Institution: University of Birmingham		
Unit of Assessment: 14 – Geography and Environmental Studies		
Title of case study: Transforming decision making in winter road maintenance using low-cost environmental sensor networks		
Period when the underpinning research was undertaken: Body of work produced from 2001 to present day. Key research is from 2006 onwards.		
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 Lee Chapman	Professor of Climate Resilience	May 2002–Present
Professor John Thornes	Professor of Applied Meteorology	April 1981–September 2011
Dr Simon Bell	Post-Doctoral Research Assistant	October 2014–Present
Period when the claimed impact occurred: January 2016 to September 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Commercial and economic impact has been achieved via the **development of an innovative sensing product**, based on the Internet of Things, that has been used to transform winter road maintenance decision making across the UK and northern Europe. Initially marketed via a University of Birmingham start-up company, and subsequently licensed to a global scientific instrumentation company, the sensors have **transformed the efficiency and cost effectiveness of winter service delivery**. The novel nature of the approach has been welcomed by the industry, **influencing policy debate** in the sector with the technology featuring in the latest **best practice UK guidance** documentation.

2. Underpinning research

Gritting roads is a critical activity in winter to keep traffic flowing. It presently costs the UK £150m a year to keep the roads snow and ice free but results in estimated savings of the order of £2bn each year. Despite this cost/benefit, millions of pounds are wasted each year by treating roads that would not actually have frozen.

For two decades, Prof. Lee Chapman and Prof. John Thornes at the University of Birmingham (UoB) have been at the forefront of research with the winter road maintenance industry. They have worked with highway engineers and forecast providers to develop a range of new approaches and optimisation techniques to better target winter maintenance efforts on the coldest road sections [e.g., 1].

However, one crucial component of the system had proved elusive. Their research highlighted that no cost-effective technique existed to monitor road conditions at the high spatial and temporal resolution demanded by the application [2]. This was reinforced by research that showed that temperature variations over very small distances (i.e., between different lanes on a motorway) presented a significant risk for motorists [3]. It became evident that **the most significant way of reducing the financial burden of winter road maintenance was to find a low-cost sensing technique capable of observing the road network at a high resolution**.

Winter maintenance engineers would then have increased confidence in the application of cost-saving techniques, forecasts and optimisation strategies.

The origins of a solution came from a NERC grant awarded in 2011 to Prof. Lee Chapman that pioneered a high-resolution approach to observe the Birmingham Urban Heat Island. This was achieved by the development of air temperature sensors that used Wi-Fi to relay real-time data over the internet — an early example of a 'thing' in the Internet of Things (IoT). The key development was the harnessing of existing low-power communications which enabled the devices to be powered for extended periods by a small battery — significantly reducing the costs of dense sensor networks [4]. The research demonstrated that robust, reliable and scalable environmental sensor networks could be built at a low-cost per node (<£100).

Subsequent funding from TSB, EPSRC and NERC then enabled Prof. Lee Chapman and Dr Simon Bell to develop an IoT road surface temperature sensor (wintersense). Key innovations included the use of:

- Thermopiles (non-contact) to allow mounting on lighting columns therefore removing the need to dig up the road;
- Emerging Low Power Wide Area Networks for communications;
- Power saving features to extend battery life (enabling a full season of unattended monitoring).

These innovations meant that **sensors could be deployed at two orders of magnitude cheaper than existing methods, finally providing the means to sense 'at scale' on the road network** [2,5,6]. Research has subsequently continued, funded by the Rail Safety & Standards Board, to transfer the approach to weather related issues on the railway (i.e., leaves on the line) [6].

The research programme has won two scholarly awards (RMetS Innovation Award, 2014; The Harry Otten Prize for Innovation in Meteorology, 2017 – Presented by the European Meteorological Society).

Key Findings:

KF1. Despite large advances in the tools available to improve decision making in winter road maintenance, the paucity of high-resolution observations on the road network is the biggest barrier to improving road safety and the efficiency of winter service delivery [1,2,3].

KF2. Advances in the IoT now mean that environmental sensors, of acceptable accuracy for industrial applications, can be built at a fraction of a cost and therefore deployed in networks containing previously unprecedented numbers of nodes [4].

KF3. The IoT provides an effective means to monitor infrastructure networks and to provide the data for the initialisation and verification of forecasts and other tools used in the infrastructure sector [5,6].

3. References to the research

[1] Chapman, L. & Thornes, J.E. (2006) 'A geomatics based road surface temperature prediction model', *Science of the Total Environment*, 360: 68–80 DOI: 10.1016/j.scitotenv.2005.08.025

[2] Hammond, D., Chapman, L. & Thornes, J.E. (2010) 'Verification of route-based weather forecasts', *Theoretical and Applied Climatology*, 100: 371–384 DOI: 10.1007/s00704-009-0189-7

[3] Chapman, L. & Thornes, J.E. (2011) 'What spatial resolution do we need for a route-based road weather decision support system?', *Theoretical & Applied Climatology*, 104: 551–559 DOI: 10.1007/s00704-011-0433-9

[4] Young, D.T., Chapman, L., Muller, C.L.,Cai, X. . & Grimmond, C.S.B. (2014) A Low-Cost Wireless Temperature Sensor: Evaluation for Use in Environmental Monitoring Applications,

Journal of Atmospheric & Oceanic Technology, 31: 938–944 DOI: 10.1175/JTECH-D-13-00217.1

[5] Chapman, L., Young, D.T., Muller, C.L., Rose, P., Lucas, C. & Walden, J. (2014) 'Winter Road Maintenance and the Internet of Things', Proceedings of the 17th SIRWEC Conference, 28 February –1 March 2014, La Massana, Andorra (http://sirwec.org/wp-content/uploads/Papers/2014-Andorra/D-5.pdf)

[6] Chapman, L., & Bell, S.J. (2018) 'High-Resolution Monitoring of Weather Impacts on Infrastructure Networks using the Internet of Things', *Bulletin of the American Meteorological Society*, 99: 1147–1154 DOI: 10.1175/BAMS-D-17-0214.1

Grants:

Lee Chapman, HiTemp: High density temperature measurements within the urban environment, NERC, 2011–2014, £610,245

John Walden (InTouch Ltd), SmartStreets, Technology Strategy Board, 2013–2014, £799,966

Lee Chapman, Demonstrating the potential of the Internet of Things in winter road maintenance, EPSRC, 2014–2016, £165,429

Lee Chapman, Reducing the ice hazard on smart motorways, NERC, 2016–2017, £64,318

4. Details of the impact

Impacts on commerce and the economy from the creation of a new company

A new business was created to enable the commercial exploitation of the 'wintersense' road surface temperature sensor [KF2, KF3]. Trading began in 2016, following the first commercial sale of sensors to the UK Met Office. The university start-up then grew significantly, **generating year-on-year revenue growth** (Y1: £2000; Y2: £32,500, Y3: £58,250, Y4: £115,000) [s1]. Trading continued until May 2019 when the **product licence for wintersense was awarded** to Campbell Scientific Ltd in a six-year royalties deal [s2]. Campbell Scientific are a US based science and instrumentation company operating from offices across the world. They procured wintersense in order to **diversify their product and service offering** in the transport market.

During the 2016 to 2019 trading period, networks of sensors were procured from UoB by over 20 UK local authorities and road agencies. **International innovation and market impact was achieved** with sensors deployed in Belgium, Germany, Ireland, the Netherlands and Sweden [s1]. **Demonstrable industrial collaborations** extended beyond local authorities, with several street lighting companies offering wintersense as an additional feature to their clients (e.g., Lucy Zodian [s1]). This followed earlier work with street lighting company Mayflower and Hampshire County Council [s3], and an invited appearance at the LUX live trade show in November 2017.

The sensing technology [KF2] has also **contributed to innovation activity through the development of new products** for the railway market as 'autumnsense', primarily to help the industry with the perennial 'leaves on the line' problem. For example, 30 moisture sensors have been used by Network Rail on the cross-city line in Birmingham to help them attain their goal of running normal levels of service rather than running a reduced service autumn timetable [s4]. **Additional sales of new autumnsense products** have since been made to Network Rail Wales and London Underground [s1].

Impacts on public services by changing the delivery of winter road maintenance

Wintersense networks have impacted **the downstream delivery/operational efficiency of winter maintenance** and improved road safety for millions of road users [KF1]. Analysis by Wigan Council (population of 320,000) of the benefits of their 27-sensor network indicated a return on investment within half a normal winter season. The adoption of wintersense improved confidence such that Wigan Council have explored lowering the threshold where treatment is required to 0.5°C (rather than the cautionary 1.0°C presently used) further reducing costs [s5]. This is attested to by the Highways Asset Manager of Wigan council who states:

> In February 2019 higher altitude routes required treatment on 12 nights whereas Wigan town centre did not fall below freezing. Across the whole season this results in a potential estimated saving of £60,000. [wintersense] has indicated the potential for further efficiencies […] such as reducing temperature treatment thresholds or route-based forecasting.

A denser sensor network of 120 nodes was deployed across Kent (population of 1.8m people), also resulting in reduced costs [s6], confirmed by the Winter Service Manager of Kent County Council:

> The (wintersense) network has informed a salting route optimisation exercise which will see the network of salting routes completely redrawn for winter 2019/20 […] This will allow us to make savings in the range of *c.*£200k per annum.

Wintersense has also **expanded existing, and opened new, markets** for road temperature sensing. The approach [KF2] has enabled sensors to be deployed at locations where gritting operations are needed, but monitoring was previously difficult, such as bridges on the UK trunk road network [s7]. The difference wintersense made is confirmed by the Project Manager for Highways England, who said:

> This innovative approach would not have been achievable with expensive conventional embedded road surface sensors that are constrained by […] mains power […] and the need to break into the bridge deck construction, something that is not permitted […].

Other examples of places where wintersense has been adopted include supermarket, office and hospital car parks (often with high numbers of vulnerable users who **benefit from associated service improvements**) [s8]. This is attested to by the managing director of IceWatch Ltd, a leading independent gritting company, who states:

> It was our desire to adopt best practice and […] provide a vastly superior service to our clients […] the low-cost nature of the approach meant that it was [now] financially feasible to instrument individual car parks and private roads […].

<u>Impacts on practitioners by influencing professional guidelines</u>

Wintersense received industrial recognition when it was awarded an Intelligent Infrastructure Award at the 2017 Highways UK trade conference. Kent County Council were also a finalist in the Association for Public Service Excellence Innovation Awards 2020 for their implementation of the technology.

The unique benefits of IoT sensing [KF3] are now well accepted by the winter road maintenance community. This began with an invited keynote to practitioners by Prof. Lee Chapman at the 2017 Cold Comfort trade show [s9]. This **stimulated policy debate via research evidence** [KF3], leading to further practitioner-led presentations on wintersense in subsequent years at Cold Comfort, and culminated in wintersense featuring in **best practice professional guidelines**. New practical guidance documents were issued in late 2020 by the UK Roads Liaison Group and National Winter Service Research Group (NWSRG) — the professional bodies that together define best practice for the winter road maintenance sector. IoT road surface temperature sensors have their own section in the documentation [s10]:

> Advances in technology have meant that [IoT sensors …] represent an opportunity to extend coverage across your network […] These individual sensors will cost less than fixed weather stations and negate the need to install the sensor in the carriageway […]. Fewer [communication] restrictions tend to apply when installing fixed non-invasive IoT enabled sensors.

The significance of this inclusion is that, at the time of publication, wintersense remained the only commercially available IoT road surface temperature sensor on the market. Indeed, prior to the launch of the revised guidelines, NWSRG commissioned Prof. Lee

Chapman to write a 'voices' communication piece for the trade journal *Highways Magazine* based on KF3.

Overall, the new technology has been extensively adopted by the winter road maintenance community leading to both **commercial impact** and **improvements in efficiencies for practitioners**. This has ultimately benefited the public via improved service delivery and road safety.

5. Sources to corroborate the impact

s1: Sample Purchase orders (sample of 5: Local Authority: Hampshire; Service Provider: Amey; 1 overseas: Klimator, Sweden; 1 Street Lighting Company: Lucy Zodian; 1 railway: London Underground);
s2: Press Release from Campbell Scientific detailing the acquisition, 3 December 2019. [Accessed 17 February 2020]. [Promotional video also available on request]
s3: Press release from Hampshire County Council, 3 February 2017 [Different link, original accessed 31 March 2018];
s4: Testimonial from Network Rail;
s5: Testimonial from Wigan County Council;
s6: Testimonial from Kent County Council [Dated September 2019];
s7: Testimonial from Highways England [Dated 31 July 2019];
s8: Testimonial from IceWatch (Independent Gritting Company);
s9: Cold Comfort 2017 programme (Prof. Lee Chapman as the only non-practitioner invited to speak);
s10: NWSRG practical guidance document: Section 12 - Weather forecasting and RWIS, 14 September 2020.