

Winter Road Maintenance and the Internet of Things

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ABSTRACT

The Internet of Things literally means ‘things’ (e.g. sensors and other smart devices) which are connected to the internet. Although this may seem insignificant, ‘things’ represent a new, and increasingly, critical infrastructure requiring their own dedicated technological ecosystem. As an industry, Winter Road Maintenance has been adept with coping with technological change, with the various data streams historically managed by bureaus and, more recently, sophisticated decision support systems. However, how well equipped is the industry to cope with the imminent inundation of additional data and information from new devices? This is a now inevitable challenge as the costs of sensors, communications and power dramatically start to fall. Indeed, since 2008, the number of ‘things’ has outnumbered users online and this trend will continue as our cities and roads become smarter and increasingly automated – it is estimated that there will be 20 billion things online by 2020. This paper describes the establishment of a winter maintenance demonstration corridor and corresponding IoT hub within a wider meteorological testbed in Birmingham, UK.

Keywords: Wireless Sensor Networks, Temperature Sensors, WiFi, IoT, Smart Cities, Gritter

1 INTRODUCTION

Winter maintenance engineers base their nightly decision making by consulting a Road Weather Information System (RWIS) which combines weather forecast data with road temperature and condition data. RWIS has evolved over the last few decades from simple ‘Ice Detection Systems’ comprising of a small number of outstations which detected when ice formed upon the integral road sensor, to mature ice prediction systems consisting of multiple outstations, thermal mapping and forecast models [1]. This approach has quickly spread across the globe and has been considerably refined as computer processing power and communications improved [2]. Indeed, the use of data intensive route-based forecasting techniques (e.g. [3]), high resolution mesoscale models and Maintenance Decision Support Systems (e.g. [4]) are now common place across the world. As such, the winter road maintenance community can be proud of the way in which it has constantly adapted and embraced new technologies to improve decision making and subsequently making highways a safer place to travel. However, there is now a new technological agenda which has the potential to be genuinely transformative in terms of operations.

The Internet of Things (IoT) quite literally means ‘things’ (e.g. sensors and other smart devices) which are connected to the internet. Since 2008, the number of ‘things’ has outnumbered users online. The recent miniaturisation of technologies coupled with reducing costs of sensors of comparable accuracy to operational and scientific instrumentation has led to the growing potential of dense sensor networks, which becomes central to the smart cities agenda, and indeed the IoT. Winter maintenance is exceptionally well placed to take advantage of this rapidly changing technological landscape given the complexities of operations and the need for high resolution data that will ultimately drive decision making. Indeed, given the maturity of the science in the sector, it could well be used as an exemplar for other industries to follow.

There are already many examples which are effectively following the IoT approach. There now exist fleets of internet connected commercial and passenger vehicles with the potential to make the high resolution surface observations required by the winter road maintenance sector [5]. The data from such mobile platforms could be hugely significant in improving and verifying road weather forecasts. The recent advances in spatial road weather forecasting provide a significant verification challenge as it is presently impossible to ‘sense’ at all forecast points on a road network at an adequate spatial and temporal resolution. A mobile fleet of sensors instantly overcomes this barrier. Not only is the data available for forecast verification, if a connected vehicle is used then it can be used in data models via real-time assimilation. An excellent example of this approach is the NCAR vehicle data translator which combines observations from vehicles with other data to assess weather conditions [6]. However this is where caution needs to be exercised. As with many technologies in the IoT paradigm, the sensors used in vehicles are numerous and therefore need to be cheap to be financially viable. As such there will be issues with ongoing maintenance, calibration, accuracy, sensor drift etc. To this end, the connected vehicle is probably just a middling technology towards bespoke IoT based winter road maintenance sensor networks.

2 METEOROLOGICAL SENSOR NETWORKS

Meteorological sensor networks are now common place and operational in many cities across the world (see [7] for a full review). The motivation for such networks is to ensure that the heterogeneous nature of urban environments can be sufficiently resolved. Of course, there are significant parallels between urban climates and road weather climates. For example, the urban heat island effect can result in variations of up to 10°C in air temperature across a city [8]. Likewise, it is not uncommon to find similar differences in road surface temperature across a road network [9]. Hence, the only way to fully resolve these variations in temperature is to use a dense sensor network.

2.1 The Birmingham Urban Climate Laboratory

The Birmingham Urban Climate Laboratory (BUCL) is a dense sensor network located in Birmingham, UK. Although the main focus is on measuring the urban climate (i.e. the urban heat island effect), it is also being used operationally as a testbed for condition monitoring on infrastructure [8], including winter road maintenance. At the time of writing, BUCL consists of three nested arrays of weather monitoring equipment and when complete, it is thought that BUCL will be the densest Urban Meteorological Network in the world (Figure 1)

- Three standard UK Met Office (UKMO) meteorological sites (standard enclosures)
- A coarse array of twenty automatic Vaisala WXT520 weather stations (average of 1 per km²) measuring air temperature, precipitation, wind speed and direction, relative humidity, pressure and solar radiation). Twenty-four of these are located within the city boundaries, whilst four are located outside in a rural setting
- A wide area array of eighty low-cost air temperature sensors and radiation shield (average spacing 1.5 km).

A decade ago, such a dense network of weather monitoring equipment would be inconceivable. The cost of sensors, power and communications would severely constrain the magnitude of the deployment. Originally, the UKMO sites were the only installations in the city, all hard-wired into the power grid and using modems for communication. Lower cost automatic weather stations have enabled this network to be expanded considerably. Stations such as the Vaisala WXT520 are compact, easy to install and are effectively self-contained requiring just a small solar panel for power and GSM / GPRS for communications (Figure 2a). Although a premium product, these are not much cheaper than other standard installs and still incur an ongoing cost for communications. As such, cost alone is a severe barrier to deployment in large numbers.

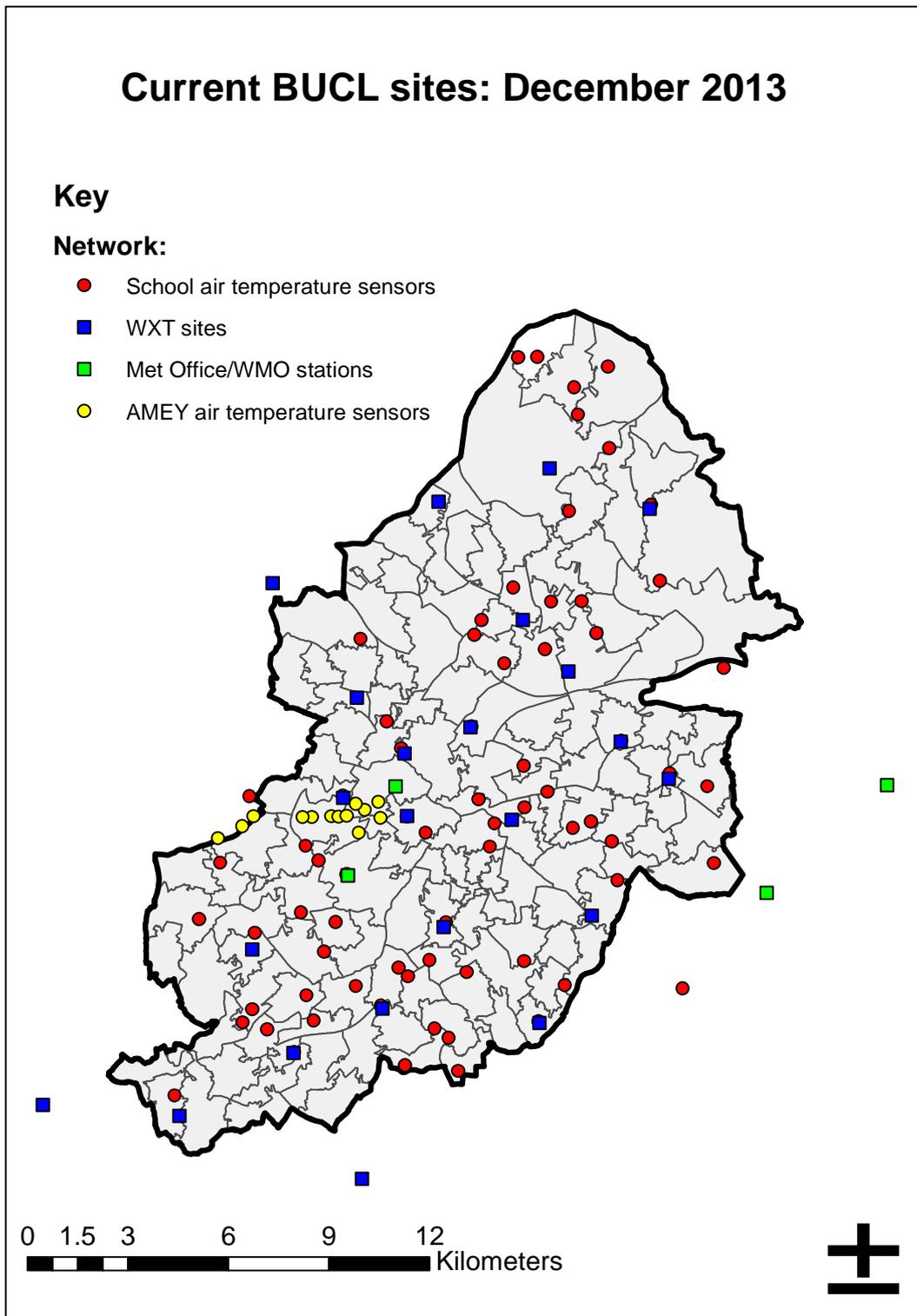


Figure 1. Current status of the deployment of weather monitoring equipment in the Birmingham Urban Climate Laboratory

2.2 Low cost air temperature sensors

The most innovative element of BUCL is the air temperature sensor. This has been specifically designed to embrace the IoT and benefits from the recent miniaturisation of reduced cost of relevant technologies. The BUCL air temperature sensor consists of a 10 k Ω Negative Temperature Coefficient thermistor and a low-powered wireless communications card, contained within a bespoke radiation shield (Figure 2b). This enables the sensor to communicate via the internet using standard IEEE 802.11 b/g 2.4 GHz WiFi at rates of up to 11 Mbps. As such, the sensor has no ongoing communications cost and can be deployed anywhere within range of a wireless network. To ensure that the sensor is fully self contained, power is provided by an AA 3.6 V Lithium-Thionyl Chloride battery that is capable of providing sufficient current for radio transmission and is reputed to be have a life of around 3 years. Although the self contained nature of the unit is a major advantage, its low cost (just £87 per unit) enables a large number of the devices to be rapidly deployed in a network. The BUCL air temperature sensor has been extensively tested against a Platinum Resistance Thermometer at the UKMO calibration laboratory where it has been demonstrated to perform well with an absolute of error $> \pm 0.22$ °C. Further comparisons in the field produced day time RMSE of ± 0.15 °C (See [10] for full details).

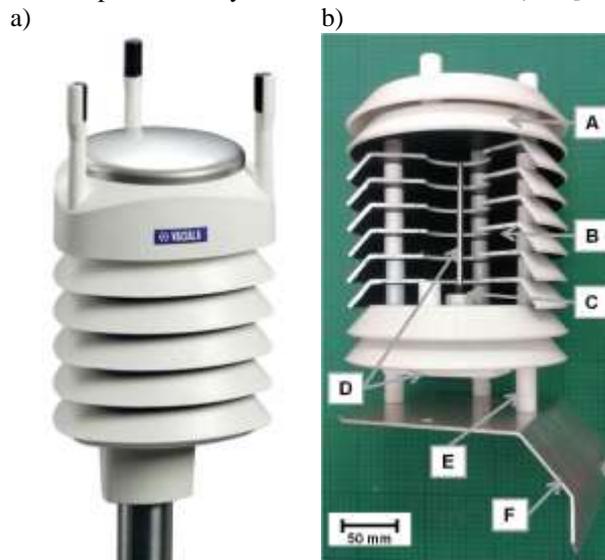


Figure 2. a) Vaisala WXT520 weather station and
b) BUCL air temperature sensor (D is the thermistor probe)

2.3 Proprietary communication networks

Communication costs can be a significant barrier for the deployment of sensor networks. However, given the increasing proliferation of WiFi networks in public spaces and municipal areas, then the utility of new low cost sensors such as the BUCL air temperature becomes increasingly apparent. In the case of BUCL, pre-existing wireless networks found in schools across Birmingham are used, but other networks are also increasingly becoming available driven by the IoT agenda.

Amey plc works across the UK managing public services and infrastructure and delivers service to local authorities, the Highways Agency, Transport for London and Transport Scotland. For example, Amey is responsible for operating and maintaining Birmingham city's 2,500km of road, 5,000km of footpath, 850 bridges and over 100,000 street lights on behalf of Birmingham City Council through a 25-year PFI contract. As part of this contract, Amey have installed a proprietary roadside telecommunications network (WiFi based Wireless Mesh) that connects roadside equipment (such as traffic signals, message signs, car park counters, CCTV cameras) via the internet. As such, all major roads (i.e. with traffic lights) in Birmingham now have WiFi coverage which enables wireless sensors to be installed anywhere on the road network.



3 A Winter Road Maintenance Prototype

Due to the presence of BUCL and the new roadside telecommunications network (Figure 3a), the University of Birmingham, Amey and InTouch have been working together to demonstrate the utility of the IoT in winter road maintenance. The first stage of this project has seen a deployment of additional temperature sensors nested within BUCL and located on lamp-posts along a major arterial road / salting route in Birmingham (Figure 3b).

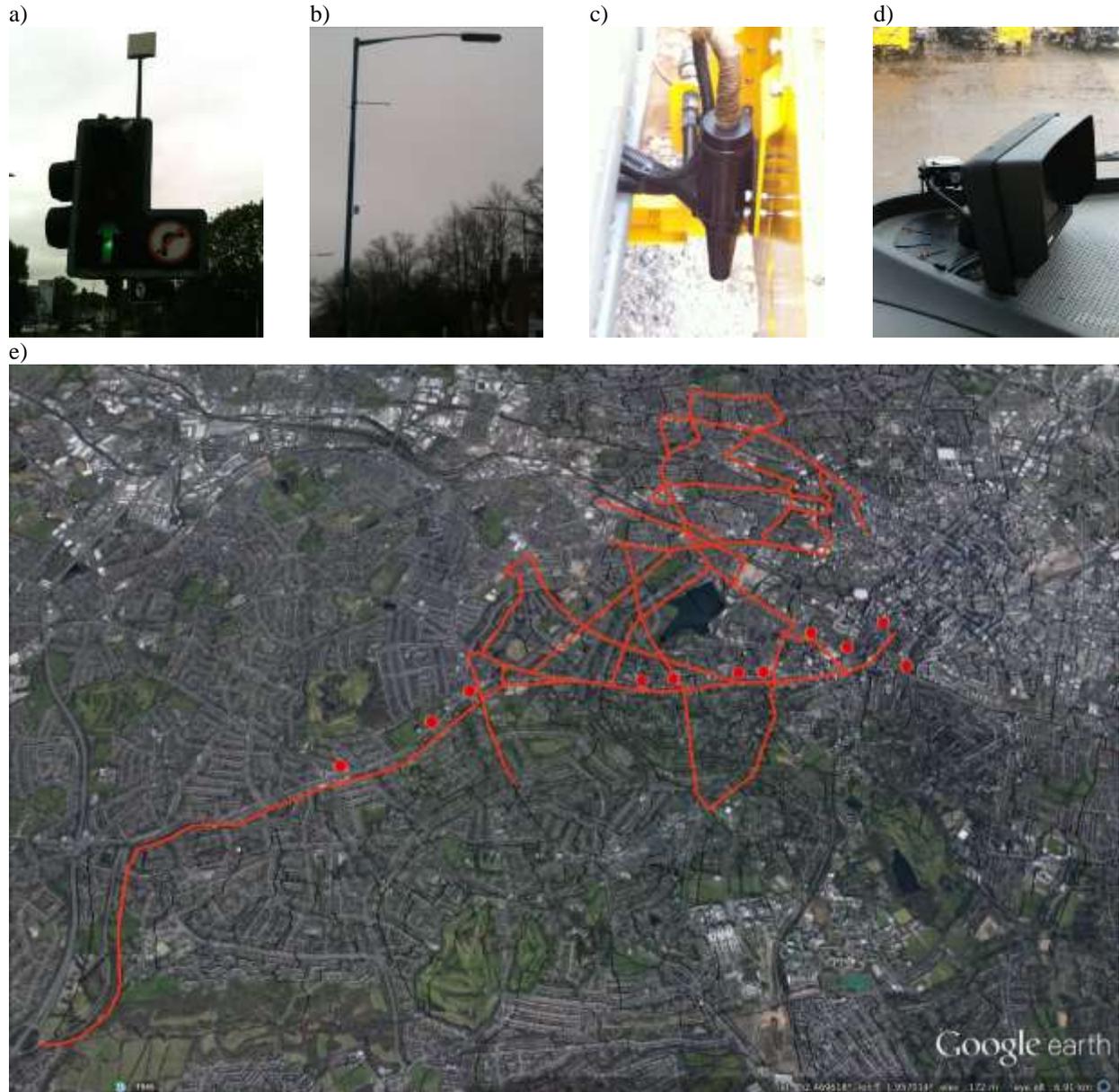


Figure 3. a) Amey wireless mesh antenna, b) lamp-post temperature sensor installation, c) Vaisala DSP111 fitted to gritter, d) forward facing camera and e) location of sensors on gritting route.

A total of 11 sensors have been installed at a small cost of under £1000 (see Figure 3e and Figure 1 for information with respect to nesting in BUCL). In addition to this, a connected gritter has been developed which contains additional instrumentation of a Vaisala DSP111 air and surface temperature probe (<http://www.vaisala.com/en/products/surfacesensors/Pages/DSP111.aspx>) as well as a forward facing camera (<http://www.vision-techniques.com/vehicle-cameras/>) to provide an indication of road conditions (Figures 3c and 3d). This prototype has been designed specifically as a feasibility study of the new emerging technologies. The sensors provide high resolution temperature data at both temporal and spatial scales where as the gritter provides even higher resolution temperature data spatially which can be cross checked with sensor measurements for quality assurance purposes. Data is then incorporated into an IoT 'hub' (Figure 4)



Figure 4. Smart Streets IoT Hub. The hub acts as a repository of a wide range of datasets and provides application developers access to the data they need to deliver new and innovative applications and services. This open hub aggregates data from an unprecedented consortium of major players in the highways maintenance industry by providing a set of open APIs to a wide range of assets and data streams.

4 DISCUSSION & CONCLUSIONS

The IoT winter maintenance prototype presented in Figure 3 is very much work in progress with data now in the process of being collected over the winter season 2013/2014. The main aim of the prototype is to assess the feasibility, and ultimately the utility of such data for winter maintenance applications. Hence, although the number and type of sensors are presently limited, the feasibility of such an approach in the sector should be evident from the demonstrator. The prototype can be viewed a testbed in which technologies can be trialled in a controlled setting. For example, the network shown in Figure 3 allows for the testing of the utility of the gritter mounted air temperature sensor (e.g. accuracy, time constant etc). Indeed, this sensor network approach could be easily extended to test the validity of air temperature data collected from connected vehicles (e.g. [11]).

This trial has also already highlighted some significant challenges with the IoT approach. The phrase ‘time waits for no-one’ is particularly relevant in this case as indeed, the technological pace of change has proved to be particularly problematic in this deployment. The air temperature sensor deployed in the prototype took approximately two years of development to ensure that the design was fit for purpose and that the readings were of comparable quality to other existing sensors on the market. However, during this time wireless technology has advanced, and the existing technology used in the device is now outdated, following the 802.11b/g protocol instead of the now more commonly used 802.11n. This has proven to be a major problem during deployment as many schools across Birmingham, and indeed the Amey wireless mesh adhere to the new protocol. Whilst this shouldn’t be a major issue, as many networks have backward compatibility, this does require local settings to be changed to facilitate the sensor. A minor task, with administrator access to the network, but the spirit of the IoT is ultimately using existing ‘black box’ IT infrastructure for new smart solutions where this may not be the case. Hence, any open access wireless network will evolve with time, yet the sensors embedded within it will date at a potentially rapid pace.

Furthermore, free wireless access isn’t universally available. Birmingham presents an interesting case study due to the availability of a wireless mesh, but this isn’t the case in many cities. Other networks are available, indeed much of the city centre is wireless, but fees are charged for use and the costs are actually comparable per sensor to that of GSM/GPRS. An additional limitation is network coverage. Whilst the Amey roadside telecommunications network exists for major arterial roads, other minor roads (which are more numerous and still require treatment) are not covered by the technology. Hence, to introduce monitoring at these locations will require a significant expansion of the mesh, or indeed consideration of an alternative technology (e.g. Zigbee). Furthermore, the number of sensors located in each cluster of the mesh will be limited by bandwidth. These limitations have been overcome in this prototype by performing spatial interpolations of the BUCL data.

Hence, the availability of existing communications are presently seen as a significant barrier to adoption of new technologies. However, in this case study, power has been found to be equally limiting – a problem which is acutely linked to issues with communications. The battery used by the temperature sensor is reported to last for around three years in ideal conditions – but conditions are rarely ideal. Indeed, it is communications which represent the biggest drain on battery life. If a sensor is located in an area with a weak or intermittent signal, the battery will quickly run flat and will require replacing. This is a job that realistically can only be done once per season as part of an annual maintenance regime and even then, could prove a considerable task in the case of a dense sensor network. Similarly, it is desirable to recalibrate each sensor in the network on a regular basis to ensure adequate accuracy and to check for drift etc – quite a challenge with a large network.

In summary, the IoT paradigm showcases a number of new and innovative prospects to the winter road maintenance sector. Perhaps the most exciting part of the paradigm, is that many of the components already exist to already start doing things differently. However, as this demonstrator has shown, bringing them all together is quite a challenge. Economies of scale dictate that a roadside telecommunications network needs to be compliant with a multitude of technologies and potential applications and there is a sense that the large scale use of non-proprietary ‘black box’ networks appears unrealistic. The need to be able to change local settings for long-term compatibility, as well as security / encryption / firewall issues make these largely unsuitable for such a task. Likewise, batteries are very much a short term solution and other energy harvesting techniques (e.g. solar) provide a more sustainable, but significantly more expensive, solution. The cost of deployment as well as ongoing maintenance and calibration costs are also significant extra factors. These ultimately limit the size of such a network. Finally, there is the actual utility of the data. The ability to monitor the road network at the temporal and spatial scales that this approach could potentially overcome the long standing problem of spatial forecast verification in winter road maintenance [12], yet it must not be forgotten that the crucial thing for the highway engineer is to have the information, not necessarily the data to inform decision making [13]. Overall, the IoT approach is still very much in its infancy, and many of the issues identified in this pilot study will be easily overcome as the technology matures. The potential of having data available at this scale would transform the sector by giving decision makers the confidence to migrate fully to route based forecasting, selective salting, dynamic routing and all the benefits that brings; winter road maintenance needs, and is ready for, the IoT.

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