

Impact case study (REF3)

Institution: University of Greenwich		
Unit of Assessment: 12 - Engineering		
Title of case study: Transforming knowledge sharing, improving design and production efficiency, and saving costs in three large global manufacturing companies		
Period when the underpinning research was undertaken: September 2006 – July 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:
James Gao	Professor & PI	01/09/06 – present
Richard Evans	Research Fellow	12/12/11 – 30/04/15
Mohammed El Souri	Research Fellow	01/05/15 – present
Period when the claimed impact occurred: August 2013 – July 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact		
<p>Knowledge is critically important to key decision-making in new product development, manufacturing and maintenance/services, especially in the high-value manufacturing sector. However, commercial ICT systems cannot effectively manage and integrate various types of knowledge in real-life dynamic operations across the global supply chain. This case study reports significant impacts of three strands of research outputs (a product lifecycle knowledge management framework, methods for managing structured knowledge, and methods for managing unstructured tacit knowledge), which had been continuously developed by a world-leading research group at University of Greenwich (UoG), through several projects funded by EPSRC, European Commission and industry. Impacts on three industrial collaborators (BAE Systems plc, Cummins Inc. & Edwards Ltd) are described. For example, Cummins Inc. reported a 15% increase in efficiency of knowledge search, product design and testing, and a 10-15% reduction in costs and time to market. Wider impact and reach were through various outreach events by UoG and the research group, and through the three industrial collaborators' own large internal and external networks of business units and partners.</p>		
2. Underpinning research		
<p>Since September 2006, Prof Gao's team at the University of Greenwich (UoG) has carried research driven by industrial needs, such as new methods and ICT tools to manage, share and re-use product-related knowledge including structured and unstructured tacit knowledge, to improve integration and collaboration between different functions in extended enterprises, in order to significantly increase efficiency, quality, time to market and reduce costs in the critical new product development process. In-depth investigation into the problems and requirements of industrial collaborators was always carried out in the first 3-6 months of a new project. An industrial steering (or stakeholders) group consisting of different functional managers/engineers reviewed the progress regularly during each project. The findings that underpinned the reported impacts were generated, improved and validated through several projects over a number of years, which can be described under three main strands below.</p>		
2.1 Definition of the Three Main Output Strands		
<p><i>Output Strand 1 (OS1)</i> is a product lifecycle knowledge management framework to support key decision making in collaborative product development, manufacturing, testing, maintenance and services in the digital manufacturing paradigm (Industry 4.0). Because most previous IT systems in manufacturing only manage structured data (knowledge, dynamic business and social aspects are missing), and are isolated 'islands of automation'. The novelty of the developed framework is that it is based on real-life dynamic processes (including social aspects) and provides the right data and knowledge at the right time to the right users across the global supply chain.</p>		
<p><i>Output Strand 2 (OS2)</i> includes methods for modelling structured knowledge based on product models that can be shared by all product lifecycle activities across the global supply chain. This</p>		

research strand sought to address the lack of standardised approach to data & knowledge sharing and system integration that previous ICT systems in manufacturing did not have. Thus, the innovative methods developed by UoG academics lie in the fact that product models are based on standardised features that can be shared by all product lifecycle applications and are implemented as Ontologies for system integration and interoperability. The product models also have modular structure with version/security control functions.

Output Strand 3 (OS3) includes methods for capturing, managing and sharing unstructured tacit knowledge. The novel way in which this method was developed is through adopting the emerging social media, video and Web 2 technologies to capture, analyse and represent unstructured and sometimes difficult-to-describe implicit knowledge. This is crucial in today's proficiency-based digital manufacturing operations. However, this type of knowledge cannot be managed by previous traditional ICT systems in engineering applications.

2.2 Contextual Information about the Three Output Strands

OS1 & OS2 were first proposed and developed in an EPSRC funded project that ran from January 2006 until December 2008 at Cranfield University entitled '*unification of design, manufacturing capability and service knowledge in collaborative product development*'. **Gao** was PI and continued to act as technical lead (and co-investigator) when he moved to UoG in September 2006, whilst the rest of the research team remained at Cranfield. Standardised features were defined as the basis for capturing, representing and reusing manufacturing capability and service knowledge to support collaborative product development. Ontology-based software, Protégé, was used for implementing the process-based framework and system validation by industrial collaborator (Edwards Ltd) **(3.1, 3.2)**.

OS1 was further developed as a dynamic knowledge management framework (adding social aspects) in an EPSRC and BAE Systems plc (BAES) funded project that ran from 2008 until 2012. **Gao** was PI and **Evans** contributed with Content Management expertise. This work involved a full-time researcher from UoG and industrial associates from BAES. This project also developed **OS3** using new digital technologies to capture, index and retrieve tacit knowledge during project meetings and interviews with retiring/leaving employees for sharing knowledge which was validated by BAES **(3.3)**. This work was awarded Best Paper at the International Conference on Interoperability for Enterprise Software and Applications (Coventry, 12-14/4/2010).

From 2009 to 2013, **OS1** was further developed using emergent social media platforms in an EPSRC/BAES funded project where **Gao** (PI) and Evans (then moved to Westminster University) collaborated with industrial associates from BAES. This involved implementing a more openly innovative environment so employees could share and interact with knowledge more effectively and easily across geographical and functional boundaries **(3.4)**. This was validated by BAES and Evans continued to develop **OS1** when he joined the EU project '*building an expertise network for an efficient innovation and training*' (REF 4177, Nov 2011–June 2015). **Gao** led a work package in this grant.

OS1 & OS3 were further developed in a project led by **Gao** and funded by Cummins Inc. and HEFCE from 2012 to 2015. This research explored how storytelling and video sharing functionalities embedded into a corporate social media site are capable of facilitating the capture and sharing of employees' knowledge in product testing processes. The framework was directly driven by knowledge users which was validated within Cummins Inc. **(3.5)**.

In 2015, EPSRC and BAES funded an additional three-year project on **OS1 & OS2**, with **Gao** as the PI, **El Souri** as a full-time researcher and in collaboration with two industrial associates from BAES. The project investigated the manufacturing capability of high value safety critical aerospace products and developed a manufacturing defect driven knowledge framework as a design support tool **(3.6)**. **El Souri** continued to develop **OS1 & OS2** when he joined the EU project '*improving the design of flexible and responsive manufacturing systems involving autonomous and collaborative robots*' (Ref: 99, Dec 2016–Nov 2021) led by **Gao**.

3. References to the research

1. Doultsinou, A., Roy, R. Baxter, D., **Gao, J.** and Mann A., Developing a service knowledge reuse framework for engineering design, Journal of Engineering Design, 20 (4), Taylor & Francis, ISSN 0954-4828, pp389-411, 2009. <https://doi.org/10.1080/09544820903149354>
Output was the result of a major EPSRC grant (Lead: Cranfield University, IMRC 51).
2. Baxter, D., Roy, R., Doultsinou, A., **Gao, J.** and Kalta, M., A knowledge management framework to support product-service systems design, International Journal of Computer Integrated Manufacturing, 22 (12), Taylor & Francis, pp1073-1088, 2009
<https://doi.org/10.1080/09511920903207464>
Output was the result of a major EPSRC grant.
3. Piorkowski, B. A., **Gao, J. X., Evans, R. D.** and Martin, N., A dynamic knowledge management framework for the high value manufacturing industry, International Journal of Production Research, 51 (7). Taylor & Francis, ISSN 0020-7543, pp2176-2185, 2013
<https://doi.org/10.1080/00207543.2012.709650>
Output was the result of an EPSRC grant co-funded by BAES
4. Evans, R. D., **Gao, J. X.,** Martin, N. and Simmonds, C., A new paradigm for virtual knowledge sharing in product development based on emergent social software platforms, Proceedings of IMechE, Part B – Journal of Engineering Manufacture, 232(13), SAGE, ISSN 0954-4054, 2018 <https://doi.org/10.1177%2F0954405417699018>
Output was the result of an EPSRC grant co-funded by BAE Systems. The main research was rewarded the best PhD thesis by University of Greenwich in 2013.
5. Zammit, J., **Gao, J.,** Evans, R. and Maropoulos, P., A knowledge capturing and sharing framework for improving the testing processes in global product development using storytelling and video sharing, Proceedings of IMechE, Part B – Journal of Engineering Manufacture, 232(13), SAGE, ISSN 0954-4054, pp2286-2296, 2018
<https://doi.org/10.1177/0954405417694062>
Output was the result of a project sponsored by Cummins Inc.
6. **El Souri, M., Gao, J.,** Owodunni, O., Simmonds, C. and Martin, N., A structured approach to defect data management for improving DFM implementation in aerospace manufacturing, International Journal of Product Lifecycle Management, Inderscience, 10(4), ISSN 1743-5110, pp282-300, 2017 <https://doi.org/10.1504/IJPLM.2017.090330>
Output was the result of an EPSRC grant co-funded by BAES.

Indicators of research quality

RQ1. The research has been published in rigorously peer-reviewed and high-quality international journals (3.1 – 3.6).

RQ2. Key Research Grants:

3a 'Unification of design, manufacturing capability and service knowledge in collaborative product development', funded by EPSRC through Cranfield University IMRC (Ref: 51). Value: £269,964. Principal Investigator: **James Gao**, co-investigator: Peter Sackett. Industrial collaborators: Rolls-Royce and Edwards Ltd. 1/1/2006 – 31/12/2008. When **James Gao** left Cranfield University in September 2006, he became the co-investigator and remained as technical lead for 2 years and 4 months until the end of the project while he was employed by University of Greenwich. Peter Sackett retired during the project and Rajkumar Roy acted as Principal Investigator.

3b 'Improving the design of flexible and responsive manufacturing systems involving autonomous and collaborative robots (CoRoT)', EU Interreg Programme (Project Ref:99). Total: €3.9m (around £3.3m). Principal Investigator (UoG): **James Gao**. Dec2 016– Nov 2020.

4. Details of the impact

The impacts of the research outputs were mainly achieved through collaborating with companies during and after the research and innovation projects, i.e., research and its impact have been intertwined continuously. During each project, monthly project meetings were held, and in many cases, the meetings were held within the collaborating companies, engaging more engineers and managers. In this way, outputs were transferred to industry effectively and timely. The research group also coordinated a 'Manufacturing Industry Focus Group in Southeast England' and

organised regular industrial workshops (normally twice a year). Companies in this region were updated with the most recent research achievements, and often further knowledge transfer activities were arranged afterwards. For example, after a workshop in 2012, Cummins Inc. requested a special seminar with the research team to further discuss **OS3** and then sponsored a three-year research project.

Transforming knowledge sharing, improving design and production efficiency, reducing failures, and saving costs at BAE Systems plc

BAES is a global defence, aerospace and security company and is among the top 5 UK ministry of defence contractors. They employ over 85,800 people worldwide. BAES Rochester operates as a manufacturing hub for avionic and maritime defence products. The company was interested in the EPSRC project (IMRC 51) presented by **Gao** at his inaugural lecture at UoG, and as a result, co-funded an EPSRC Industrial Case Grant which ran from 2008 until 2012. This project aimed to further develop the knowledge framework (**OS1**) to address social and cultural aspects in product lifecycle activities. During the project, unstructured tacit knowledge (**OS3**) in project meetings, and knowledge of retired/departed employees were captured, properly managed and reused to improve business operations in the company. Since then, the work was so successful that BAES co-funded two other EPSRC Industrial Case Grants with **Gao** as PI, expanding all outputs strands from the UoG research in a collaboration that ran for over 10 years.

During all three projects, UoG research team worked closely with the company to capture their requirements, knowledge and feedback, and regularly demonstrated the outputs (**OS1**, **OS2** & **OS3**) with their case studies to a stakeholders' group consisting of managers and engineers from design engineering, testing, manufacturing, quality, IT and procurement departments. Through this the research was transferred to all members of the respective departments. **BAES (Rochester) reports that changes directly impacted by the research in the eligible period were (5.1):** *Increased employee acceptance of new work-sharing platforms as standard ways of working; Knowledge management culture has significantly improved through an increase in the use of knowledge repositories including risk reduction knowledge; Transfer of knowledge plans put in place for retiring experts; Local and cross-organisation communities of practice was established with respect to the knowledge framework which improved knowledge sharing; The knowledge framework was used as a reference model by the IT department to improve company-wide product lifecycle management system, which increased knowledge search efficiency and accuracy; Design and production efficiency were increased, part failures & re-works reduced, time to market and cost reduced.*

The research outputs were also shared across the whole enterprise of BAES and its external partners globally through their internal research and innovation conferences and dissemination channels. The majority of which have been captured in over 37 collaborative academic papers. *Prof Gao was nominated by BAES for the Chairman's Award (Nomination title: Making the most of our Research, ID: 40719, 2019). The award is given by the chairman to recognise an individual's contributions to BAES and the positive impact they have made to the business. Although not eventually elected, his persistent collaboration over a decade with the company was recognised and highly appreciated.*

Transforming knowledge sharing, improving design and testing efficiency, saving costs, and improving employee satisfaction at Cummins Inc.

Cummins is a global power leader that designs, manufactures, sells and services diesel and alternative fuel engines, with 55,400 direct employees worldwide. Its Power Generation Business (Ramsgate site, UK) participated in the regular industrial workshops headed by **Gao** and this eventually led to them co-funding a three-year research project in 2015 to further develop and implement the knowledge framework for improving their testing processes in global product development (**OS1**). During the project, storytelling and video sharing functionalities were embedded into a corporate social media site which was capable of facilitating the capture and sharing of employee knowledge, including employee feedback (**OS3**) in global product development processes. The knowledge framework developed by UoG researchers was directly driven by the knowledge users, providing both knowledge direction and content. The company's

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IT manager and engineers also further developed and applied the knowledge framework (**OS1**) to manage standardised and modular product models with structured engineering knowledge (**OS2**) for integrated design, manufacturing and resources across the global supply chain. The results were validated in the Ramsgate (UK) site and its global R&D centre in the USA and applied across its global operations.

During the eligible period, significant changes have been achieved which were directly impacted by the research outputs, as evidenced by Cummins Ramsgate (UK) (5.2): Employees in testing and design functions better understood the importance of sharing their knowledge and were more willing to share with others; Testing and design engineers are more willing to use social media platforms and enterprise-wide frameworks to share knowledge; The knowledge framework was used as a reference model by the corporate IT department to improve company-wide product lifecycle management system, which increased knowledge search efficiency (15%) and accuracy (10%); Design and testing efficiency were increased (15%), Time to market reduced (15%), costs in design and testing saved (10%); Employees were more satisfied, motivated and inspired by learning from others and their knowledge used by others to generate business benefits.

Transforming knowledge sharing, improving design and production efficiency and accuracy, and saving costs at Edwards Ltd

Edwards is a brand of the Vacuum Technique subdivision of Atlas Copco, with over 4,200 employees globally. Edwards has global customers and is a prominent supplier to the semiconductor industry. It manufactures mainly in South Korea, China and Eastern Europe, and its core technologies, global processes and governance are based in the UK. Edwards was the main industrial partner of the research project that first proposed and developed the knowledge framework (**OS1**) in 2006. When **Gao** moved to UoG, the team captured manufacturing capability and maintenance/service knowledge in the company and implemented them based on the product model using standardised features (**OS2**). The framework made use of the best practices in machining and inspection knowledge in the company to support its global new product development process. *A new product-service system was also implemented which supports maintenance planning and also provides specific service-related requirements/constraints to designers.* The company's engineers and technologists continued to implement and apply the research outputs after the project ended in 2008. After enough time had passed for the benefits to be fully understood and appreciated, the company once again co-funded a new research project (Edwards/HEFCE, 1/9/2019–31/8/2022) to further develop and implement the framework (**OS1**) to support designers to select optimised tolerances using real manufacturing capability (inspection data) (**OS2**).

*Since August 2013, Edward's Burgess Hill (UK) site reported the following changes directly impacted by the research outputs (5.3): Formation and influence of an Advanced Manufacturing Technology Group; Employees in design, manufacturing and maintenance functions understood the importance of sharing their knowledge and were willing to share with others; The knowledge framework was used as a reference model to improve company-wide product lifecycle management which increased knowledge retrieval efficiency and accuracy; Maintenance/service data and knowledge fed back to designers for improving product quality and reliability; Optimal tolerance selection reduced manufacturing costs; New product development efficiency was increased, project time reduced, and costs saved. The research outputs were also shared across the company's global operations through their corporate R&D dissemination channels and repositories. The standardised design, manufacturing and service information and knowledge (**OS2**) is also shared across their entire corporate operations through the product lifecycle data/knowledge management framework (**OS1**).*

5. Sources to corroborate the impact

1. Testimonial (BAE Systems), to corroborate the impact on BAE Systems plc.
2. Testimonial (Cummins), to corroborate the impact on Cummins Inc.
3. Testimonial (Edwards), to corroborate the impact on Edwards Ltd.