Impact case study (REF3)

REF2021

Institution: University of Oxford

Unit of Assessment: 12 – Engineering

Title of case study: Oxbotica – Creating Universal Autonomy for Vehicles

Period when the underpinning research was undertaken: 2003-2016

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:
Prof. Paul Newman Prof. Ingmar Posner	BP Professor of Information Engineering Professor of Engineering Science	2003-present 2005-present

Period when the claimed impact occurred: Nov 2014 – Dec 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

The Department of Engineering Science's Oxford Mobile Robotics Group (now the Oxford Robotics Institute) has led in the research and development of Autonomous Vehicle (AV) technology worldwide, shaping UK policy, creating the successful spinout Oxbotica, and helping establish the UK as a world leader in AV. Research conducted by Prof. Newman and Prof. Posner as part of the Oxford Mobile Robotics Group led, in 2014, to the creation of Oxbotica. The company engineers driving software for autonomous vehicles that are being used across a wide range of industries, beyond automobiles: from air travel, to mining, to logistics. Oxbotica now employs 170 people across 4 sites in the UK and Canada and has commercial partnerships with major industrial companies.

Oxbotica and the research group's work is shaping AV policy in the UK and they have led or taken part in major UK AV trials (LUTZ, AUTODrive, and DRIVEN). Prof. Newman also serves on the Department of Transport's Science Advisory Council sharing his expertise to develop the AV Strategy as a part of the wider Industrial Strategy for Great Britain.

2. Underpinning research (indicative maximum 500 words)

The underpinning research that resulted in the successful spinout of Oxbotica was conducted at the University of Oxford between 2003 and 2016. Over a decade the Department of Engineering Science's Mobile Robotics Group advanced and developed the concept of 'Universal Autonomy' – the ability of machines to learn, navigate, and understand without external props, sensors, or infrastructure – via the creation of algorithms that allowed infrastructure-free mobile autonomy.

Universal Autonomy allows an autonomous vehicle (AV) to operate with no dependency on external infrastructure (such as GPS) or human interaction, over long periods of time, and in a multitude of changing and challenging conditions [**R4, R1**]. The independence from GPS allows operation in places where GPS is not available (indoors, underground, or in dense cities) and the resilience to changing conditions allows operation in dynamic environments in many weather conditions. Together these attributes extend the operational domain – and thereby utility, and addressable market size – of autonomous vehicles.

At the heart of Universal Autonomy are three principles, successfully developed at the University of Oxford:

1. Developing a mathematical representation of space (maps) which allows constant time updating with new sensor data [**R1**]. *This basic innovation made it possible for Oxbotica to build an*

autonomy product into domains of arbitrary size to manage (update) those maps easily and at scale across fleets.

*2. A method of updating this representation with processed sensor data that allows maps to be used in any conditions, providing immunity to weather [**R2**, **R3**]. This basic innovation made it possible for Oxbotica to build software providing autonomy using computer vision in weather conditions not previously possible.*

3. A reference design for a system of communicating processes to form the underpinning architecture of an autonomous vehicle. This reference design allows Oxbotica to build modular software that is compatible with software components provided by third parties. For example, it stimulated the OpenAutonomy paradigm with Wenco Mining. This opens up new markets where a closed end-to-end system is commercially unacceptable.

From this origin, Prof. Posner and Prof. Newman created a prototype AV architecture which could operate without GPS and external infrastructure dependency, using redundant and independent modalities: radar, vision, and lidar. This prototype architecture was deployed in the Oxford Robotcar project (2010-2015; the vehicle is now with the London Science Museum) and the Transport System Catapult's LUTZ Pathfinder Project (2014-2016). It formed the basis for what would later be developed into the Selenium and Caesium software sold commercially by Oxbotica.

This fundamental work and closely related topics that led to the foundation of Oxbotica appeared in 180 papers, which have garnered 16,000 citations, and 22 registered patents. From this origin, Oxbotica's prime product became software for Universal Autonomy – the ability for any land vehicle to operate autonomously anytime and anywhere.

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

[**R1**] W. Churchill and P. Newman, "Experience-based Navigation for Long-term Localisation," *The International Journal of Robotics Research (IJRR)*, 32:14, 1645-1661, 2013 doi: 10.1177/0278364913499193 (Journal article)
[**R2**] C. Linegar, W. Churchill, and P. Newman, "Made to Measure: Bespoke Landmarks for 24-Hour, All-Weather Localisation with a Camera", in *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, Stockholm, Sweden, 2016. Doi: 10.1109/ICRA.2016.7487208 (Conference proceeding)
[**R3**] C. Linegar, W. Churchill, and P. Newman, "Work Smart, Not Hard: Recalling Relevant Experiences for Vast-Scale but Time-Constrained Localisation," in *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, Seattle, WA, USA, 2015. doi: 10.1109/ICRA.2015.7138985 (Conference proceeding)
[**R4**] D. Z. Wang and I. Posner, "Voting for Voting in Online Point Cloud Object Detection," in *Proceedings of Robotics: Science and Systems*, Rome, Italy, 2015 (Conference proceeding) https://www.robots.ox.ac.uk/~mobile/Papers/2015RSS_wang.pdf

Grants
[**G1**] 2010 - EP/M019918/1 - Mobile Robotics: Enabling a Pervasive Technology of the Future and EPSRC Programme Grant; PI Paul Newman
[**G2**] 2012 - EP/J012017/1 Intelligent Workspace Acquisition EPSRC Grant; PI Paul Newman
[**G3**] 2015 - EP/I005021/1 Lifelong Infrastructure Free Navigation EPSRC Leadership Fellowship; PI Paul Newman

4. Details of the impact (indicative maximum 750 words)

The research described in section 2, and the development of prototype software that could enable Universal Autonomy (the ability of machines to learn, navigate, and understand without external props, sensors, or infrastructure), led directly to the formation of Oxbotica in 2014 (Prof. Posner is a Founder and Prof. Newman is a Founder and Chief Technology Officer (CTO) at the company). The same research, and EPSRC funding [**G1**, **G2**, **G3**], has subsequently underpinned the company's commercial success, allowing it to begin trading from day one. It is because of the

development of this autonomy platform, and the continued collaboration with the Department's Oxford Mobile Robotics Group, that Oxbotica and its founders have been able to influence UK Autonomous Vehicle (AV) policy, leading and taking part in UK trials and being used as a showcase by Government.

Policy Impact – Influencing the UK government's autonomous vehicle policies

By the time Oxbotica was spun out in September 2014, Prof. Posner and Prof. Newman's group had already used the prototype AV architecture detailed in section 2 to deploy and test an autonomous vehicle on public roads – the RobotCar, the first autonomous vehicle on UK roads (2013), developed in partnership with Nissan. Results from this work informed the UK Government's February 2015 report 'The Pathway to Driverless Cars', which referenced the RobotCar and concluded that "The UK is a premium location to develop automated vehicles" and identified an action plan to update current legislation and a roadmap for bringing driverless vehicles to market. [**S1**]

The report also set out a plan for a pioneer **Code of Practice** (published in 2015). Because of their research expertise, the Oxford group and Oxbotica were asked to play a central advisory role throughout. The Chief Scientific Adviser, Department for Transport (DfT) explains that DfT and Prof. Newman:

"…worked on a code of practice and safety case to allow this technology out on the roads. […] This heavily informed the DfT (on technical aspects) as it worked towards creating the UK code of practice which provides a framework to encourage the uptake and development of AV tech in the UK landscape (the point here is that Paul supported the wider field and not just Oxbotica, through his engineering expertise and his contribution to the national landscape)." [**S2**]

This code continues to shape the way in which autonomous vehicle trials are conducted in the UK, and an updated version was published in 2019. [**S1**]

Prof. Newman sits as one of 9 members on the **Department for Transport's Science Advisory Council**. The DfT draws upon the expertise of Prof. Newman and Oxbotica for advice on autonomous vehicle technology in relation to the Government's Industrial Strategic Plan, as evidenced by the Chief Scientific Adviser at the DfT and the Chair of the DfT's Science Advisory Council respectively in 2018:

"[Paul] provides me with independent advice on the range of issues that ensures that I put Science, Engineering and Technology at the top of the DfT's agenda. Paul's contribution to this, and to Government in general, has been invaluable, in particular his contribution to the ambition we have in the UK to be the world leader in Connected and Autonomous vehicle systems. He has also helped the Department shape the Year of Engineering, which has been led out of the DfT throughout 2018." [**S2**]

"[Paul] is an active and enthusiastic member of the Department of Transport's Science Advisory Council, which I chair, and makes invaluable contributions to much of our work, particularly in relation to strategy and policy on Artificial Intelligence and Future Transport technologies." [**S2**]

Advice was also provided to the **House of Lords Select Committee on Science and Technology's Inquiry into Connected and Autonomous Vehicles** (CAV) in 2016, which resulted in 39 conclusions and recommendations by the House of Lords on all aspects of CAV, from UK governance and coordination to international cooperation and standards, as well as future research. Regarding Prof. Newman's advice, the Chair of the DfT's Science Advisory Council, also a member of the Committee, says:

"He has made a major impact on the rapidly developing AV world, and is regarded as the leading expert in the UK. […] Paul Newman gave an outstanding presentation at a special

seminar for the Committee at the outset of the Inquiry, as well as subsequently providing comprehensive and authoritative evidence to the Inquiry." [**S2**]

Oxbotica was part of the steering group consulted for the **PAS 1881:2020 specification, 'Assuring the Safety of Automated Vehicle Trials and Testing'**, facilitated by the British Standards Institute. The PAS (Publicly Available Specification) is a fast-track standardisation document that supports the government's commitment to creating a standardised and consistent approach to safety case development for autonomous vehicle testing, by developing a robust safety case framework specification for organisations involved in trialling autonomous vehicles based upon the UK Government's Code of Conduct. This document is continually being refined and updated to reflect the rapidly changing Autonomous Vehicle environment. [**S3**]

Demonstrating and recognising Oxbotica's position as world leaders in autonomous vehicle development, in 2019 the Minister of State for the Future of Transport interviewed Prof. Newman and used Oxbotica's autonomous technology as a **national showcase** and as an exemplar of "*the very best of technology* […] *in the UK*". [**S4**]

Policy Impact – Delivering the roadmap to bring driverless vehicles to market

From launch onwards, owing to the proven research expertise that underpins the company, Oxbotica and the Oxford Mobile Robotics Group have led or participated in the major UK AV trials (LUTZ, AUTODrive, and DRIVEN). These trials have helped to guide and shape autonomous vehicle policy and practice in the UK, and have strengthened the UK Government's perception of the UK as a "global leader in this space". [**S5**]

Oxbotica partnered with the University of Oxford to provide the Selenium operating system behind the Milton Keynes-based LUTZ project (2014-2016), which demonstrated that autonomous vehicles could work in urban environments and be accepted by the people encountering the vehicles. Coordinated by the Transport Systems Catapult (TSC), at its conclusion the TSC Programme Director said:

> *"This public demonstration represents a major milestone for autonomous vehicles in the UK and the culmination of an extensive project involving UK companies and experts. Oxford University's technology will go on to power automated vehicles around the world, and the LUTZ Pathfinder project will now feed into a much wider programme of autonomous trials across the UK. Driverless vehicles are coming to Britain, and what we have demonstrated today is a huge step on that journey."* [**S6**]

Following the LUTZ project, Oxbotica and the University of Oxford participated in the 2018-2019 UK Autodrive Project – one of the largest of the successful consortia to be selected by Innovate UK – to trial and showcase autonomous vehicles on UK streets and explore the wider issues of the deployment of autonomous vehicles, including business models, and the legal, ethical, and public acceptance issues. [**S7**]

In Autumn 2019, Oxbotica operated the first trial of autonomous vehicles on London's roads in culmination of the DRIVEN project. The DRIVEN consortium was led by Oxbotica, and included key stakeholders in the public sector, transportation and insurance industry as well as the Oxford Robotics Institute (Mobile Robotics Group). The team secured a GBP8,600,000 grant in 2017 from Innovate UK and the Centre for Connected and Autonomous Vehicles to complete the trial. [**S8**] The Minister of State at the Department for Transport said at its conclusion:

> *"We want to drive the roll-out of self-driving vehicles and continue to support innovators developing this ground-breaking technology. The success of trials like project DRIVEN underpin our Future of Mobility: Urban Strategy, highlighting our ongoing support for innovation, research and the trialling of exciting new technology which cements our position as a global leader in this space."* [**S5**]

Economic Impact – commercial partnerships and wealth generation

Oxbotica span out from the University with a prototype code-base in 2014; by 2016 this had been developed into 2 autonomous software products, Selenium and Caesium, which are commercialised. The launch with a prototype product allowed Oxbotica to begin trading from day one in an industry predicted by Oxfordshire Local Enterprise Partnership (OxLEP) to be worth over GBP50,000,000,000 and set to create over 320,000 new jobs in the automotive industry in the UK by 2030. Oxbotica now has 170 staff (headcount: 170), and has offices in both Oxford and Toronto, Canada. [**S9**]

The significance of Oxbotica's technology is demonstrated via the quantity and diversity of commercial partners who are benefiting directly from using, licensing, or piloting Oxbotica's operating systems. These companies include Ford, Nissan, Toyota, Caterpillar, BHP, Navtech Radar, Cisco, Wenco, Addison Lee, the UK Atomic Energy Authority, aiPod, Nacco, Guidance Ltd, and IAG among others. [**S9**]

Oxbotica has won numerous awards for being a world-leader in autonomous driving software: a Frost & Sullivan Award, a Technology Leadership Award (2016); the Financial Times Arcelor Mittal Boldness in Business Award (2017) and Barclays Award for Innovation (2019) [**S10**].

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

[**S1**] Governmental reports corroborating the University's and Oxbotica's involvement in the drafting of Governmental plans of action for driverless vehicles and a Code of Conduct, comprising:

    a) *The Pathway to Driverless Cars: Summary report and action*, Department for Transport, February 2015 – a governmental summary and plan of action for driverless vehicles
    b) *The Pathway to Driverless Cars: A detailed review of regulations for automated vehicle technologies*, Department for Transport, February 2015 – DfT main document
    c) *2015 Code of Practice: Automated Vehicle Trialling;* (**d**) updated 2019

[**S2**] Letters of support for Paul Newman's RAEng Silver Medal from the Chief Scientific Adviser Department for Transport and the Chair of the DfT's Science Advisory Council, corroborating Prof. Newman's expertise in influencing DfT policy and code of conduct on autonomous vehicles, 2018

[**S3**] PAS 1881:2020 'Assuring Safety for Autonomous Vehicle Trials and Testing – specification' evidencing Oxbotica as a member of the steering group for this specification, 2020

[**S4**] Interview between the Minister of State for the Future of Transport and Prof. Newman, using Oxbotica as a case study and evidencing Oxbotica's position as a world leader in the field, 2019

[**S5**] Minister of State at the Department for Transport on the DRIVEN Trials website at the trial's conclusion, corroborating that the success of the trials would underpin future UK Government strategies, 2019

[**S6**] Programme Director at the TSC on the LUTZ Pathfinder Project website at the project conclusion, corroborating the milestone represented by the trial, the importance of Oxford University's technology and how it would underpin future autonomous vehicles, 2016

[**S7**] UK Autodrive Project Final Report, evidencing that Oxbotica and the University were a part of the successful consortia to be selected by Innovate UK to trial and showcase autonomous vehicles on UK streets, 2019

[**S8**] UK Government website using Oxbotica as a case study, evidencing that the DRIVEN project was awarded GBP8,600,000 from Innovate UK in 2017 (led by Oxbotica in collaboration with University of Oxford and others), 2019

[**S9**] Corroborator 1: CEO of Oxbotica, who can be contacted to confirm figures and collaborators.

[**S10**] Portfolio of awards for Oxbotica as a world leader in autonomous driving software from 2016 to 2019, from the following awarding bodies:

    a) Frost & Sullivan European Autonomous Driving Software Technology Leadership Award, 2016
    b) Financial Times Arcelor Mittal Boldness in Business Award, 2017
    c) Barclays Entrepreneur Award for Scale-up Entrepreneur of the Year, 2019