Institution: Nottingham Trent University (NTU)

Unit of Assessment: B11 – Computer Science and Informatics

Title of case study: Novel wireless and mobile networking technologies for the design of intelligent transport systems and smarter cities.

Period when the underpinning research was undertaken: 2003 - 2020

Details of staff conducting the underpinning research from the submitting unit:

Names:	Roles:	Periods employed by submitting HEI:
Dr Evtim Peytchev	Associate Professor	1995-present
Prof Andrzej Bargiela	Professor	1992-2007
Stylianos Papanastasiou	Research Fellow	2011-2015
Javad Akhlaghinia	Research Fellow	2014-2017

Period when the claimed impact occurred: 2014 – 31 July 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

NTU's research on traffic simulation frameworks has been adopted in Sofia Municipality's (Bulgaria) smart traffic management systems and new Traffic and Public Transport Control Centres, and in a Dynamic Routing Traffic Management System in Coventry (UK). NTU's connected vehicles simulation framework research has underpinned the creation of a public open transport e-platform, that provides services including, trip planning, ticket reservation, fare calculation and mobile payments. This has been adopted as a standard by the Basque Country (Spain) and Athens and has been adopted and implemented by Transport for West Midlands. New technologies developed using NTU's research in car-to-car communication algorithms and traffic simulations have been adopted by company Control F1, helping the company to secure £5M in investments and contracts, and supporting IP development leading to the company's acquisition. NTU's novel wireless networking algorithms were also applied to provide real time energy maps in a scheme in which 400 homes received energy efficiency upgrades. This enabled citizens to make informed energy consumption decision and enabled Nottingham Council to save money and reduce carbon emissions.

2. Underpinning research

Urban mobility is a major contributor to economic growth, jobs and competitiveness but cities in Europe are facing increasing challenges from congestion, air pollution and an urgent need to reduce the transport sector's carbon footprint. Congestion in urban areas of the EU costs around EUR 100 billion, or one per cent of the EU's total GDP, annually, according to European Commission estimates.

Research by NTU's Network Infrastructures and Emerging Technologies (NIET) research group, led by Dr Evtim Peytchev, has focused on the development and application of novel wireless and mobile communications technologies designed to optimise traffic flows within sustainable, intelligent transport systems. With Peytchev as PI, the Traffimatics project (**G1**), developed new insights into the use of vehicular ad-hoc networks and car-to-car communication algorithms to create a rapidly deployable telematics platform designed to challenge the highly centralised structure of traditional traffic information systems. By utilising the existing capabilities of vehicles, including peer-to-peer networking and GPS, vehicles took part in collaborative signal and information processing via wireless links, allowing global information to be reconstructed from locally observed data (**R1**).

Building on this work, the group designed a suite of algorithms to cover the generation of traffic knowledge through collaborative and ad-hoc wireless frameworks. A key generic algorithm, developed and validated in collaboration with University of Nottingham and industry partner Infohub Ltd, enabled an accurate estimation of urban travel times from lane occupancy measurements. They showed that by interpreting time series as statistical processes with a known distribution, it was possible to estimate travel time as a limit value of an appropriately defined statistical process (**R2**). They also proposed an autonomous vehicle-to-vehicle communications protocol that limited the number of vehicles used to determine the location of areas where certain traffic conditions applied, thus imposing only a minimal load on the network (**R3**).

This technical architecture was a key contribution made by NTU's NIET group as partners in the EU FP7 MODUM project (**G2**). Traffic congestion contributes 70% of urban pollution. MODUM sought to develop a novel traffic management system that could minimise environmental impact and improve quality of life for citizens. The result was a prototype system capable of dynamically adapting traffic flows to unexpected disturbances in order to minimise carbon emissions. It was able to anticipate the likely reactions of commuters to the system's suggestions for alternative transport modes. Running pilots in Nottingham and Sofia, the NTU NIET group led the development of the MODUM Integrated Simulation Model - *Traffic Simulation Incorporating Real Time Traffic Data*, a bundle of software that modelled real-time and near-future traffic flow on a city's road network based on sensor data and wireless vehicle-to-vehicle communication (**R2**).

The algorithms that the NTU NIET group co-developed on the MODUM framework formed the basis of their contribution to the Holistic Personal public Eco-mobility (HoPE, 2014-2017, EU Competitiveness and innovation framework programme) project, which created an open platform capable of combining Interoperable Fare Management and Intelligent Transport Systems. Through pilots in Coventry and other EU cities, the adapted MODUM simulation was used to identify optimal public transport routes (using real time data from the cities' traffic control centres) that citizens could choose and pay for through their mobile phones.

Peytchev's NTU NIET group developed further novel algorithms to design commercial intelligent transport systems. Transmitting data over a vehicular ad-hoc network can result in storms and unreliability. In order to improve message delivery, Peytchev and the project researchers proposed a collaborative process of utilising real-time road traffic information and route knowledge to enhance routing decisions, maximising packet delivery ratio and reducing delays in transmission (**R4**). In collaboration with University of Huddersfield, Peytchev contributed to the development of an autonomous agent that used integrated sensor and historical traffic data to deal with exceptional events such as traffic saturation (**R5**).

The NTU NIET group applied their wireless connectivity architecture for transport systems to a local authority-run scheme in Nottingham that aimed to make older housing stock more energy efficient. Under the EU Horizon 2020 project REMOURBAN (REgeneration Model for accelerating the smart URBAN transformation) (**G4**), they designed a low-cost open source ICT architecture for smart monitoring using connected wireless energy monitoring nodes and a server to collect and process detailed information about the electrical energy consumption of home appliances (**R6**).

3. References to the research

Underpinning research quality evidenced by rigorously externally peer reviewed outputs:

R1. M. Tomas, E. Peytchev and D. Al-Dabass, 'Auto-Sensing and Distribution of Traffic Information in Vehicular Ad Hoc Networks', International journal of simulation: systems, science & technology, Vol 5, Issue 3, pp. 59-63, ISBN/ISSN: 1473-804X, 2004. https://ijssst.info/Vol-05/No-3&4/THOMAS.pdf

R2. E. Agafonov, A. Bargiela, E. Burke and E. Peytchev, 'Mathematical Justification Of A Heuristic For Statistical Correlation Of Real-Life Time Series', European Journal of Operational Research, Vol.: 198, Issue: (1), Pages 275-286, 2009. http://dx.doi.org/10.1016/j.ejor.2008.06.040

R3. Ø. Risan and E. Peytchev, 'A Vehicle-To-Vehicle Communication Protocol For Collaborative Identification Of Urban Traffic Conditions', Springer Lecture Notes Of The Institute For Computer Sciences, Social Informatics And Telecommunications Engineering, Vol: 1, Pages 482-494, ISBN/ISSN: 978-3-642-17994-5, 2010. http://dx.doi.org/10.1007/978-3-642-17994-5_33

R4. N. Anyameluhor, E. Peytchev and J. Akhlaghinia, 'Improving Message Delivery In Vehicular Ad-Hoc Networks', Proceedings of the European Council for Modeling and Simulation, 2017. http://doi.org/10.7148/2017-0555

R5. G. Antoniou, S. Batsakisa, J. Davies, A. Duke, T. L. McCluskey, E. Peytchev, I. Tachmazidis and M. Vallati, 'Enabling the use of a planning agent for urban traffic management via enriched

and integrated urban data', Transportation Research Part C 98, pp. 284–297, 2019. https://doi.org/10.1016/j.trc.2018.12.005
R6. E. Peytchev, M. Lyaskov, K. Popovski and G. Spasov, "Home Energy Monitoring System based on Open Source Software and Hardware", ACM conference CompSysTech '16, 2016. http://doi.org/10.1145/2983468.2983504

The high quality of the underpinning research is further indicated by the following competitive peer reviewed public funding investment in the research and its dissemination:

G1. Traffimatics project, Department of Trade and Industry (DTI). Overall funding: £1.08m; £145,000 for NTU. Dates: 1 March 2003 to 30 Sept 2005. PI: Dr Evtim Peytchev.
G2. MODUM project - Models for Optimising Dynamic Urban Mobility, EU FP7. Overall funding: €2.35m; €403,000 for NTU. Dates: 1 October 2011 – 30 September 2014. http://modum-project.eu/
G3. IMPART – Intelligent Mobility Partnership between Transport Systems Catapult and 4 universities including Nottingham Trent University led by Loughborough University. Overall funding £600 000, £125 000 from the project for NTU, Dates 01 March 2015 – 28 February 2018, https://www.lboro.ac.uk/departments/design-school/research/projects/impart/
G4. REMOURBAN project, EU Horizon 2020. "REgeneration MOdel for accelerating the smart URBAN transformation", Overall funding: €24M (€1M for NTU). Dates: 2015-2020.

4. Details of the impact

NTU's research on traffic simulation frameworks has been adopted in Sofia Municipality (Bulgaria), in smart traffic management systems and in new Traffic and wider Public Transport Control Centres, and in a Dynamic Routing Traffic Management System in Coventry (UK)

The public transport systems in Sofia, Capital of Bulgaria, are fully integrated and are run by Sofia Urban Mobility Centre EAD (SUMC), which is a company of well over 1,000 employees owned by Sofia Municipality. SUMC has responsibility for the organization, management, supervision and finance of Sofia's public transport, including the operation of unified automated fare collection systems (ticketing system) and the operation of information-management systems for monitoring and supervision of the traffic, based on GPS-identification (**S1**). The Director of Strategies, Sofia Urban Mobility Centre, confirmed that "*the core of the MODUM project was the simulation model accepting real-time data from GPS positions from public transport control systems built by Dr Peytchev as a result of his previous research in wireless systems and traffic simulation frameworks*" (**S2**). The outcomes of the EU FP7 MODUM project (**G2**), including Peytchev's work, have had beneficial impact on the decision making within the Sofia Urban Mobility Centre in implementing new Intelligent Transportation Systems as part of the company's work to build sustainable city transportation systems. Moreover, the Director of Strategies lists specific new control Centres that "*use the approach of MODUM for identifying traffic demand through simulation using real-time data*" (**S2**) in the Sofia Municipality, including "*20 Smart traffic lights intersections*", "*110 smart traffic lights intersections and a New Traffic Control Centre under EIB Loan for more than EUR 20 million*", and "*A new public transport control system (2016) with overall funding of EUR 1 million*" (**S2**).

On the Intelligent Variable Message Systems iVMS project, Coventry City Council sub-contracted Infohub Ltd, and through them Peytchev, to deliver a simulation model that merged real-time data into a Coventry traffic model. The iVMS project was funded by the Coventry and Warwickshire Local Enterprise Partnership (CWLEP). The CEO of Infohub confirmed that "*This work was an implementation and further development of Dr Peytchev's research in wireless systems*" (**S3**). The Transport Innovation Manager at Coventry City Council confirmed that, "*This task's implementation relied heavily on the outcomes from the MODUM project and Dr Peytchev's research in wireless systems. The results of the iVMS project were incorporated in the Dynamic Routing Traffic Management System in Coventry and in use today*" (**S4**). A CWLEP press release quotes the portfolio holder for transport and planning with Warwickshire County Council as saying, "*The result of this investment is that traffic flows can be monitored much easier, which*

will lead to economic and social benefits since commuters will reach their places of work on time and it will lead to better air quality at key junctions since traffic won't be standing still" (**S5**).

NTU's research has underpinned the creation of a public open transport e-platform, that provides services including, trip planning, ticket reservation, fare calculation and mobile payments. This has been adopted as a standard by the Basque Country (Spain) and Athens and has been adopted and implemented by Transport for West Midlands

The Transport Innovation Manager for Coventry City Council (**S4**) credits the collaboration between Nottingham and Coventry Traffic Control Centres, and the NIET research group, with originating the ideas to develop and apply real-time simulation and wireless networking research to improving urban traffic management. These ideas underpinned the successful award of the MODUM EU FP7 funded project (**G2**) and were further developed by Peytchev in collaboration with the partners on the subsequent HoPE EU FP7 project ("Holistic Personal public Eco-mobility", 2014-2017, EU Competitiveness and innovation framework programme) (S3). The HoPE project created an open platform, capable of combining Interoperable Fare Management and Advanced Traveller Information ("Intelligent Transport") Systems. The open platform utilises the connected vehicles simulation framework documented in Peytchev's research outputs (**S3**). The Transport Innovation Manager for Coventry City Council credits Peytchev's role in this development, and comments on the subsequent impact of this work as follows: "*This open platform has been developed by NTU and it is based on the connected vehicles (CV) simulation framework. After the project the framework has also been adopted as a standard for IFM* [Interoperable Fare Management] *in the Basque Country (Spain) and Athens, Greece*" (**S4**).

Furthermore, based on the connected vehicles simulation framework results, West Midlands is now providing a publicly available route-finding facility and online ticket purchasing through its SWIFT card (**S3**). The open platform developed through the HoPE project has heavily influenced the development of the public transport customer service in West Midlands and as a result Transport for West Midlands "*has implemented it into practice by creating publicly available route finding facility and ticket purchasing online (wirelessly) based on the platform created by the HoPE project and reflecting Dr Peytchev's research in wireless systems*" (**S4**)

New technologies developed using NTU's research in Car-to-Car Communication Algorithms and Traffic Simulations have been adopted by company Control F1, helping the company to secure £5M in investments and contracts, and supporting IP development leading to the company's acquisition.

The Innovate UK i-Motors project developed smart technologies for car-car communications between driverless vehicles, as well as with the wider environment, in order to reduce traffic congestion and accidents. The NIET research group made a key contribution to the successful outcomes of the project, incorporating vehicle-to-vehicle and vehicular ad-hoc network algorithms (**R3**, **R4**) and the MODUM simulation model (**G2**) into a novel wireless communications framework capable of processing real-time data on road works, congestion, weather conditions and allowing vehicles to autonomously report hazards or vehicle faults. The former Product Development Director at Control F1, who was the lead for the i-Motors project, confirmed that "*Peytchev's research in the area of wireless communications between cars was essential for the successful completion of the project. For his part in the development within the project, his algorithms for collecting traffic data through ad-hoc networking between cars resulted in steps towards a communication framework capable of improving the autonomous car's awareness of the surrounding traffic*" (**S6**).

The Product Development Director added that the i-Motors project was instrumental for development and economic impact for Control F1, confirming that the company secured around £4M of further investment and new contracts in UK and around Europe with total value above £1M. In August 2018, it was reported in a 'Yorkshire Post' article that Control F1 was acquired by autonomous and driverless vehicles specialist Intercept IP, with the article noting that, "*The acquisition comes as a direct result of the successful Control F1-led iMotors project … which resulted in a number of new technologies, including a worldwide patented software system for driver recognition*" (**S7**).

NTU's novel wireless networking algorithms were applied to provide real time energy maps in a domestic energy efficiency scheme in Nottingham, in which 400 homes received energy efficiency upgrades.

The REMOURBAN EU H2020 project (**G4**) designed and validated a new sustainable 'Urban Regeneration Model' in 3 Lighthouse cities (Nottingham in the UK, Valladolid in Spain, and Tepebasi/Eskişehi in Turkey) for initial replication in two EU Follower cities. The project's new 'Urban Regeneration Model' is a methodological guide resulting from the technical innovations developed and implemented during the project. Peytchev was a co-investigator on the project responsible for ICT for city integration.

The NIET research group applied wireless networking algorithms from their research to create a simulation model that could predict domestic energy consumption. This model was used to select homes that would participate in a new scheme in partnership with Nottingham City Council and Nottingham City Homes, based on the Energiesprong initiative, to upgrade the energy efficiency of older, council-owned homes in order to meet low carbon standards set for 2050. Nottingham City was the first UK council to adopt the Energiesprong approach, which demonstrated monthly energy bill reductions from £120 to £60-£70 in the pilot phase of the REMOURBAN project for Nottingham residents (**S8**). The Smart City Manager for Nottingham City Council confirmed that, "*Dr Peytchev's research in wireless systems and home energy use monitoring systems has been instrumental for REMOURBAN*", adding that, "*the monitoring systems in the project are base for two of the four core system services of the REMOURBAN project – real time energy maps core system and serious games core system. Dr Peytchev's research underpins both of these systems*" (**S9**). The real time energy map gave citizens access to better knowledge of the energy consumption through visual data, enabling them to make informed decisions. This helped Nottingham City Homes to predict immediate future usage and balance demand of renewable technologies through their Energy Centre to save money and reduce carbon emissions (**S10**). By 2020, 400 homes in Sneinton in Nottingham had received energy efficiency upgrades, including the energy use monitoring systems, within the REMOURBAN project (**S9**).

5. Sources to corroborate the impact

S1. Web-links: Structure and remit of Sofia Urban Mobility Centre, https://www.sofiatraffic.bg/en/common/struktura/41/struktura, https://www.linkedin.com/company/sofia-urban-mobility-centre/about/.
S2. Testimonial letter: Director Strategies, Sofia Urban Mobility Centre
S3.* Testimonial letter: CEO of Infohub Ltd, UK Lead of the EU-FP7 HoPE project.
S4.* Testimonial letter: Transport Innovation Manager, Coventry City Council
S5. Web-link: https://www.cwlep.com/news/innovative-app-leads-upgraded-transport-infrastructure-coventry
S6. Testimonial letter: Product Development Director, Control F1, Lead for the i-Motors Innovate UK project (reference 102586, May 2016 to April 2018).
S7. Web-link: https://www.yorkshirepost.co.uk/business/intercept-acquire-control-f1-deal-take-technology-global-264326 Yorkshire Post article, Intercept IP acquisition of Control F1.
S8. Web-link: https://www.theguardian.com/society/2019/jan/07/dutch-eco-homes-idea-arrives-in-uk-and-cuts-energy-bills-in-half-nottingham-energiesprong Guardian newspaper article on the impact of the Remourban-Energiesprong initiative in Nottingham.
S9. Testimonial Letter: Smart City Manager, Economic Development, Nottingham City Council
S10: Web-link: http://www.remourban.eu/kdocs/1948018/remourban_final_brochure_web.pdf, REMOURBAN project final brochure.

* participant in the process of impact delivery