- Understanding the process physics interacting with electronics assemblies during reflow soldering **[3.1, 3.2]**, including ratios of heat transfer mechanisms provided by the various classes of reflow soldering equipment.
- Experimental protocols to characterize processes for representation within simulations **[3.1]**.
- Techniques to capture physics in a simulation environment in sufficient detail to allow process and product optimizations, including techniques for simplification of the transient thermal process and representations of electronics components and materials that together allow accurate simulations with suitable analysis duration **[3.2, 3.3]**.
- Solver technology specifications to enable accurate process simulation of complex materials and process combinations, e.g. accounting for the non-linear thermal properties such as phase changes and physical movement within the process **[3.1]**.

Several research awards saw expansion to more manufacturing processes and increased capability. For example, one project, Complex Low Volume Electronics Simulation **[G3.2]**, extended simulation to a wider range of processes and a methodology for on-line process defect data capture for root-cause-analysis of faults and associated corrective actions **[3.3]**.

In the project Design and Simulation of Complex Low Volume Electronics Production (DISCOVER) **[G3.3]**, significant development was enabled by the creation of a standalone framework that incorporates design data input, defects capture and integration with quality processes. The framework allows the seamless integration of the hybrid-modelling environment, presenting physics-based models, discrete event simulation, stochastic and knowledge based approaches **[3.3]**.

The modelling environment was then extended by the project Electronics Manufacturing Process Advancement Towards High Yields **[G3.4]** to incorporate an experimentally derived model for solder paste printing and integration within the IT infrastructure of a collaborator.

Towards Commercialization of the CLOVES Toolset **[G3.5]** saw a Knowledge Transfer Account support the commercialization of the software, including improving software robustness and development of the value proposition and business case for licensing.

With the commercial partner Datapaq Ltd **[G3.6]**, the core understanding of process simulation techniques for reflow soldering was utilized to deliver a new product for the company that has seen significant success in the industry. This project delivered a software tool that provides a predictive capability for reflow soldering and a methodology with a hardware validation artefact to enable automatic creation of the process model and subsequently determination of process settings **[3.4, 3.5]**.

Loughborough staff and researchers involved were Paul Conway (Professor, 1989 - present), David Whalley (Senior Lecturer, 1989 - present), David Williams (Professor, 1989-1998 and 2002-present), Andrew West (Professor, 1989 - present), Mehrdad Kalantary (Research Associate, 1993 - 1996), Farhad Sarvar (Research Associate, 1993 - 1997), Anthony Wilson (Research Associate, 2005 - 2008), Diana Segura (Research Associate, 2006 - present), Lina Huertas (Research Student and then Associate, 2010 - 2011) and Stuart Hyslop (Research Associate, 2003 - 2004).

**3. References to the research** (indicative maximum of six references)

**3.1 Sarvar, F. and Conway, P.P., "Effective Modelling of the Reflow Soldering Process: Basis, Construction and Operation of a Process Model", IEEE Transactions on Components, Packaging and Manufacturing Technology Part C: Manufacture, 21(2), April 1998, pp 126-133, ISSN 1083-4400, DOI: 10.1109/3476.681389.**

**3.2 Sarvar, F. and Conway, P.P., "Effective Modelling of the Reflow Soldering Process: Use of a Modelling Tool for Product and Process Design", IEEE Transactions on Components, Packaging and Manufacturing Technology, Part C: Manufacturing, 21(3), July 1998, pp 165-171, ISSN 1083-4400, DOI: 10.1109/3476.720413**

3.3 Huertas Quintero, L.A.M., West, A.A., Segura-Velandia, D.M., Conway, P.P. and Wilson, A.R., "Integrated simulation tool for quality support in low-volume high-complexity electronics manufacturing domain", International Journal of Production Research, 48(1), Sept. 2008, pp 45-68, ISSN 0020-7543, DOI 10.1080/00207540802427886.

**3.4 Whalley, D. C. “A Simplified Reflow Soldering Process Model”, Journal of Materials Processing Technology, Vol. 150, 1 July 2004, pp 134-144, DOI: 10.1016/j.jmatprotec.2004.01.029**

3.5 Whalley, D. C. “Reflow Soldering Process Simulation: A Simplified Model”, Proceedings of the 25th IEEE ISSE Conference, Prague, May 2002, pp 323-328, ISBN 0-7803-9824-6 **(Winner of the conference Excellent Paper Award for Scientists)**. Available at https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/3979/1/RC54c.pdf or at request from Loughborough University.

***Research and knowledge transfer grants:***

G3.1 04/93-05/96, EPSRC GR/J 07167, “Modelling and experimental investigation of reflow soldering”, (£296k), P. P. Conway, D. C. Whalley and D. J. Williams.

G3.2 12/05-11/07, DTI (TSB), “Complex Low Volume Electronics Simulation (CLOVES)” (£425k; Investigators: P. P. Conway, A. A. West, D. C. Whalley.

G3.3 03/06-01/09, EPSRC/IeMRC Under GR/T07459/01, “Design and simulation of complex low volume electronics production”, £253k, A. A. West, P. P. Conway, D. C. Whalley.

G3.4 02/10-01/11, TSB Project No: 100793, TP No: BD008K “Electronics Manufacturing Process Advancement Towards High Yields (EMPATHY)”, £500k, P. P. Conway & A. A. West.

G3.5 10/11-09/12, EPSRC KTA, “Towards commercialisation of the CLOVES toolset”, £89k, P. P. Conway & A. A. West.

G3.6 Datapaq Ltd, “DATAPAQ ROS” (£17k); Investigators: D. C. Whalley; Researcher: S M Hyslop.

**Evidence on the quality of the research**

The underpinning research we have cited is in all cases original and rigorous, as exemplified by our references, especially 3.5, which was the Winner of the Prague IEEE Excellent Paper Award. The significance of the research is indicated by the extent to which it has since won competitive funding awards, totalling £1.58M.

## 4. Details of the impact

We now present evidence for research cited in s2 and s3 to show impact in the development of new software and hardware technologies that have delivered commercial and economic benefits, with examples cited for two companies. The first demonstrates very specific impact within the original industrial sector; the second shows that the impact has extended beyond the original domain.

**Example 1**

The understanding of process simulation for reflow soldering was utilized within a research contract with Datapaq Ltd, leading to a new product offering that has seen significant success **[5.1]**. Datapaq’s Rapid Oven Setup (ROS) currently enjoys sales of around 700 units per annum, of which 90% are exported. Datapaq is the market leader in Europe, with substantial market shares in China, the USA and SE Asia **[5.2]**.

Datapaq is a process data logging company, selling hardware with associated software to visualise and analyse acquired data. This project extended their offering with a software tool (ROS) that provides a predictive capability for a given process and a methodology utilising a characterisation artefact (Heat Transfer Sensor (HTS)) that enables automatic process model creation. Loughborough developed the algorithms, simulation techniques and methodologies for automated model creation and calibration, along with designing the prototype HTS **[3.1, 3.4 & 3.5]**.

The reflow soldering of printed circuit boards (PCBs) is a key step in the manufacturing of electronics. PCBs vary in cost from a few pence to tens of thousands of pounds, with the more expensive boards playing safety-critical roles in, for example, aviation. Improving control of the ovens used for reflow soldering reduces failure rates, benefitting the industry, its customers and end-users.

For each new product or solder paste introduced the reflow settings have to be optimised. This is traditionally a time consuming process, but ROS automates it quickly, easily and accurately by calculating the optimum settings for any combination of oven, product and target profile. ROS also reads CAD files, automatically producing detailed PCB thermal models. By using Datapaq’s HTS to measure the specific oven performance, the ROS tool can ensure the optimum profile is found, thereby reducing scrap and saving time and money. It works on all reflow ovens.

The understanding of reflow soldering derived from the research **[3.1 & 3.2]** enabled the derivation of control strategies to ensure PCBs fell within specific process metrics by adjusting zone temperatures, airflow rates and conveyor speed **[3.4 & 3.5]**.

The understanding derived from the original project in the process control and optimisation strand **[3.1]** was capitalised on allowing Datapaq to deliver novel products to the electronics-manufacturing sector. They state: *“The technical advantage that we gained from working in partnership with Loughborough University has enabled us to maintain our market leadership position in Europe particularly in Germany and France. In these developed markets the end users need the benefit afforded by working with a solution that maximizes production efficiency to be able to compete with competitors from lower wage cost economies.”* **[5.2]** The impact from our research in developing the ROS product has clearly generated both commercial benefits for the company concerned and has been economically beneficial in terms of contributing to its market position.

**Example 2**

Specifications and involvement with our research partner Maya Heat Transfer Technologies **[5.3]**, led to new solver capabilities, based on research in s3 **[3.1 & 3.2]**. These capabilities are:

(a) automated FE model building direct from electronics CAD. Maya state: *"This demonstrated the feasibility and time savings associated with this approach. Maya then worked with its business partner (now Siemens PLM) to incorporate this technology into the finite element pre-processing environment as a new FE model creation method. The technology was successfully developed and delivered to customers worldwide. It has found application in other areas of thermal analysis including spacecraft and automobiles. In the latest generation of software (NX CAE) the technology has been extended to provide direct creation of an FE mesh from the PCB definition. This has removed the need to create a mesh for the PCB and for each component type."* **[5.3]**

(b) a technique to define physical movement during a thermal simulation, for which Maya state: *"modeling of motion, was added to the thermal solver with enhancements to the UI to allow definition of the motion. Again, the technology has been delivered to customers worldwide and has been used in other industries. As well as modeling PCB's in reflow ovens the technology has been used to model other manufacturing processes, sun tracking antennas and various spacecraft mechanisms."* **[5.3]**

Maya's business partner has several hundred active licenses for software containing these capabilities.

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

The following sources can be made available at request:

[5.1] http://support.fluke.com/datapaq/Download/Asset/9290321_ENG_A_W.PDF

[5.2] Supporting Letter, Datapaq Ltd, UK

[5.3] Supporting Letter, Vice-President, Maya Heat Transfer Technologies, Montreal, Canada.