

Institution: University of Hull		
Unit of Assessment: 12 – Engineering		
Title of case study: Mass Transport Access Security		
Period when the underpinning research was undertaken: 01/10/2012 – present		
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:
Professor JD Wadhawan	Professor of Chemical Engineering	2005 – present
Dr Nathan Lawrence	Senior Lecturer	2016 – present
Period when the claimed impact occurred: 01/10/2014 – present		
Is this case study continued from a case study submitted in 2014? No		
1. Summary of the impact <p>Hull's research into specialist inks has enabled Bemrose Booth Paragon (BPP) to become a world-leader in magnetic ink production for mass transit and car-parking tickets and other security applications. BBP was a struggling company, but was transformed through collaboration with Hull University allowing it to achieve financial sustainability, to give back to the community and develop in-house R&D and manufacturing capabilities, which will sustain these impacts into the future. BBP increased its workforce (139 to 174) and turnover (£8.7M to £22.8M) between 2014-2016 and, pre-Covid-19, supplied its parent company with 20 magnetic inks for customers including UK railways (typically one billion tickets per annum) plus the London and Paris mass-transport systems.</p>		
2. Underpinning research <p>This impact arises from the research carried out at Hull into advanced magnetic inks and printing techniques. The underpinning research centres around the design, production and deposition of solutions of nanoparticles with defined magnetic properties in stable, uniform films of a defined thickness and resolution on substrates such as paper [REF1-3] and advanced printing techniques [REF4,5]. As part of the work, the team created an in-house manufacturing and QA/QC facility at BBP for new, printable magnetic inks for paper tickets with sector-leading performance for information density, complexity, readability over distance (for passive and active tickets) and long-term stability (of data storage).</p> <p>Research theme 2.1: Smart tickets for mass transport systems</p> <p>This activity is based on research in the synthesis, characterisation and deposition from aqueous colloidal solutions of nanoparticles from 2012-2020 [REF1-3]. Wadhawan's understanding of printing processes for redox-active inks from 2015 [REF4] then provided the expertise to fine-tune these parameters for magnetic inks for commercially-viable, high-resolution, volume printing of magnetic inks at the high speeds (60 m/min) required for commercial ticket applications. These specifications include much-improved values for the viscosity, solid content, colour, and minimal coagulation/phase separation of magnetic inks over time in storage. From 2014-2020 the University/ BBP R&D team used this underlying research to optimise a range of magnetic inks with the required values of surface wettability, quick-drying, shape-retention and magnetic properties needed to meet different technical specifications and customer requirements over the lifetime of smart, digital tickets [REF5]. In collaboration with the University, BBP (which became</p>		

ParagonID from 2017) then established a bespoke R&D and production capability that could design, formulate, test and manufacture new print inks as stable colloidal solutions of magnetic ferrite nanoparticles for smart paper tickets for the mass-transport and car-parking markets, for example.

Research theme 2.2: Radio frequency identification (RFID) tags

The successful underpinning research on formulating magnetic inks from 2014-2018 [REF1-5] allowed the Hull University/ParagonID R&D team to develop a completely new ink between 2018-2020 based on stable colloidal solutions of electrically conducting silver nanoparticles. This novel ink can be used in RFID tags that can be printed on paper and plastic substrates, such as PET (polyethylene terephthalate), for recyclable identification and device-location-tracking products. Such tags allow the NHS, for example, to manage the allocation of medical equipment, moveable beds, trolleys, etc. These in-house printed RFID tags will also allow for more environmentally-friendly production techniques (scheduled for 2021) to replace those currently sourced from China, shortening the supply chain and re-shoring jobs to the UK (Hull).

Research theme 2.3: e-Passports and other RFID security solutions

The new RFID tag development has also facilitated the development of new generations of smart cards, passports, e-identity cards, etc, with enhanced levels of security and information-content. These developments and capability allowed ParagonID to tender for the printing of passports for Mexico and the USA (October 2020, decision pending).

Wadhawan's research into the electrochemistry of explosive residues (commercially sensitive), coupled with knowledge of electrochemistry of ink dopants [REF4], has also produced a novel ink capable of the detection of explosive residues on tickets (Hull patent invention record 2019), with wide-ranging potential impacts for security and safety applications.

3. References to the research

Hull researchers are shown in bold.

1. **RW Bourne, SM Kelly, JD Wadhawan**. 2012. Synthesis and characterisation of organic-modified inorganic nanorods. *Journal of Experimental Nanoscience*, 7, 673-687.
2. **NS Alahmadi, JW Betts, F Cheng, MG Francesconi, SM Kelly, A Kornherr, TJ Prior, JD Wadhawan**. 2017. Synthesis and antibacterial effects of cobalt-cellulose magnetic nanocomposites. *RSC Advances*, 7, 2020.
3. **E Halls, KJ Wright, JE Pickersgill, JP Smith, AA Altalhi, RW Bourne, P Alaei, T Ramakrishnapa, SM Kelly, JD Wadhawan**. 2012. Voltammetry within structured liquid nanosystems: towards the design of a flexible, three-dimensional framework for artificial photosystems. *Electrochimica Acta*, 70, 215-227.
4. CC Dai, P Song, **JD Wadhawan**, AC Fisher, **NS Lawrence**. 2015. Screen-printed Alizarin-based carbon electrodes: monitoring pH in unbuffered media, *Electroanalysis*. 27, 917-923.
5. **HJ Ward, TA Armstrong-Telfer, SM Kelly, NS Lawrence, JD Wadhawan**. 2020. Evaporative rate loss measurement as a quality control tool for quality assurance in the manufacture of inks suitable for high speed (≥ 60 m/min) printing. *J. Electroanalytical Chemistry*, 872, 114328.

Research Grants

- Innovate UK: *The design, formulation, characterisation and production, on a commercial scale, of colloidal solutions of surfactant-stabilised magnetic micro-particles for deposition*, 01/06/2014 - 30/05/2016 (KTP 009576), £121,942.
- Innovate UK: *The development of innovative and enabling technologies for the detection of dangerous substances in a high-throughput environment: the development of a prototype sensor for an emerging threat, suitable for commercialisation*, 02/04/2018-31/03/2020 (KTP 010844), £122,696.
- EU: SURFUNCELL, 01/12/2008-30/11/2012 (FP7 THEME NMP-2007-2.1-1; Grant Agreement No: 214653), £415,260.
- EPSRC: *Study of nanocrystal-polymer composites for blue light-emitting diodes*, 01/10/1999-30/09/2002 (GR/M769982), £173,020; *Anisotropic photovoltaic nanotubes*, 31/03/2012-30/03/2015 (GR/N65943), £293,624; *Liquid crystalline hybrid dielectrics for monodomain organic semiconductors*, 31/03/2012-30/03/2015 (EP/J001597/1), £517,190.

4. Details of the impact

The impact of this research is significant and its 'reach' is truly large with the result of the work already used millions of times per day in many countries around the world. It has transformed a previously-failing local company (BBP) into a world-leader in magnetic ink production for mass transit and other ticketing and security applications, providing substantial financial and reputational benefits to the company [4.1], as well as significant local economic and societal benefits [4.2]. The introduction of new in-house R&D and manufacturing capabilities within BBP [4.1] has also secured the company's long-term future with a number of new product developments already poised to transform the industry further [4.3].

Impact Dimension 4.1: Economic and end-user benefits

University of Hull's research in colloid-stabilised nanoparticles, printing and magnetic materials [REF1-5] led to a collaboration between BBP and the University in 2012 to create an R&D team and in-house production with quality assurance/control (QA/QC) facility at BBP for the formulation, testing and manufacture of novel printable magnetic inks for the magnetic stripe on the *verso* side of tickets for automatic reading and ticket validation. The strategic intent behind this collaboration was not only to eliminate a business-critical, single source of failure (BBP's suppliers of magnetic inks were due to cease trading), but also to create a portfolio of novel magnetic inks with sector-leading performance for each of BBP's market sectors.

By 2014 the in-house R&D team and production and QC/QA facility had been created at BBP, together with optimised printing processes. This capacity was enhanced further via two Knowledge Transfer Partnerships (KTPs) with the University of Hull (ranked 'outstanding' by Innovate UK) [EVID1-2]. The success of this collaboration allowed BBP to acquire its main UK competitor from administration in 2015, underpinned by its new capabilities in innovative magnetic ink design, manufacture and state-of-the-art printing at its Hull site [EVID3].

This market consolidation provided BBP (renamed ParagonID from 2017) with a significantly larger customer base for tickets with sector-leading performance offering product-specific low- and high-coercivity magnetic inks from its new production and QA/QC facility [EVID4]. As a result, BBP increased its UK market share, its workforce (139 to 174) and its turnover (£8.7M to £22.8M) between 2014-2016 [EVID3-6]. Paragon (ParagonID's parent company) is now the world's largest provider of paper tickets for the transport and car-parking markets using nearly 20 different magnetic inks requiring the manufacture of typically 200 tons per annum exclusively in Hull. For example, its low-coercivity inks are used for London Underground tickets and its high-coercivity inks are used in Nice Tramway tickets [EVID3-6]. Other markets include the UK railway network (typically one billion tickets per year) and mass-transport systems in Paris (RATP), New York, Phoenix, Nice, Cairo, Caracas, Tyne & Wear and Canada.

Impact Dimension 4.2: Enriching the ticket-printing sector and local communities

ParagonID's highly profitable business now allows it to sponsor business exhibitions, e.g. the Transport Ticket Global conference [January 2021, EVID7], and to encourage other innovators within their sector as well as provide support for local ventures [EVID8]. There have also been important social impacts from the University/ParagonID collaboration, including creation of a significant number of well-paid, high-tech jobs [EVID3, 5, 6] in Hull, which is one of the twenty most deprived socio-economic regions in the UK. Finally, BBP/ ParagonID's growth and development has provided significant tax revenue and local pride [EVID8].

Impact Dimension 4.3: Increased R&D capability for sustainable market leadership

ParagonID's partnership with Hull University has created an outstanding research and innovation capability that fuelled its rapidly expanding business portfolio. This continuing relationship ensures that these developments are sustained into the future. For example, a new ink formulation has been successfully trialled for large-scale printing of Radio-Frequency Identification (RFID) tags at high speeds [EVID9]. Trials have demonstrated that these printed RFID tags are cost competitive and logistically and environmentally more sustainable than ParagonID's current RFID tags (produced in China using a costly and environmentally unsustainable etching process). Thanks to

these developments, ParagonID has recently tendered (October 2020) for several national passport contracts based on these prototype RFID tags that are printed with the new Hull inks.

In the longer term, the new RFID tags are expected to impact across the travel sector as travellers' baggage identification is upgraded from simple barcodes to smart RFID tags [EVID9]. Hence, despite significant COVID-related challenges in the global printed ticket market, the future of this R&D and magnetic ink production facility has been secured by exploitation of the research from the two KTPs with the University of Hull (as confirmed by the testimonial/supporting letter from ParagonID's General Manager [EVID10]. These KTPs and their impact also earned a wider degree of recognition and esteem, for example, KTP1 (2014-16) received the Best Business Impact Award at the 2019 'KTP Best of the Best' Awards [EVID11]. KTP1 also won or was shortlisted for the following awards:

- 2018 Yorkshire Business Masters Investment Award:
<https://www.thebusinessdesk.com/yorkshire/news/2017462-shortlist-revealed-for-yorkshire-business-masters-awards-2018>
- 2017 Yorkshire Post Excellence in Business Turnaround Award:
<https://www.businessupnorth.co.uk/bemrosebooth-paragon-celebrates-awards-success/>
- 2017 Yorkshire Business Masters (in both the Innovation and International categories):
https://www.thebusinessdesk.com/yorkshire/news/746269-yorkshire-business-masters-shortlist-revealed?news_section=5%29
- 2017 Made in Yorkshire Awards in both the Advanced Manufacturer and Manufacturer of the Year categories:
<https://www.insidermedia.com/event/made-in-yorkshire/coverage>
- 2016 Educate North Award:
<https://www.prolificnorth.co.uk/awardsevents/featured/2016/03/educate-north-awards-2016-shortlist-announced#table>
- 2016 Times Higher Education Leadership and Management Awards in the Knowledge Transfer Partnership of the Year category:
<https://www.timeshighereducation.com/news/times-higher-education-leadership-and-management-awards-thelmas-2016-shortlist-announced>

Mr HJ Ward, former KTP Associate (now ParagonID's Technical Development Manager) was also nominated for or won:

- 2018 Top 30 Under 30 award for the Humber region:
<https://www.top30under30.co.uk/alumni>
- Shortlisted for the 2018 Young Manufacturer of the Year by The Manufacturer magazine:
<https://www.themanufacturer.com/articles/the-manufacturer-mx-awards-2018-shortlist-revealed/>

5. Sources to corroborate the impact

- EVID1 a. Knowledge Transfer Partnership 009576 details, between BBP and UoA, available at: <https://info.ktponline.org.uk/action/details/partnership.aspx?id=9576>
b. KTP 009576 Certificate of Excellence
- EVID2 a. Knowledge Transfer Partnership 010844 details, between BBP and UoA, available at <https://info.ktponline.org.uk/action/details/partnership.aspx?id=10844>
b. KTP 010844 Certificate of Excellence
- EVID3 Bemrose Booth Paragon Limited. Filing history, available at:
<https://beta.companieshouse.gov.uk/company/04891375/filing-history>
- EVID4 Journal paper exemplifying the methodologies developed by the University to support the QA/QC activities of ParagonID:
<https://www.sciencedirect.com/science/article/abs/pii/S1572665720305555>

- EVID5 KTP between BBP and UoH, used as a success story by Innovate UK, available at:
<https://innovateuk.blog.gov.uk/2019/05/03/research-post-graduates-cant-help-my-business-or-can-they/>
- EVID6 Impact case study in Kingston upon Hull at:
a. <https://www.hull.ac.uk/work-with-us/business/case-study/paragon-id/>
b. <https://bdaily.co.uk/articles/2016/05/26/bemrosebooth-paragon-creates-20-new-jobs-after-investing-in-its-hull-facility/>
- EVID7 Evidence of ParagonID's wider contribution to the ticket printing sector:
<https://www.transport-ticketing.com/meet-our-sponsors-and-exhibitors> &
<https://www.transport-ticketing.com/>
- EVID8 Evidence of ParagonID's community engagement, available at:
<https://www.hulldailymail.co.uk/news/business/paragon-id-backing-teenagers-bizarre-1629264>
- EVID9 Promotional page for RFID tags developed by ParagonID
<https://www.rfiddiscovery.com/inspiration/rfid-vs-barcode>
- EVID10 Testimonial letter from ParagonID's General Manager confirming the invaluable impact that Hull's research and collaboration has had on ParagonID's business
- EVID11 Business Impact Award 2019 for the KTP between BBP and UoH, available at:
<https://www.gov.uk/government/news/ktp-best-of-the-best-2019-winners-announced>