Institution: Coventry University		
Unit of Assessment: 12		
Title of case study: Development of a Comprehensive National Test Facility for Connected & Autonomous Vehicles		
Period when the underpinning research was undertaken: 2016-2021		
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:**
Stratis Kanarachos	Reader	2014-2019
Andrew Parkes	Professor	1999-2020
Olivier Haas	Reader/ Associate Professor	1997- present
Sujan Rajhbandari	Senior Lecturer	2015-2019
Period when the claimed impact occurred: 2016- 2021		
Is this case study continued from a case study submitted in 2014? No		

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

Externally funded research at Coventry University worth £6.1M has facilitated the development of hybrid systems exploiting artificial intelligence (AI) and accelerated the use of comprehensive testing facilities for connected and autonomous vehicles (CAV), through 'digital twins' of both the vehicle and road environments. It has significantly contributed to the development of the National CAV testing infrastructure promoted by the UK government in the CAM (Connected and Automated Mobility) Testbed UK initiative. It has also led to specific impact in the following areas.

- New business models and revenue streams for company Horiba-Mira.
- Increased effectiveness of traffic management, leading to reduced congestion and associated environmental and social benefit.

2. Underpinning research (indicative maximum 500 words)

CCAAR (Centre for Connected and Autonomous Automotive Research) at Coventry University has undertaken research which has fed into the development of national Connected and Autonomous Vehicles (CAV) testing facilities through a number of national and international projects, including ITEAM; iVMS; TIC-IT; ASSURED CAV Parking and Digital-CAV.

The development of CAVs encompasses both the design of the vehicle itself, with its highly automated and autonomous systems, and determining how the vehicle and its systems interact with the wider road environment and other road users. To gain maximum benefits from CAVs, a comprehensive, systemic approach, encompassing formative and summative assessments, is required for their design, development and implementation. It is estimated that by 2030 the introduction of (CAV) will add £51bn a year to the country's economy, creating 320,000 new jobs in the UK, of which 25,000 will be in the automotive sector. This will help prevent accidents, reduce pollution, decrease congestion, and help enhance productivity.

In the European consortium ITEAM 2016-2019 (Marie Curie EC ITN in Multi-Actuated Gro undertaken und Vehicles), research at CU focused on development of a model-based approach for the construction of a highly skilled Autonomous Vehicle. Artificial neural networks (ANNs) and parameter estimators (algorithms that calculate the values of the variables for the model that are selected to represent the real system) were combined with physical models to form meaningful novel hybrid systems. These were applied to create reliable tyre models when operating at the limits of handling with estimates of road friction [R1]. Subsequently, this enabled the creation of hybrid structures combining ANNs with model predictive control, exploiting knowledge of the terrain with improvement of the drift control shown by human drivers [R2].

Work on tyre-road interface and vehicle dynamics from ITEAM [R1, R2] has led to the TIC-IT (Trusted Intelligent CAVs) project which provides a realistic, controlled, high-speed, limit-handling, and fully connected environment for testing Automated Vehicles. By allowing real-world CAV driving scenarios to be created, including testing that cannot be conducted in public environments, it has accelerated development and testing to ensure CAVs are safe, comfortable, and secure. CU developed novel algorithms and methodologies to identify and create appropriate edge (safety) case scenarios ideal for manufacturers and Tier One suppliers to use, to verify, and to certify safe operation [R5]. This, together with digital twins, allows the validation, replication and verification of real experiments in a virtual environment [R1, R2, R6].

Moving towards more summative testing, research on ASSURED CAV Parking, funded by CCAAV through Innovate UK, 2019-2021 involving HORIBA MIRA and CU, has created a flexible facility to speed up testing of parking scenarios. The toolchain [R1, R4] for modelling and validation work was adopted to implement the digital twin of the ASSURED CAV City and ASSURED CAV Parking test facility, whilst the algorithms were exploited to model the autonomous vehicle to test automated parking scenarios.

Further research via the project Digital-CAV Proving Ground (2018-2020, CU and HORIBA MIRA), investigated the means of building a CAV simulation platform. This platform accelerated testing based on evaluating sensor models with deliberate degraded performance to mimic the results of operating in harsh environments. The models, resulting from [R1, R4], are integral to the simulation platform.

The summative approach was further exemplified by the on-the-road testing evaluations undertaken by the iVMS (Intelligent Variable Messaging System) consortium, which comprised Coventry City council, Siemens, HORIBA MIRA, CU and Serious Games International. The focus of the research undertaken at CU using neural networks and modelling enabled behavioural influence [R3] in traffic simulations to be incorporated, which facilitated the determination of the most appropriate route and time of travel to reduce congestion on Coventry roads and improved journey time reliability.

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

[R1] Acosta, M., Kanarachos, S. and Fitzpatrick, M.E. (2018) 'Robust Virtual Sensing for Vehicle Agile Manoeuvring: A Tyre-Model-Less Approach'. IEEE Transactions on Vehicular Technology, 67 (11), 1894-1908 https://doi.org/10.1109/TVT.2017.2767942

[R2] Acosta, M. and Kanarachos, S. (2018) 'Teaching a vehicle to autonomously drift: A data-based approach using Neural Networks'. Knowledge-Based Systems 153, 12-28 https://dx.doi.org/10.1016/j.knosys.2018.04.015

[R3] Christopoulos, S.G., Kanarachos, S. and Chroneos, A. (2019) 'Learning Driver Braking Behavior Using Smartphones, Neural Networks and the Sliding Correlation Coefficient: Road Anomaly Case Study'. IEEE Transactions on Intelligent Transportation Systems 20 (1), 65-74 https://doi.org/10.1109/TITS.2018.2797943

[R4] Weber, Y. and Kanarachos, S. (2019) 'The Correlation between Vehicle Vertical Dynamics and Deep Learning-Based Visual Target State Estimation: A Sensitivity Study'. Sensors. 19, 4870 https://doi.org/10.3390/s19224870

[R5] Batsch F., Kanarachos, S., Cheah M., Ponticelli R. and Blundell M. (2020) 'A taxonomy of validation strategies to ensure the safe operation of highly automated vehicles'. Journal of Intelligent Transportation Systems https://doi.org/10.1080/15472450.2020.1738231

[R6], S., Cieslak, M., Kanarachos Blundell, M. *et al.* (2020) 'Accurate ride comfort estimation combining accelerometer measurements, anthropometric data and neural networks'. Neural Computing and Applications, 32 (12), 8747–8762 https://doi.org/10.1007/s00521-019-04351-1

Grants

[G1] ITEAM (January 2016-August 2019), £201,634 was awarded to Coventry University by Marie Sklodowska-Curie Actions. Stratis Kanarachos was PI.
[G2] iVMS (March 2016-November 2018), £400,000 was awarded to Coventry University by Coventry and Warwickshire Local Enterprise Partnership. Olivier Haas was PI.
[G3] TIC-IT (March 2019- August 2020), total project award was £32m, with £4.78m allocated to Coventry University, by Connected and Autonomous Vehicle Fund, Innovate UK. Professor Andrew Parkes was PI.
[G4] ASSURED CAV Parking (March 2019-February 2021), total project award was £131,638.00, with £498,939 allocated to Coventry University, by Connected and Autonomous Vehicle Fund, Innovate UK. Stratis Kanarachos was PI.
[G5] Digital-CAV (December 2018-August 2020), total project award was £X, with £105,311 allocated to Coventry University, by Innovate UK. Stratis Kanarachos was PI, December 2018-May 2019; Sujan Rajbhandari was PI May 2019- November 2019 and Rahat Iqbal was PI until the end of the project.

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

The UK Government with its industry partners is investing £200m into CAM (Connected and Automated Mobility) Testbed UK https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/929352/innovation-is-great-connected-and-automated-vehicles-booklet.pdf [S1]). This encompasses world-class proving grounds, on-the-road, and virtual testing facilities for the development of CAV technologies. These will provide the UK with the capability to develop CAV concepts both virtually and physically. CCAAR at Coventry University, with HORIBA MIRA, is a major partner in this initiative (https://zenzic.io/testbed-uk/horiba-mira-coventry-university-cav-testbed/ [S2]).

> *The findings of the CCAAR research from testbed projects such as TIC-IT, PARK-IT and Midlands Future Mobility, supported the update of the second version of the* [Zenzic] *Roadmap. The outcomes of this research were incorporated into our core milestones, required for the creation of a virtual testing environment for CAM Testbed UK, an ecosystem of facilities with industry, government and academia, working together to develop a unique space to facilitate safe connected and autonomous vehicle testing.* [S3]

Coventry University is also a partner in another of the six major CAM Testbed UK initiatives, *Midlands Future Mobility*, which provides 'a comprehensive real-world CAM ecosystem' for trialing CAV technology on a diverse road network containing high speed, rural and urban roads (https://zenzic.io/testbed-uk/midlands-future-mobility/ [S3]). It is estimated that CAVs will require significant testing (275 million km, costing €34.98 billion).
The impact of individual aspects of the research undertaken has also led to commercial, societal and environmental impact in the following areas.

- New business models and revenue streams for HORIBA MIRA.
- Increased effectiveness of traffic management, leading to reduced congestion (hence associated environmental and social benefits) in Coventry

Commercial Impact: New business models and revenue streams

A direct beneficiary of Coventry University's research is HORIBA MIRA, a major research consultancy company that supports the Automotive industry. Changes to HORIBA MIRA's business proposal were facilitated by joint research funding and research programmes that are coordinated through the umbrella of the CCAAR.

Coventry University's underpinning research in control systems, neural networks, and modelling and simulation' [R1,R2,R5] has led to "*new business lines around simulation and modelling activity leading to strategic investment decisions taken by* HORIBA MIRA *to create new commercial revenue streams*". This work has expanded and diversified HORIBA MIRA's customer base enabling new stakeholders reached as a result, e.g., Transport for London, Highways England and infrastructure organisations such as Vodafone and Amey' [S4]. [Text removed for publication].

Further benefit to HORIBA MIRA from Coventry University's research is the creation of a 'plug and play' framework with scripting methods that parameterises the scenario-based testing environment and CAV capabilities. This framework has "Intellectual capital" stemming directly from the work with Coventry University that has contributed to the physical testing and verifications of ADASs (Advanced Driver Assist Systems). The combination of a virtual testing offering, combined with further physical vehicle testing in realistic environments has enabled HORIBA MIRA to commercialise its offering in 'Accelerated testing to ensure the safety of CAVs' with a Japanese Tier 1 automotive supplier [S6]. "HORIBA MIRA are selling physical testing and have just signed their first contract for simulation and modelling relating to testing using virtual methods." [S6]

The strategic research relationship between Coventry University and HORIBA MIRA has supported the rapid growth within the global intelligent mobility sector to address future transport testing and development needs. This is a step change and represents a robust barrier to entry for competitors by creating a go-to market proposition that is very strong and cannot easily be replicated.

Societal and Environmental Impact: Increased effectiveness of traffic management, leading to reduced congestion and associated social and environmental benefits

The knowledge gained from the simulation studies that exploited the data collected using the mobile app [R3] was used to study traffic congestion, These data were then further exploited in the iVMS project (2016-2018) where Coventry University developed traffic simulation models exploiting journey time and driver's behaviour data. From this, a new capability to study traffic congestion was developed making it possible to assess the impact on commuters' journey times and the environment. From this effective traffic management solutions to '*demonstrate the*

reduction in congestion…on three main routes in Coventry city' were developed. It was found that '*Modelling has identified the relative small scale of driver behavioural change required on the individual corridors within the city to achieve congestion benefits'*. [S5]
As a direct result, Coventry city has achieved '*increased effectiveness of traffic management, leading to reduced congestion and associated social benefits'* [S5]. Coventry city has now also positioned itself as a pioneering "living lab" for the testing of CAVs (https://zenzic.io/testbed-uk/midlands-future-mobility/) encouraging new innovations [R3] and demonstrators [R5].

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

[S1] Information booklet stating the existing 202 status of CAV technology in the UK (October 2020) 'Innovation is Great: Connected and Autonomous Vehicles'.Centre for Connected and Autonomous Vehicles, Department for Transport, Great Minster House, 33 Horseferry Road, London, SW1P 4DR (online as at 26/02/21)
https://www.gov.uk/government/publications/connected-and-automated-vehicles-in-the-uk-2020-information-booklet

[S2] HORIBA MIRA – Coventry University CAV Testbed: Testing to the limit of controllability (online as at 26/02/21) https://zenzic.io/testbed-uk/horiba-mira-coventry-university-cav-testbed/

[S3] Midlands Future Mobility: A comprehensive real-world CAM system (online as at 26/02/21) https://zenzic.io/testbed-uk/midlands-future-mobility/

[S4] Joint testimonial letter of support from Head of Horizon Scanning and Head of Connected and Autonomous Vehicles at Horiba-Mira, Watling Street (A5), Nuneaton, CV10 0TU

[S5] Testimonial letter of support from Transport Innovation Manager, Coventry City Council, One Friargate, CV1 2GN

[S6] Testimonial letter of support from Chief Executive Officer of ZENZIC, 6th Floor, 60 Gracechurch Street, London, EC3V 0HR