Collaborative Sensor Rotation Programme (CSRP)
Accuracy and Application of Low Cost Environmental Sensors

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1 Introduction

1.1 Purpose of this paper

This paper describes the progress and early findings of Phase 1 of the Transport Scotland Collaborative Sensor Rotation Programme (CSRP). The CSRP is a series of collaborative air quality and noise assessments piloting low cost sensors at locations where the Trunk Road network interfaces with the Local Authority road network in urban areas. This Introduction examines the background to air quality and transport (Section 1.2), the wider application of low cost sensors to Intelligent Transport Systems and Environmental Incident Management (Sections 1.3 to 1.5 inclusive), the collaborative approach to the CSRP (Section 1.6), and the Phase 1 CSRP timetable (Section 1.7).

Section 2 of this paper describes the air pollutants from road traffic, Section 3 describes the equipment chosen for the CSRP, Section 4 describes the Field Correlation Process, Section 5 describes the Phase 1 CSRP Rotation Sites, Section 6 describes the Site Construction Work, and sections 7, 8, and 9 describe the Next Steps, Challenges, and Conclusions respectively.

The CSRP is a live project and further detail will be provided during the presentation of this paper.

1.2 Air Quality and Transport

According to a long standing and growing body of epidemiological evidence, air pollution is known to have negative health effects, and is a substantial public health concern. Poor air quality reduces the average life expectancy in the UK by approximately 7 to 8 months, with associated costs of up to £20 billion each year (DEFRA, 2007). Worldwide, it is estimated that in 2012 around 7 million people died as a result of air pollution exposure, with 3.7 million deaths attributed to outdoor air pollution (World Health Organisation, 2014). Additionally, in February 2014, the European Commission launched legal proceedings against the UK for failing to reduce excessive levels of nitrogen dioxide (NO2) from air pollution caused by traffic (European Commission, 2014). Although air quality in Scotland is generally good, there are 32 Air Quality Management Areas across the country, and Glasgow, the home of the STAR conference, is one of the 32 affected conurbation areas.

Poor air quality can also cause acidification (a build-up of acids in soil, affecting plant growth) and eutrophication (a build-up of pollutants in water systems).

The primary cause of poor air quality (where air quality exceeds set air quality standards), is road traffic. Scottish authorities at various levels have acted jointly to improve poor air quality, and ensure the concentrations of harmful chemicals within the air are reduced to acceptable levels. Some recent measures, actions and policies are as follows:

- The Scottish Government's Climate Change Delivery Plan commits to "almost complete decarbonisation of road transport by 2050, with significant progress by 2030".
- In localised areas where pollutant concentrations regularly exceed the acceptable levels, Local Authorities have declared Air Quality Management Areas (AQMA). Associated with these are Action Plans to improve air quality. As noted above, as of 7 April 2014 there were 32 AQMAs across Scotland, with more expected to be declared. Almost all of these AQMA have been declared due to traffic emissions.

- Formation of the Scottish Transport Emissions Partnership (STEP), a collaborative and cross professional Air Quality Technical Group that provides technical support to Scottish organisations working to address poor air quality caused by emissions from road transport.
- The Scottish Government is currently reviewing the Local Air Quality Management system and will be consulting on a Low Emissions Strategy during 2014.

1.3 Low Cost Sensors within an Intelligent Transport System (ITS)

At the roadside level, Intelligent Transport Systems (ITS) have an important role to play in addressing air quality challenges. This is illustrated by the examples in the report "Air Quality Measures near Roads within Europe", from the CEDR air quality group July, 2005. A well designed ITS, supported by a low cost air quality sensor network, can (1) monitor roadside air quality levels and can (2) invoke a traffic management strategy to alter traffic patterns to reduce air quality impact.
Current live project developments in this area include the following:

- CARBOTRAF - aiming to adaptively influence traffic in real-time to reduce carbon dioxide (CO2) and black carbon (BC) emissions caused by road transport.
- The iTRAQ project: Integrated Traffic Management and Air Quality Control Using Space Services - drawing on space as well as ground-derived data to develop a dynamic, air quality-oriented traffic management system.
- Speed limit reductions in the Netherlands and England to manage traffic flow and reduce emissions.

To effectively manage traffic related air quality in a manner which will reduce exceedences of air quality standards it is necessary to be able to monitor the concentrations of harmful chemicals caused by road traffic within the air in real-time, over a wide geographical area, and taking into account weather conditions and sources of release. Traditional Air Quality Monitoring (AQM) equipment is expensive (in terms of both capital cost and maintenance cost). It is also bulky and time consuming to both install and maintain. It is also non-portable and has high power consumption. It is therefore not directly suitable for such a purpose and a low cost, pervasive, system is preferred.

1.4 Application of ITS to an Environmental Incident Management Systems (EIMS)

In addition to assisting with the monitoring of roadside air quality data, ITS can also help manage improvements in local air quality. By integrating low cost air quality sensors to other ITS elements, such as Urban Traffic Control (UTC), Urban Traffic Management and Control (UTMC), or Variable Message Signs (VMS), the detection of high air pollution can be triggered to invoke a traffic management strategy. This might include the alteration of traffic signal timings, the use of variable speed limits, online traveller information services, or the use of VMS to encourage the use of Park and Ride facilities. In this way, the air pollution in the affected area can be reduced on a short-term basis, or awareness raised and behavioural change encouraged, with a minimum of human intervention. An ITS driven Environmental Incident Management System (EIMS) has the potential to play a part in reducing the number of exceedences of air quality standards, and ultimately reduce the likelihood of the UK Government and Devolved Administrations imposing large fines from the current Infraction proceedings.

1.5 Developing and applying an EIMS algorithm

An analysis of the CSRP real-time measured air quality data, and real-time measured traffic data, will lead to a clearer understanding of the relationship between these two data sets. From this analysis a truer algorithm could be developed between real-time measured traffic data (volume, classification, speed, and weather conditions), and real-time modelled air quality at the roadside. Applying such an algorithm to the numerous traffic count sites located throughout Scotland could provide a more accurate spatial and temporal overview of air quality, and thereby avoid the deployment of a large

number of AQM devices. Such an algorithm would however require regular calibration using "supersites" at a small number of locations. A system of this type could be used to predict the effect of new developments or road schemes upon air quality, or to provide advance warning of exceedences of pollutants – allowing strategies to be triggered in advance. Much work has been done in this area and the CSRP approach to collaboration is described in Section 1.6.

1.6 CSRP Collaboration

The success of the Collaborative Sensor Rotation Programme (CSRP), and any application of a low cost sensor system in an EIMS, is reliant on a range of organisations working together, in an "Open Door" manner to gain confidence in the effectiveness of low cost sensor technology to provide real-time air quality data of practical value. The key purpose of such data is to provide information to inform the road user, and (where possible) to manage the traffic to minimise the effects of pollution. Neither of these will be possible without correlation, calibration, validation, and consensus on the quality of the real-time air quality data.

The key partners noted in Table 1 below, and their wider networks, are working collaboratively within the CSRP to apply the findings of this research to an EIMS.

Table 1: Key Partners

Organisation	Details	Project Role
Envirologger	AQMesh supplier	Supplier
IBI Group	Consultant	Transport Scotland ITS Test Bed, commissioning, traffic data and equipment support, ITS supplier liaison
Local Authorities	Rotation locations	Data, coordination and air quality background
Scottish Government	Air quality policy	Contributory funding and link to wider policy
Scottish Transport Emissions Partnership (STEP)	Air quality technical group	Sharing information
SEPA	Agency	Correlation, technical input and support
TDC Systems	HI-TRAC PM and EMOTE supplier	Supplier
Transport Scotland	Scottish Government agency	Leadership, coordination and defining of objectives
University of Strathclyde	Academic institution	Defining sensor metrics, project review and settling of wider context

To date, the CSRP project team has researched, made contact, and held discussions with a significant number of organisations linked to pervious and current work on low cost monitoring and managing of air quality. These organisations are listed below in Table 2 below.

Table 2: Organisations contacted by CSRP Project Team

Organisation	Topic	Details	Date of contact
Centre of Ecology and Hydrology	Air Quality Monitoring	Trialling the Dylos air quality monitoring equipment and linking with current research on low cost air quality monitoring.	Winter 2013
Edinburgh University	Air Quality Monitoring	Low cost sensor design.	Winter 2013

Organisation	Topic	Details	Date of contact
City of Edinburgh Council	Use of EMOTES	Semi structured meeting held to discuss history and findings from work on Corstorphine High Street Edinburgh.	Summer 2013
Fife Council	Discussion	Discuss collaboration.	2013
Future Cities Work	Collaboration	Future Glasgow is an ambitious £24 million programme which will demonstrate how technology can make life in the city smarter, safer and more sustainable. Links being developed with the project, there is still potential to feed into this work and our project progress is being shared with Future Cities Glasgow.	2013
Glasgow City Council	CARBOTRAF	A project to realise a method, system and tools for adaptively influencing traffic in real-time to reduce Carbon Dioxide and Black Carbon emissions caused by road transport in urban and inter-urban areas. A semi structured meeting was held to discuss collaboration.	February 2014
IOM	CITI-SENSE Project	Using sensors to measure selected air pollutants at various locations in Edinburgh. Interested persons will be able to access the data via various supporting web tools and apps. IOM have currently received 5 AQMesh units for piloting early 2014. Transport Scotland helped co-locate these AQMesh units at the Bargeddie site to allow for comparison and evaluation.	January 2014
ITS UK	SEIG	Presentations made regarding progress and an Environmental Incident Management Conference is planned for November 2014.	2013
Newcastle University	Peer review	As leaders on the topics of Environmental Incident Management the CSRP team met for peer review and discussion regarding CSRP project outline.	Summer 2013
NHS Scotland	Epidemiology research	Discussion regarding research on the impacts of air quality on health.	2014
Scottish Urban Air Quality Group (SUAQG) modelling	Air Quality Steering Group	SUAQ is progressing with work developing a fine grained real time emissions model based on live traffic data. Aberdeen has been chosen as a first area for this.	2013
STEP	Collaborative partnership	Presented to STEP on progress to date and planned outcomes.	2013
Strathclyde University	PhD project	Aim of this NERC PhD project is to develop novel methods for design and field evaluation of monitoring networks for deployment of state of the art passive and real-time air quality monitoring systems and will evaluate and optimise the deployment of these to air pollution exposure models.	2013

1.7 Phase 1 CSRP timetable

The key elements of the CSRP timetable, and progress to date, are shown in Table 3 below.

Various joint meetings are held where collaborative opportunities exist and monthly briefing notes for the project are issued to all partners. Details of briefing notes and reports are also stored on the Transport Scotland website.

Table 3: CSRP Timetable and Progress to date

#	Item	Details	From	To	% Complete
1	Sensor choice	An assessment of the sensors available and an evaluation of an appropriate package.	July 2013	November 2013	100
2	Correlation	Working collaboratively with SEPA, Strathclyde University, and sensor manufacturers gather data on the effectiveness of the equipment	November 2013	February 2014	100
3	Progress Report 1	A report on progress to date including sensor choice, collaboration, calibration and validation,	January 2014	February 2014	90
4	Rotations 1 to 3	Rotation of the equipment to the locations defined in Section 4	February 2014	April 2014	40
5	Report 2	Reporting of the findings to date	April 2014	May 2014	0
6	Remaining rotations	Final rotation of the equipment	May 2014	August 2014	0
7	Report 3	Reporting of the overall findings and presentation of results	August 2014	November 2014	0

2 Air Pollutants from Road Traffic

2.1 EU Directive Air Quality Objectives

The objectives of the EU air quality framework directive (1996/62/EC) are as follows.

- Define and establish objectives for ambient air quality in the Community designed to avoid, prevent or reduce harmful effects on human health and environment as a whole.
- Assess the ambient air quality in member states on the basis of common methods and criteria.
- Obtain adequate information on ambient air quality and to ensure that it is made available to the public, inter alia by means of alert thresholds.
- Maintain ambient air quality where it is good and improve it in other cases.

The framework directive describes common assessment criteria and defines limit values and threshold values and mentions 13 air pollutant components for which limit values will be described in succeeding daughter directives.

The 9 main air pollutants related to road traffic, and the relationship to the CSRP, and Scottish Air Quality Objectives are briefly stated in Table 4 below, and the equipment chosen in Section 3 was selected to measure the pollutants noted.

Table 4: Main Air Pollutants from Road Traffic

Pollutant	Symbol	Comments (DEFRA, 2011)	Relevant Objectives from National Air Quality Strategy			Measured in CSRP
			Level	Measured as	Target Date	
Benzopyrene (Polycyclic Aromatic Hydorcarbon – PAH)	$C_{20}H_{12}$	Increased risk of cancer	0.25 ng m^{-3}	Annual mean	31 December 2010	No
Carbon Monoxide	CO	Reduces ability of blood to carry oxygen	10.0 mg m^{-3}	Running 8-hour mean	31 December 2003	Yes
Sulphur Dioxide	SO_2	Causes acidification; causes lung airway constriction	266 µg m^{-3} not to be exceeded more than 35 times a year	15-minute mean	31 December 2004	Yes
			350 µg m^{-3} not to be exceeded more than 24 times a year	1-hour mean	31 December 2004	
			125 µg m^{-3} not to be exceeded more than 3 times a year	24-hour mean	31 December 2005	
Nitrogen Dioxide	NO_2	Causes acidification, eutrophication, and ground-level ozone; increased risk of respiratory problems and enhances response to allergens	200 µg m^{-3} not to be exceeded more than 18 times a year	1-hour mean	31 December 2005	Yes
			40 µg m^{-3}	Annual mean	31 December 2005	

Pollutant	Symbol	Comments (DEFRA, 2011)	Relevant Objectives from National Air Quality Strategy			Measured in CSRP
			Level	Measured as	Target Date	
Particulate Matter	$PM_{2.5}$	Causes respiratory and cardiovascular illness	12 µg m-3 (limit)	Annual mean	2010	Yes
Particulate Matter	PM_{10}	Causes respiratory and cardiovascular illness	50 µg m-3, not to be exceeded more than 7 times a year 18 µg m-3	24 Hour mean Annual mean	31 December 2010 31 December 2010	Yes
Ozone	O_3	Causes irritation to eyes, nose and airways; increased risk of respiratory problems	100 µg m^{-3} not to be exceeded more than 10 times a year	8 hourly running or hourly mean*	31 December 2005	Yes
Lead	Pb	Variety of health effects, particularly upon the nervous system	0.25 µg m^{-3}	Annual mean	31 December 2008	No
Benzene	C_6H_6	Increased risk of cancer and leukaemia	3.25 µg m^{-3}	Running annual mean	31 December 2010	No

3 Equipment Chosen

3.1 Sensor Choice Methodology

A key development in low cost sensor technology occurred between 2006 and 2009, when a three year research project titled “Mobile Environmental Sensing System across Grid Environments (Message)” began work on low cost sensors and development of a pervasive network for environmental and traffic monitoring. The project developed three different types of low cost sensor and communication technologies based on work at Newcastle University, Imperial College London, and Cambridge University. Field trials of this early equipment are now complete and findings have been published. Following the Message project and further improvements in sensor technology, a wide range of low cost sensor devices are currently commercially available to monitor a range of air pollutants, and new devices are continually being introduced.

For the CSRP a review of low cost environmental monitoring devices was undertaken, based on a variety of factors including: commercial availability, cost, measured metrics, power requirements, data storage and transfer, ease of installation, and supplier understanding of the project needs. Following this review the following devices were selected:

- AQMesh
- EMOTE
- HI-TRAC PM

Details of each device are given in the sections 3.2 to 3.4 inclusive and use of the equipment to date on the CSRP is provided in section 3.5. At present additional equipment is being assessed and may be included in the project later in the year.

3.2 AQMesh – by Envirologger

AQMesh pods (see Figure 1 below) are small battery operated air quality monitoring devices with electrochemical sensors which measure NO, NO2, SO2, CO and O3 gases at ppb (parts per billion) and µg m^{-3} (micrograms per cubic meter) in air along with temperature, pressure and humidity. Measurements from each pod sensor are transmitted in real-time by cellular communications to the Envirologger servers. The data is then corrected for field conditions using an in-house algorithm before being made available in near real-time. The outputs can be analysed over the Internet using Envirologger software. Corrected data can be downloaded by PC and smart phone app. Data can also be accessed in Excel format, allowing further analysis to be conducted when combined with external information such as traffic count data. In addition the Envirologger software allows pollutants to be compared to temperature, pressure and humidity so that interference can be monitored.

Figure 1 - AQMesh Pod

Figure 2 – AQMesh Pods installed at the Bargeddie Site

Typically a network of sensors is deployed with units attached to street furniture such as lamp columns and railings, Figure 2 above.

The units have been quick and simple to install. They appear to have been designed for all weather conditions and, to date, maintenance has been relatively straightforward. As shown in Figure 3 below, the device is uncomplicated to inspect and maintain, with the sensors easily accessible and user replaceable.

Figure 3 - AQMesh device scheme

3.3 EMOTE – by TDC Systems

The EMOTE (see Figure 4 below) is a pervasive sensor device designed to enable dense deployments in urban areas to allow continuous, minute-by-minute monitoring of the pollution distribution over an area. The devices are battery and solar powered to facilitate simple installation and use a low-power, ZigBee-based communication protocol to route data between nodes and to a central Gateway for backhaul to the data management system.

Figure 4 - EMOTE device

Typically a network of sensors is deployed with sensors attached to street furniture (at a height of up to 2.5 metres; e.g. lamp columns and railings) with 80 - 100 metres between nodes. The units are stated to be quick and simple to install, designed for all weather conditions and are low maintenance, although we cannot yet confirm this.

EMOTEs record any three of the following gases (CO, NO, NO2, SO2, H2S, Cl) using electrochemical sensors and also temperature, humidity, noise and vibration.

A central gateway unit, known as an iGate, is used in the centre of the sensor deployment area. This contains a high gain antenna which can be mains powered or Powered over the Ethernet (PoE). The Gateway connects with the server via Ethernet of GSM router.

The data recorded by the device is stored on a TDC Systems virtual machine and can be accessed via a web-based interface.

This equipment has been ordered but has not yet arrived.

3.4 HI-TRAC PM – supplied by TDC Systems

HI-TRAC PM (see Figure 5 below) is a roadside particle monitor that measures PM10, PM2.5, or Total Suspended Particulate (TSP) concentration at roadside locations. The HI-TRAC PM uses a nephelometer which automatically measures real-time airborne PM10, PM2.5, or TSP particulate concentration levels using the principle of forward laser light scatter. Sample air is drawn into the monitor and through the laser optical module, where the particulate in the sample air stream scatters the laser light through reflective and refractive properties. This scattered light is collected onto a photodiode detector at a near-forward angle and the resulting electronic signal is processed to determine a continuous, real-time measurement of airborne particulate mass concentrations. For the CRSP PM2.5 is measured by the HI-TRAC PM.

Figure 5 - HI-TRAC PM device

HI-TRAC PM monitors require mains power and are interfaced with HI-TRAC iGATE intelligent gateway devices allowing real-time data to be accessed through 3G, GPRS or cabled and fibre TCP/IP connection.

The data recorded by the device is downloaded from the IBI Group development server in Glasgow.

3.5 Use of Equipment to Date

During the first 4 months of operation (November 2013 to February 2014) six sensor failures in the AQMesh units were experienced. The manufacturer supplied a new cradle for the units to try to lessen the effects of moisture or condensation but this did not appear to reduce the number of sensor failures. No pattern in the sensor failures was apparent as there were three different gas sensor failures.

The supplier provided a prompt replacement service for all failed sensors and we will receive feedback from the sensor manufacturer on the cause of the failures.

Of the two TDC HI-TRAC particle monitors purchased (Unit One and Unit Two) only Unit Two powered up on delivery, and Unit One was returned to TDC Systems for diagnosis. Unit Two was installed at Bargeddie, on the A8, and initially performed well but approximately six weeks after installation it was noticed that a ‘Flow Error’ was reported by the unit. The flow error was investigated on site but we were advised it would need to be returned to the original manufacturer in the USA to be repaired.

After a four week inspection by the supplier Unit One was returned and installed in early December at Birnam on the A9. Again it initially performed well but it was noticed that the data would spike several times a day. This was explained as a normal occurrence by the supplier, but in light of no similar spikes in Unit Two further investigation was required.

At this point, with both units not performing, it was decided by TDC Systems to return both units to the manufacturer for a full service and calibration to identify if there were any issues with the units. Both units were returned after three weeks and are planned to be installed shortly.

The use of the equipment to date is shown in Table 5 below.

Table 5: Use of Equipment to Date

No		Ordered	Received	Applied	Maintenance Issues
1	AQ Mesh 1	September 2013	October 2013	Bargeddie Dundee	Sensor Failure
2	AQ Mesh 2	September 2013	October 2013	Bargeddie Dundee	Sensor failure
3	HI-TRAC PM Device Unit One	September 2013	October 2013	Birnam	Returned for servicing
4	HI-TRAC PM Device Unit Two	September 2013	October 2013	Bargeddie	Returned for servicing
5	HI-TRAC I-Gate	September 2013	October 2013	Bargeddie Birnam	Awaiting HI-TRAC PM Device return before deployment
6	EMOTE 1	November 2013	Delayed	-	-
7	EMOTE 2	November 2013	Delayed	-	-
8	Gateway	November 2013	Delayed	-	-

The supplier has advised that EMOTEs are not currently available due to sensor issues. Following this the Key Partners in Table 1 are currently considering replacement equipment.

4 Field Correlation of Equipment

4.1 Description

When trialling a new product, it is good industry practice to calibrate and correlate its outputs against those of a more traditional solution, that is known to be accurate. If such an exercise is successful, it can provide a high degree of confidence that the new product records data with acceptable accuracy.

Two AQMesh devices and one HI-TRAC PM device were correlated against an AQM mobile laboratory, provided by SEPA (see Figure 8 below). As noted in Section 3.5 above, delivery of the EMOTE devices has been delayed, therefore, it has not been possible to correlate these devices at the time of writing. The SEPA mobile laboratory is capable of recording measurements of multiple pollutants, including those recorded by the devices under test.

Figure 6 – SEPA Mobile Laboratory

The devices under test, and the mobile laboratory, were located at Traffic Scotland's Weigh-in-Motion (WiM) site on the A8 at Bargeddie (see Figure 7 below).This site does not have permanent AQM facilities. However, it was selected for the initial field correlation of the devices for the following reasons:

- Low volume of interference from other emissions sources.
- The availability of hard standing to facilitate safe site access.
- Availability of mains power.
- A number of Traffic Scotland weather stations in close proximity.
- This site already records a variety of traffic data, including volume and speed.
- Telemetry site.
- A variety of traffic conditions throughout the day.
- Previous air quality data from the Eureka footprint study.

Figure 7 - SEPA Mobile Laboratory and devices under test on site at Bargeddie

The devices under test and the mobile laboratory were set to record pollutant levels for the same period of time. This allowed the data from the devices and the laboratory to be compared, which provided a degree of confidence in the devices' accuracy. It will also be possible to compare pollutant levels with other parameters, such as traffic volume, traffic speed and weather conditions – these variables are anticipated to provide the starting point for an air quality modelling tool.

4.2 Data

To date, the following sets of data from the field correlation exercise have been collected:

- NO, NO2 and NOX - Teledyne T200 (chemiluminescence)
- CO - Teledyne T300 (infra-red)
- SO2 - Teledyne T100 (UV fluorescence)
- PM1, PM2.5, PM10 – GRIMM EDM180 (nephelometer)
- PM2.5 - HI-TRAC PM device (nephelometer)
- NO, NO2, CO, SO2 and O3 - two AQMesh devices (electrochemical sensors)
- Traffic volume and speed data from the Traffic Scotland WiM site
- Weather data collected from SEPA and Traffic Scotland weather station at Riddrie
- Local Authority AQ data from the Scottish Air Quality Database

Span checks and zero checks using certified gases and scrubber were carried out weekly by SEPA while the mobile laboratory was on site.

The data was collected over the period 1st January 2014 to 9th February 2014. Some of the data collection devices were faulty for a short time during this period. Nevertheless, sufficient data was collected to undertake some basic, initial data comparisons. A subset of the collected data is briefly discussed here.

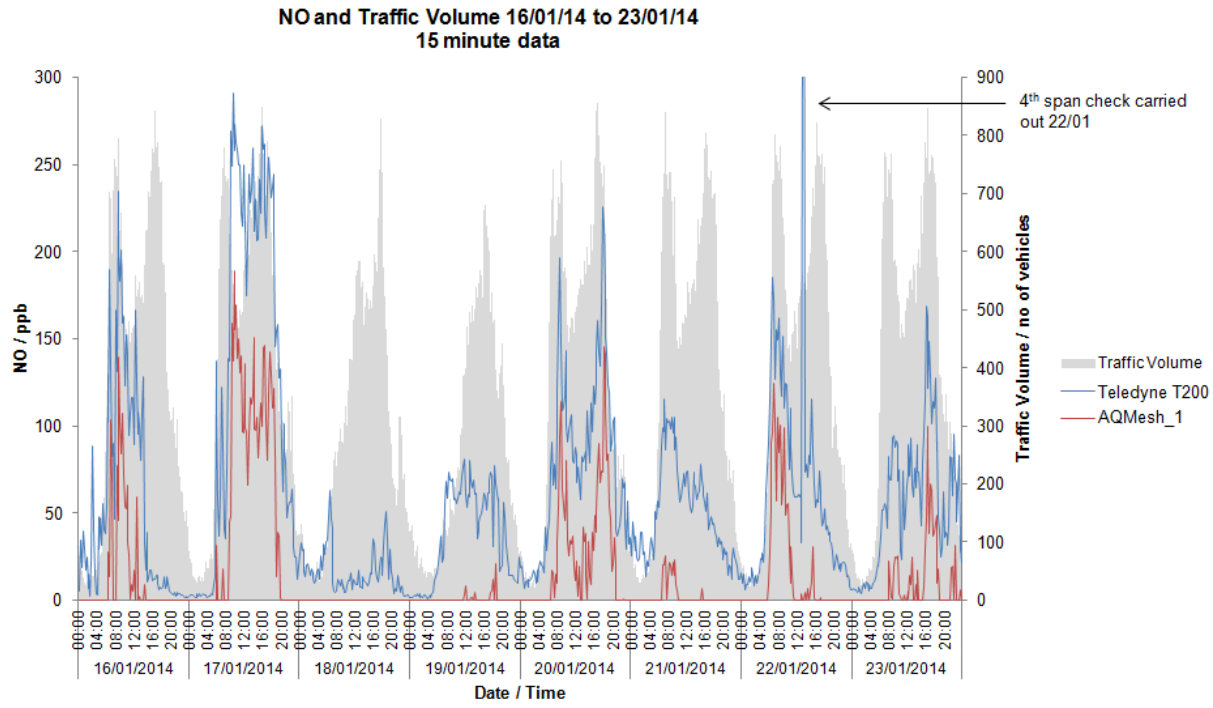

Figure 8 – NO and Traffic Volume 16/01/14 to 23/01/14

Figure 8 above shows the NO levels measured by the AQMesh_1 device and a Teledyne T200 machine along with the traffic volume measured by the WiM site for the period 16th January to 23rd January.

The traffic volume data shows distinct AM and PM peaks on weekdays (16th - 17th, 20th – 23rd); lower volume and the absence of a well-defined AM peak during weekend days (18th-19th). The NO data shows correlation to the diurnal traffic patterns, particularly on 17th and 20th; with the AQMesh_1 NO data following similar trends to the Teledyne T200 data. There appears to be evidence of a possible offset in the baseline of the AQMesh_1 NO data which could account for the consistently lower NO readings from the AQMesh_1 unit.

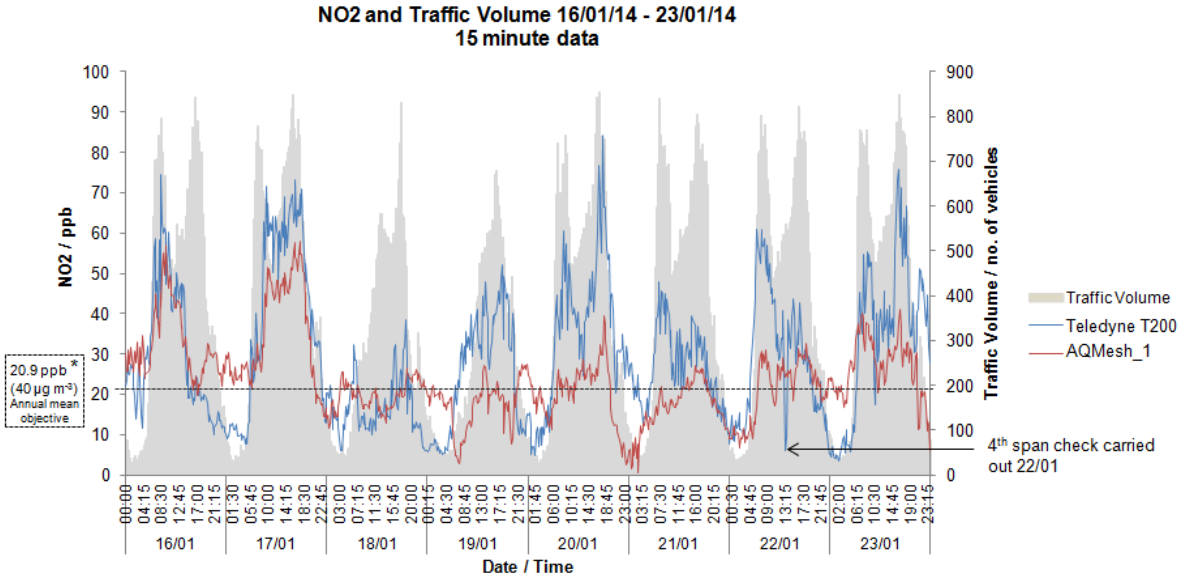

Figure 9 – NO2 and Traffic Volume 16/01/14 to 23/01/14[1]

Figure 9 shows the NO2 levels measured by the AQMesh_1 device and SEPA along with the traffic volume measured by the WiM site for the period 16th January to 23rd January.

Again NO2 data shows correlation to the diurnal traffic patterns, particularly on 17th and 20th. Daytime NO2 levels, measured by both instruments, generally exceed 20 ppb; with measurements reaching up to 80 ppb in PM peak 15 minute periods during the week. The two instruments do not follow the same daily trends consistently; further investigation is required to determine factors possibly contributing to this.

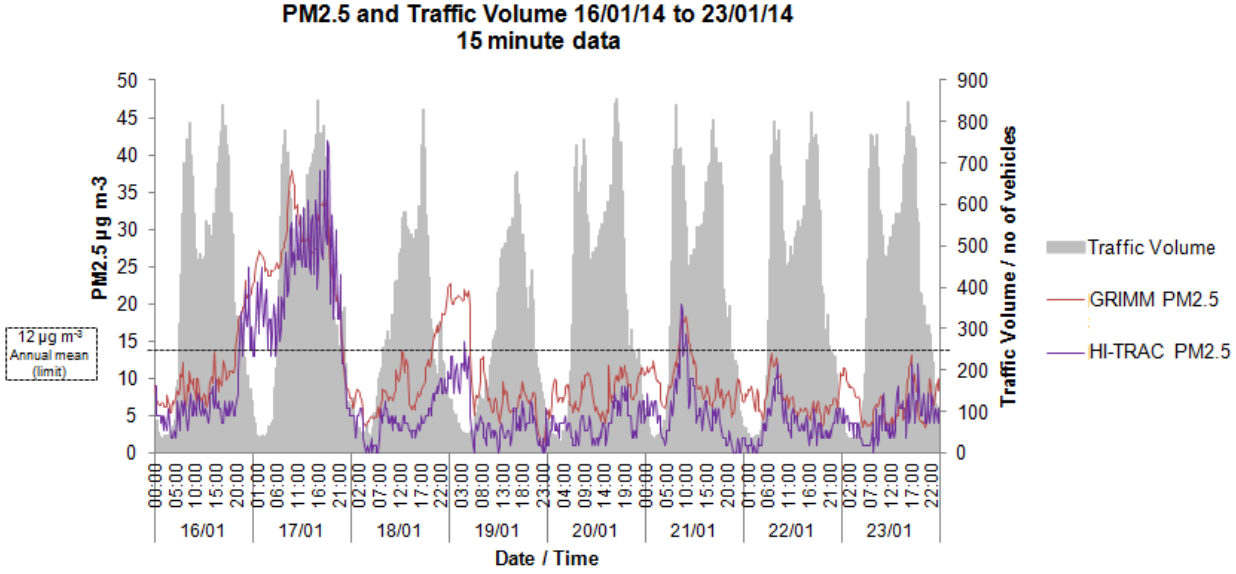

Figure 10 – PM2.5 and Traffic Volume 16/01/14 to 23/01/14

Figure 10 shows the PM2.5 data measured by the HI-TRAC device and GRIMM unit along with the traffic volume measured by the WiM site for the period 16th January to 23th January. Note that GRIMM unit measured PM10, PM2.5 and PM1 (concentration of particles with a diameter of 10µm,

[1] * Nitrogen dioxide: 1 ppb = 1.91µg m-3. On the UK Air Quality Archive, and for reporting data to the European Commission, the appropriate conversion factors at 20 °C and 1013 mb are used. http://uk-air.defra.gov.uk/assets/documents/reports/cat06/0502160851_Conversion_Factors_Between_ppb_and.pdf

2.5µm and 1µm respectively); the HI-TRAC device only measures PM2.5. However, for the sake of clarity, only the PM2.5 data recorded by the GRIMM unit is presented here.

The PM2.5 data correlates reasonably well and seems to correspond to the volume of traffic, albeit not always at the same level: the increase in PM2.5 on 17th January exceeds the increases on other days with a similar volume of traffic, peaking at 40 µm m-3. There also seems to be an increase in PM2.5 in the evening of 18th January, which does not have a corresponding increase in traffic volumes.

The HI-TRAC appears to records PM2.5 data at a consistently lower level than the GRIMM unit. The reason for this will need to be investigated.

4.3 Speed Flow Relationship

As stated above, the relationships between parameters will be explored further in subsequent data analysis. To provide an indication of this analysis early AQMesh and traffic data gathered at the Bargeddie site has been plotted; the parameters are traffic flow, speed and NOX (NO+NO2), Figure 11 below. On this graph three groups of points have been annotated:

A. This group represents free-flow traffic; high speed, low volume and low levels of NOX measured;
B. This group represents more heavier traffic conditions, much higher volumes of traffic, the speed is falling and there are more varied levels of NOX, particularly levels greater than 200 ppb;
C. This group represents congested conditions, with speeds of 30 mph and lower, flow is reduced and more measurements of NOX greater than 400 ppb are more frequent.

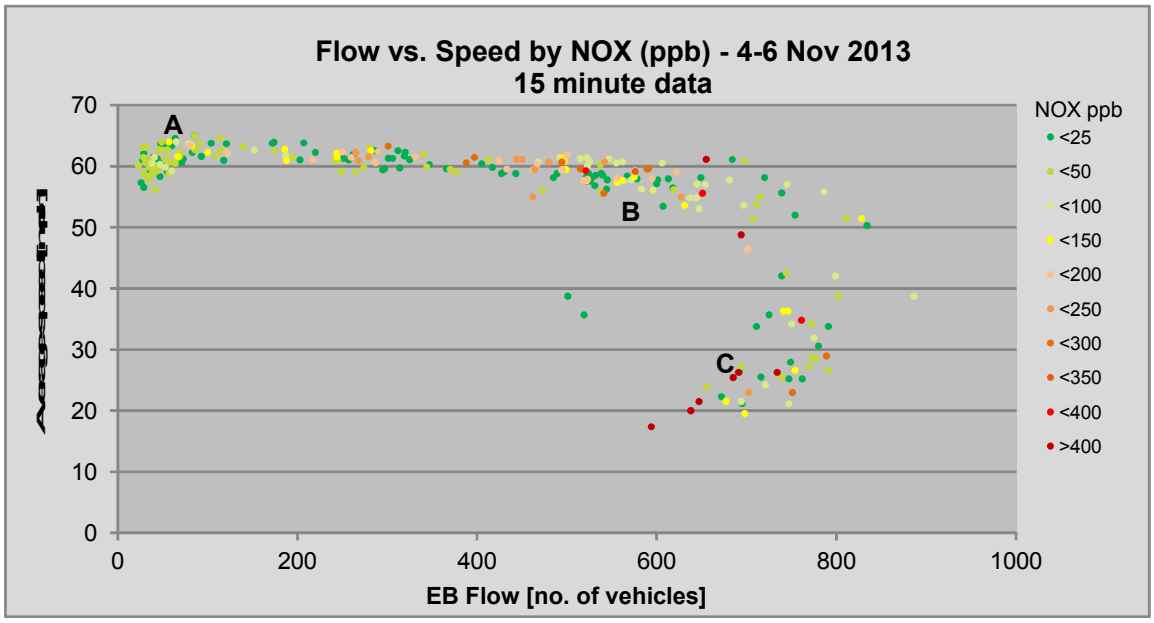

Figure 11 - Flow / Speed and NOX data

5 Rotation Sites

5.1 Site Selection Criteria

The site locations for the CSRP were chosen by assessing all Transport Scotland schemes from the 2013 to 2014 programme (60 schemes over 14 Local Authorities areas), and ranking the top eight most appropriate geographic areas. Following this ranking individual locations were chosen within the Local Authority area to utilise available traffic data. This two stage process was developed to ensure a balanced approach to objectives.

The 60 schemes were scored using the following Assessment Criteria:

- Scheme value.
- Road type.
- Scheme type.
- Before and after study opportunity.
- AQMA Location.
- NMA Location.
- Opportunity for partnership working.

A typical example of the scoring process, for site 3 in Table 6 (A90 Dundee Kingsway) is shown in Table 6 below.

Table 6: Typical Site: Main Air Pollutants from Road Traffic

Scheme	Scoring method	Kingsway East A92	Forfar Road A90	Tay Bridge Roundabout A92
Value	>£100m.....8 £20m to £100m .....4 <£20m 2	2	2	2
Road type	Trunk.....2 Local.....1	2	2	2
Bypass	Yes.....2 No.....1	1	1	1
Before and after study opportunity	Yes.....2 No.....1	2	2	2
AQMA	Yes.....2 No.....1	2	2	2
NMA	Yes.....2 No.....1	2	2	2
Microsimulation model available	Yes.....4 No.....0	4	4	4
AQM Equipment in operation	Yes.....5 No.....0	0	0	0
Project totals		15	15	15
Total for Dundee area (area within top eight geographic locations)		45		
Location chosen (site 3)		A90 Dundee Kingsway		

5.2 Selected Sites

The eight selected sites for Phase 1 of the CSRP are shown in Table 7 below.

Table 7: Year 1 – Selected Sites

Site	Location	Environment	AQMA	Comments
1	Bargeddie Super Site	Dual carriageway	No	M8/M73/M74 Motorway Improvements – before and after TS WIM site with existing infrastructure and convenient site access for equipment testing
2	Birnam Super Site	Single carriageway	No	A9 Dualling - before and after TS WIM site with existing infrastructure and convenient site access for equipment testing
3	A90 Dundee (Kingsway)	Suburban	Yes	Major schemes and collaboration
4	A9 Perth – Broxden	Suburban / semi-rural	Yes	Perth and Kinross council collaboration
5	A90 / A96 Aberdeen – Anderson Drive	Urban	Yes	Air quality modelling trials AWPR
6	A985 Rosyth	Urban	No	Detailed assessments undertaken in 2009 and 2012 relating to NO2 and PM10
7	A82 Inverness	Urban	No	
8	A720 Sheriffhall Roundabout	Semi-rural	No	City of Edinburgh Council collaboration Congested

As an example of the type of site selected, Figure 12 shows Site 3 on the A90 at Dundee. There is a significant proportion of HGVs on this trunk road, with the potential of adding to air and noise pollution as they decelerate towards and accelerate away from the Old Glamis Road roundabout. There are also residential properties in close proximity to the carriageway (shown on the left of the photograph: Figure 12 below). This site is also close to a college and a secondary school (out of shot).

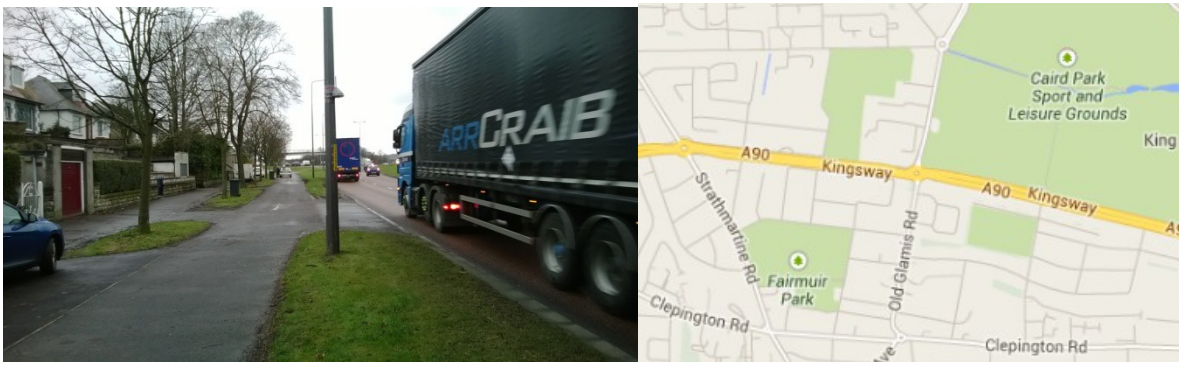

Figure 12 – A90 Dundee (Kingsway) site

Although analysis of the AQMesh data from the calibration exercise is not yet complete (see Section 4 of this paper), an AQMesh device has been installed at this site (centre of shot): it was considered preferable to continue to collect data using the device, at a site with different characteristics to the calibration site, once the data collection period of the calibration exercise was completed.

Figure 13 - A90 / A96 Aberdeen (Anderson Drive) site

Figure 13 above shows the Haudagain Roundabout at the junction of the A90 and A96, a planned site (Site 5) in Aberdeen.

6 Site Construction Work

6.1 Location Modification

All the rotation sites required site construction work to be carried out to allow the rotation to take place. This included power connection checks, structural assessment of equipment mount locations, and assessment and development of communication systems. This process required discussion and liaison with Local Authorities, Transport Scotland Operating Companies, and Transport Scotland Staff across a range of directorates. In addition site visits were completed at each location and power and support needs were assessed.

7 Next Steps

7.1 What we plan this year

The next stage in the process is formalising the data analysis strategy with SEPA; this will examine the correlation between data sets, the anomalies in the data mentioned in Section 4.2 and any others found, and include the relationships with weather and ambient conditions at the Bargeddie site.

When any additional equipment is included in the project it will be calibrated, and any anomalies investigated, in a similar manner.

Once all anomalies are understood, it is intended to install the devices at the sites mentioned. They will be rotated throughout the year: this will test their suitability to accurately measure pollutants in a variety of environments and will serve as a good test of their resilience and portability. This will then be combined with local modelled data to assess the potential impacts of traffic pollution. It is intended that the emergence of portable devices will allow air quality to be measured on a temporary basis, for example to measure the effect of a major event such as a music festival or football match. Periodically, between Rotation Site deployments the equipment will be co-located at Automatic Urban Network sites containing referenced equipment to re-measure correlation and drift.

The rotational programme will be planned carefully to avoid any major events causing interference with the data.

It is intended to correlate the pollutant data recorded by the devices to weather data within the vicinity. In this way, any variants in pollutant levels caused by weather conditions (such as high winds blowing pollutants from an industrial facility into the vicinity of the sensor, or, alternatively, dispersing pollutants from road traffic) can be allowed for, to yield a more accurate picture of the pollutants caused by road traffic. Correlation to weather data and traffic data will also allow the development of a modelling software package that can predict air quality, given traffic volumes, speeds and weather conditions as inputs.

We also intend to model key locations and relate this data to real time air quality measurements.

The best package of pollutant data to be recorded will be ascertained. The study will help to increase confidence that the proposed metrics are suitable to measure roadside air quality levels and to link these to flow and fleet characteristics and weather conditions.

It is also intended to develop an integration mechanism to other ITS components to allow strategies to be invoked whenever the concentration of a certain pollutant exceeds a predefined value. This could include the use of VMS to encourage the use of Park & Ride, the use of variable speed limits, or the alteration of traffic signal timings.

8 Challenges

8.1 What we found

There are a number of challenges required to be overcome if the next steps described in the preceding section are to be realised. These include (but are not limited to):

- The relationship between weather conditions and pollutants is still unclear. This will be required to be learned if an accurate picture of pollutants in the air as a direct result of road traffic is to be ascertained.
- The effects of traffic volume, traffic speed, and weather conditions upon pollutants is still unclear. These will all require to be learned if these effects are to be built into a modelling package.
- It is presently unclear why the devices record data with a similar trend to more conventional AQM systems, but with a consistently higher or lower reading. It is believed that this may relate to the configuration of the devices: further research is required to be undertaken.
- The EMOTE has yet to be received from TDC Systems.
- The potential interventions required additional research:
    - The effects of harder measures (for example imposing lower speed limits, altering signal phasing), have been applied by other authorities around the world but a clearer understanding of the methodologies and effects is needed;
    - The effects of softer measures (such as alternative mode encouragement or road user information) are much more complex to measure and evaluate.

9 Conclusions

9.1 Observations on progress to date

To date the project is in a very early stage of its research, and it is difficult, at present, to draw any definitive conclusions as to the success of the low cost AQM devices; much less of an Environmental Management System. However, the preliminary data received to date indicates a reasonable level of accuracy for the HI-TRAC PM and the AQMesh devices for certain pollutants. As the rotations complete, and reports 1 to 3 noted in Table 3 are published we anticipate much greater clarity on these very early findings and we hope that this will be able to explain some of the anomalies in the data. Once this is done, we believe the possible application of low cost sensors to measure air pollutants caused by road traffic and ultimately forming part of an Environmental Incident Management System or air quality modelling software appears promising.

As noted in Section 1.6 the key to the success of the CSRP is collaboration, and robust links and partnerships have already been made. The project has already brought together a number of key strategic partners and has cultivated important links between the delivery partners and industry. Through these relationships the project team has fed observations, suggestions and experiences through the product supply chain. This project has also broadened knowledge and understanding of similar activities being undertaken and resources that can be drawn upon.

9.2 Key findings to date

The key findings to date are as follows:

- Low cost sensor technology can provide air quality outputs of possible value.
- Currently available equipment requires regular monitoring and maintenance.
- The sensor technology supply chain is receptive to the ITS industry requirements.

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