Measuring Air Pollution from Ambulances (MAPA) Pilot Study

Final Report

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Executive Summary

In the United Kingdom there has been increasing concern about delays offloading patients from ambulances arriving at Emergency Departments (ED). During such time, ambulances frequently idle their engines to maintain care, and this may increase exposure to air pollutants which can harm respiratory and cardiovascular health. As little data exists on air quality in or around ambulances, the Measuring Air Pollution from Ambulances (MAPA) Pilot study explored staff exposures to pollutants within ambulances and in one urban ED ambulance bay during routine shifts.

Between November 2024 and March 2025, the MAPA Pilot study prospectively ran three overlapping workstreams. Workstream1: monitored particulate matter (PM), Nitrogen Dioxide (NO_2), and Carbon Monoxide (CO) outside ED in relation to ambulance queues. Data were collected at Cambridge University Hospital's courtyard-style, partially canopied ED ambulance bay and Cambridge Ambulance Station. A Main sensor was in the ED ambulance bay and compared with a Reference sensor located before the entrance to the ED. Workstream 2: measured PMs, volatile organic compounds, and CO inside the front and back of six ambulances during routine shifts with reference to time of day and ambulance location and activity data. Workstream 3: recorded CO percentage saturation in healthcare staff working within the ED ambulance bay using a Massimo RAD57 Pulse CO-Oximeter.

Workstream 1 found statistically significantly higher pollutant concentrations near the ED ambulance bay during the night and day, compared to the Reference sensor site, and PMs showed greater differences than CO or NO_2. There were incidences where the legally binding DEFRA threshold was breached in one or both sensors. No correlation between the number of ambulances at the ED and pollutant concentrations were found. Workstream 2 found in-ambulance $PM_{2.5}$ above DEFRA and WHO annual limits, with occasional high CO peaks observed in all activities. In Workstream 3, a total of 160 participants had CO % saturation recorded on 9 different days during the study period. There were no incidences of CO saturations above the level of clinical significance (10%). However, about a fifth of participants reported symptoms that started whilst in the ambulance bay, the most common being headache, fatigue and/or back pain.

It should be noted that MAPA Pilot was conducted in a busy period of ambulance activity and during the coldest months of the year, so the findings should be interpreted with some caution. That said, MAPA Pilot has demonstrated a need for further investigation of air quality in ED ambulance bays and into the occupational exposure of ambulance staff to air pollution. Other recommendations include investigation of the effects of season and architecture on ED ambulance bay pollution, the potential impacts of air pollution on other NHS staff and patients, and efforts to find solutions to reduce ambulance engine idling at ED.

Contents

Introduction

In the United Kingdom (UK) there has been increasing concern about delays to the offloading of patients from ambulances arriving at Emergency Departments (ED); in December 2022 1,814 ambulances waited more than 10 hours outside English EDs[1]. Whilst waiting, ambulances use heating, cooling, lighting and medical equipment, and although a vehicle's battery can provide electrical power for limited time, climate control and additional power is provided by running the engine, also known as idling, whilst a diesel burning heater provides heating.

Exhaust fumes from idling engines contain carbon monoxide (CO), hydrocarbons, nitrogen dioxide (NO_2), particulate matter (PM) and carbon dioxide (CO_2)[2]. Ambulance staff and patients are exposed to such air pollution whilst waiting outside ED, however at present there is no data available about exposure levels.

Ambulance staff also spend a significant amount of time inside ambulances during their shifts. Air quality within a motor vehicle is influenced by several factors and will comprise of many separate pollutants[3]. There is limited evidence about indoor compared to outdoor air pollution[4], especially related to occupational health. At present, there is no data available about the air pollution ambulance staff and patients are exposed to inside an ambulance.

High levels of air pollution are known to negatively interact with respiratory and cardiovascular physiological function, with repeated exposure leading to an increased risk of ill health and premature death[5]. However, demonstrating the effects of this air pollution can be difficult and only detectable at a population level[6]. The World Health Organisation (WHO) publishes guidance on levels of air pollution that may be harmful to health[7] and Department for Environment, Food and Rural Affairs (DEFRA) defines legally binding maximum levels of air pollution[8].

The MAPA Pilot study aimed to explore the level of air pollutants that ambulance staff were exposed to during routine shifts, and any relationship with the phenomenon of queuing outside the ED. It also sought to test different methods of measuring air quality to inform the design of future research exploring air quality associated with a variety of ambulance bay layouts at different hospitals. MAPA Pilot focused on measuring the following common components of exhaust pollution:

- Fine particulate matter with a diameter of 1 to 2.49 microns (PM_1),
- Fine particulate matter with a diameter of 2.5 to 9.99 microns ($PM_{2.5}$),
- Coarse particulate matter with a diameter of 10 or more microns (PM_{10}),
- Volatile organic compounds (VOCs),
- Nitrogen Dioxide (NO_2), and
- Carbon monoxide (CO).

Methods

Study Design and Setting

MAPA Pilot data collection was conducted prospectively between 26th November 2024 and 1st March 2025 and comprised three overlapping Workstreams, each carried out by its own team of experts under the direction of East of England Ambulance Service NHS Trust (EEAST) Research Support Services (RSS) acting as Sponsor. Workstreams 1 to 3 each had specific aims as follows:

1. **WS1 Ambulance Bay Air Quality Monitoring**: Explored the concentrations of $PM_{2.5}$, PM_{10}, NO_2 and CO outside one EEAST ED with reference to the number of ambulances queuing outside.
2. **WS2 In-Ambulance Air Quality Monitoring:** Explored the average concentrations of PM_1, $PM_{2.5}$, PM_{10}, VOCs, and CO in both the front and back of ambulances with reference to time of day and ambulance location and activity data.
3. **WS3 Staff CO Saturation Measurements**: Explored the average level of CO saturations measured in healthcare staff outside one ED with reference to Workstream 1 data.

For convenience, Cambridge University Hospital (CUH) and Cambridge Ambulance Station were utilised for the setting. The ambulance bay at CUH ED would be described as a courtyard layout with partial canopy (Figure 1, below).

Workstream 1: Ambulance Bay Air Quality Monitoring

Two stationary EMSOL Praxis (EMSOL ltd, London, UK) air quality sensors were installed at CUH by air quality monitoring specialists, EMSOL (London, UK). One sensor (the 'Main sensor') was positioned directly outside of the doors used to enter the ED from the ambulance bay, with the second sensor (the 'Reference sensor') sited on the access road leading to the ambulance bay. As the CUH site included other sources of air pollution, the reference sensor placement was selected as the most useful reference point available to the study (see Figure 1, right)

Figure 1: Arial photo of CUH ED ambulance bay with partial canopy

The sensors were active for the data collection period from 9th December 2024 to 1st March 2025. Data was recorded at 15-minute intervals, capturing concentrations of CO, NO_2, $PM_{2.5}$, and PM_{10}, and transmitted to EMSOL's services by 4G cellular data collection. The EMSOL Praxis sensors provided accurate measurements of air pollution, complying to the Monitoring Emissions to Air, land and Water standards set out by the Environment Agency[9]. The sensors were accompanied by a camera, positioned to provide a view of vehicular activity in the ambulance bay, whilst images of people and windows were digitally obscured to maintain anonymity.

Workstream 2: In-Ambulance Air Quality Monitoring

Atmotube Pro portable sensors (Atmotech Inc., San Francisco, USA) were used to measure PM_1, $PM_{2.5}$, PM_{10} and VOCs. Atmotube Pro devices were set to record data every second and were synchronised with the Atmotube application on Apple iPad Operating System via Bluetooth connection at the end of every shift. Field and laboratory testing by AQ-SPEC at South Coast AQMD found that Atmotube PRO provides highly accurate particulate matter measurements, demonstrating a correlation greater than 0.88 with regulatory-grade air monitoring instruments [7].

The Dräger PAC 6500 series of portable sensors (Drägerwerk AG & Co. KGaA, Lübeck, Germany) were used to measure CO, and data were collected every second. All Dräger PAC 6500 devices were calibrated by Drägerwerk 2-weeks prior to the start of the data collection period. Data were downloaded at the end of each shift using USB wired connection to Draeger CC-Vision Basic software (version 8.1.4) on a laptop based at

Cambridge Ambulance Station. All data were interpolated to 60-second mean averages for analysis, and comparison to ambulance position and activity data.

Six EEAST ambulance staff based at Cambridge Ambulance Station volunteered to manage four pollution sensors each for the duration of the data collection period from 2nd December 2024 to 17th February 2025. Each volunteer was provided with two air quality monitors (Atmotube) and two CO monitors (Dräger). During routine shifts, two sensors, one of each type, were placed in the front of the ambulance, secured with a loop strap to a hook behind the driver at head height, positioned away from fans, vents, and windows. Similarly, two sensors, one of each type, were installed in the back of the ambulance, attached via a loop strap to the ceiling at standing head height in the centre of the space, also away from fans, vents, and windows. These sensors remained in place for the entire shift. After completing their first shift, one of the volunteers opted to withdraw from the study and their devices were allocated to a further volunteer.

At the end of Workstream 2 data collection, volunteer ambulance staff were asked to provide anonymous feedback via a survey distributed on Microsoft Forms. The survey asked about their experience of taking part in the study and views on the sensors and study processes. The staff were provided with a £30 voucher as compensation for the time involved.

To understand the value of these different approaches, measurements of $PM_{2.5}$ and PM_{10} from in-ambulance monitoring were compared with measurements at the Main sensor using interclass correlation coefficient (ICC)[10] and Bland-Altman analysis[11] to assess inter-rater reliability. ICC estimates and their 95% confidence intervals were calculated based on a mean-rating ($k = 2$), absolute-agreement, and 2-way mixed-effects model.

Bland-Altman plots were created to represent bias scores and 95% confidence intervals for mean differences between the Main Sensor and in-ambulance measurements. The bias score and the 95% limits of agreement were used, and the 95% confidence intervals were calculated as the bias ± 1.96*SD of the difference of the measurements recorded in laboratory vs. field setting. The Bland-Altman analysis may be associated with proportional bias. This is present when the difference in values from two sets of data increases or decreases proportionally to the average values[11]. Therefore, a simple linear regression was applied to aid comparisons and determine whether proportional bias is present. Alpha was set at 0.05 in all cases to determine significant results.

Ambulance Location and Activity Data

RSS arranged to collect data from the EEAST Computer Aided Dispatch (CAD) system from the 9th December 2024 to 13th March 2025. Such CAD systems are utilised to direct ambulances to the location of 999 calls and monitor activity. Each ambulance has a unique call-sign and is allocated to 999 incidents by control-room staff. The ambulances are tracked by GPS, and the ambulance crew record their activity using a data terminal in the cab. The CAD system records the location, and every stage of the ambulance journey, from the crew 'booking on' at the start of their shift, mobilising towards an incident, on scene with patients, and travelling to hospital, etc.

Including CAD data in the study allowed MAPA Pilot to explore air quality measurements with reference to the number of ambulances outside the ED, as well as air quality inside the front and back of ambulances during different phases of each shift. MAPA Pilot used a sub-set of the data available on CAD, with the following definitions:

Queue
The number of ambulances outside CUH ED was monitored using CAD software and provided to RSS. For each 30-minute interval, the highest number of vehicles in the ambulance bay was recorded and used to represent the queue length at that time. This allowed comparison between the number of vehicles in the queue and pollution levels measured.

Travelling
The CAD system logged time when the ambulance was in transit as "Mobile". For analysis, data was used from the entire time that the CAD system logged ambulance location as "Mobile".

At Hospital
The CAD system logged the period during which the ambulance was at a hospital - usually at ED - as "At hospital". The CAD system also recorded which hospital the ambulance attended. For analysis, data was used from the entire time that the CAD system logged ambulance location as "At hospital".

Meal Breaks
The CAD system logged time when ambulance staff were taking breaks as "Meal break". Data from the final 10-minutes of each meal break period was analysed.

Day and Night Shifts
Day shifts were assigned to data collected between the times of 07:00 and 19:00. Night shifts were assigned to data collected between the times of 19:00 and 07:00.

Workstream 3

The Massimo RAD57 Pulse CO-Oximeter (Massimo Corporation, Irvine, California, USA) was used to measure blood CO saturation levels. Data were recorded using a secure survey link on Microsoft Forms, and measurements were carried out by study team Paramedics. Staff working in the ambulance bay of CUH ED were approached by study team Paramedics and invited to participate in MAPA Pilot. After consenting and completing a short health survey, blood CO saturations were measured. Data was recorded by the study team in MS Forms on a convenience sample of 9 separate days within the study period. CO Saturation percentages were compared to concentrations of CO measured in the air using Pearson's product-moment correlation test.

Comparison to DEFRA Air Quality Objectives and WHO 2021 Air Quality Guideline thresholds

DEFRA and WHO set daily and annual mean concentration limits of common air pollutants. DEFRA's standards are legally binding, with required actions to reduce air pollution below these levels outlined by the government's 2023 Environmental Improvement Plan[8]. These targets set both the concentration limit and the allowable number of exceedances per year. For example, the target for PM_{10} is that concentrations should not exceed a daily mean of 50 µg/m3 more than 35 times a year.

Separately to the legislative targets published by DEFRA, WHO publishes Air Quality Guidelines[7], developed by experts in the field. These guidelines recommend maximum daily and annual mean concentrations for key pollutants. DEFRA specifies the number of days in each year that the daily mean can be exceeded, known as breaches. The WHO guidelines are more stringent than the DEFRA's and recommend that mean daily concentration thresholds should be exceeded not more than 3-4 days per year.

In MAPA Pilot, the measurements of air pollution concentrations were compared to the daily and annual thresholds for mean concentrations set by DEFRA and WHO (summarised in Table 1, below). Daily comparisons are easy to calculate and have been shown, however as MAPA Pilot collected data for a significant part of the year (one quarter) it is appropriate to consider the comparisons to annual mean thresholds. These are included to give an indication of the long-term exposure to the measured concentrations of air pollutants. It should be noted that MAPA Pilot was conducted in a busy period of ambulance activity and during the coldest months of the year, so mean concentrations should be interpreted with caution.

DEFRA and WHO present concentrations of NO_2 using µg/m^3 and CO using mg/m^3; so to allow for comparison to these thresholds, the units have been converted in accordance with the conversions given in DEFRA's Environmental Improvement Plan[8]:

CO: 1 ppm = 1.15 mg/m^3 NO_2: 1 ppb = 1.88 µg/m^3

	DEFRA		**WHO**	
Pollutant Type	Daily mean	Annual Mean	Daily mean	Annual Mean
$PM_{2.5}$ (ug/m3)	Not set	20	15	5
PM_{10} (ug/m3)	50	40	45	15
CO (mg/m3)	10	Not set	4	Not set
NO_2 (ug/m3)	Not set	40	25	10

Table 1: Daily and Annual thresholds for mean concentrations of pollutants set by DEFRA and the WHO Limits as from Air_Quality_Objectives_Update_20230403.pdf and What are the WHO Air quality guidelines?

Results

Workstream 1: Ambulance Bay Air Quality Monitoring

The Main sensor data collection period was 9th December 2024 to 1st March 2025, and Table 2 below summarises the pollutant data collected. Due to a software error, there was one period of data-loss between 1st and 5th January 2025 for NO_2 and CO data.

Sensor		**$PM_{2.5}$ (µg/m³)**	**PM_{10} (µg/m³)**	**NO_2 (ppb)**	**CO (ppb)**
Main	count	9,069	9,069	8,540	8,537
	Mean	19.56	33.79	31.61	332.83
	SD	16.68	17.85	8.18	98.92
	Peak	86.09	99.26	186.27	2,190.35
Reference	count	8,938	8,938	8,409	8,409
	Mean	13.5	27.81	28.61	288.31
	SD	11.36	15.24	4.57	56.07
	Peak	55.21	143.88	49.46	948.07

Table 2: Mean, standard deviation and peak concentrations of $PM_{2.5}$, PM_{10}, CO and NO^2 at the Main and Reference sensors, as well as results of Paired Sample t-test

It is obvious from Table 2 that pollutant concentrations were, in general, higher at the Main sensor than the Reference sensor. The range of concentrations measured was extremely wide, with daily and hourly variation evident. This is explored in more detail in following sections of the report, although time-series analysis was beyond the scope of MAPA Pilot.

Consideration was given to the difference between day and night shifts, and this is summarised in Table 3, below. The pollution levels during the night were not dissimilar to those during the day.

Sensor	**Shift**		**$PM_{2.5}$ (μg/m³)**	**PM10 (μg/m³)**	**CO (ppb)**	**NO_2 (ppb)**
Main	Day	count	4,529	4,529	4,271	4,272
		Mean	18.13	32.57	329.41	32.30
		SD	16.42	18.00	93.98	8.48
		Peak	82.53	99.26	2,005.54	186.27
	Night	count	4,540	4,540	4,266	4,268
		Mean	20.97	35.01	336.24	30.92
		SD	16.82	17.61	103.53	7.81
		Peak	86.09	96.23	2,190.35	150.48
Reference	Day	count	4,456	4,456	4,199	4,199
		Mean	12.31	26.19	286.08	29.74
		SD	10.77	14.62	56.70	4.35
		Peak	52.57	127.22	948.07	49.46
	Night	count	4,482	4,482	4,210	4,210
		Mean	14.69	29.42	290.52	27.48
		SD	11.80	15.67	55.35	4.52
		Peak	55.21	143.88	693.72	43.83

Table 3: Mean, standard deviation and peak concentrations of $PM_{2.5}$, PM_{10}, CO and NO_2 at the main and reference sensors during the Day and Night

$PM_{2.5}$

Variation in $PM_{2.5}$ concentrations during the study recording period is shown in Figure 2. There were notable changes in $PM_{2.5}$ levels with time, and peak concentrations as high as 80 μg/m^3 were observed at the start of February 2025. Main sensor recordings were consistently (92%) higher than those of the Reference sensor.

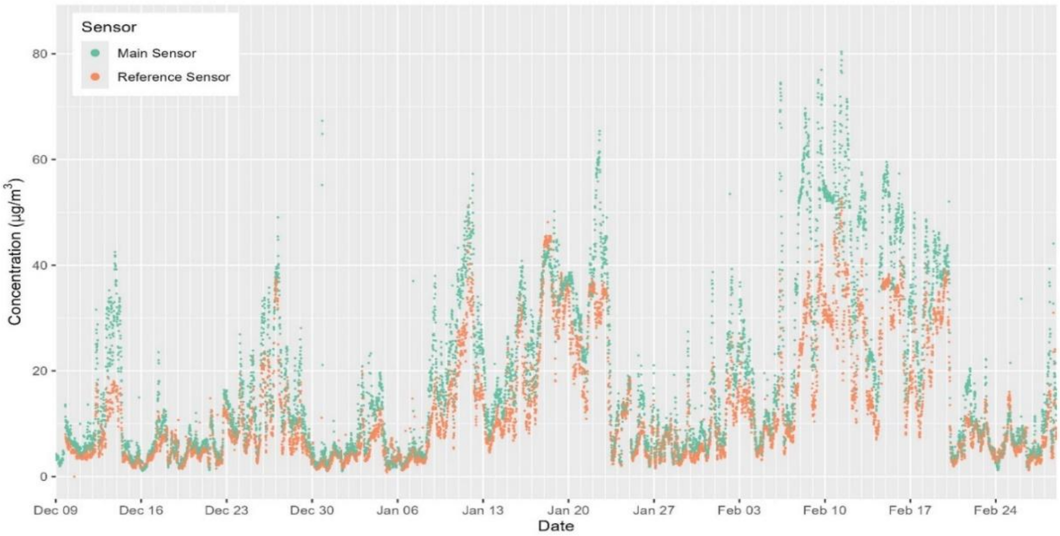

Figure 2: Concentrations of $PM_{2.5}$ measured at the main and reference sensors

PM_{10}

Main and Reference sensor measurements of PM_{10} concentrations are shown in Figure 3, below. As with $PM_{2.5}$, concentrations of PM_{10} showed significant variation throughout the period. Concentrations measured at the main sensor remained higher than the reference sensor for 85% of the study period. Again, the peak concentration measured was around 80 μg/m^3 in early February 2025.

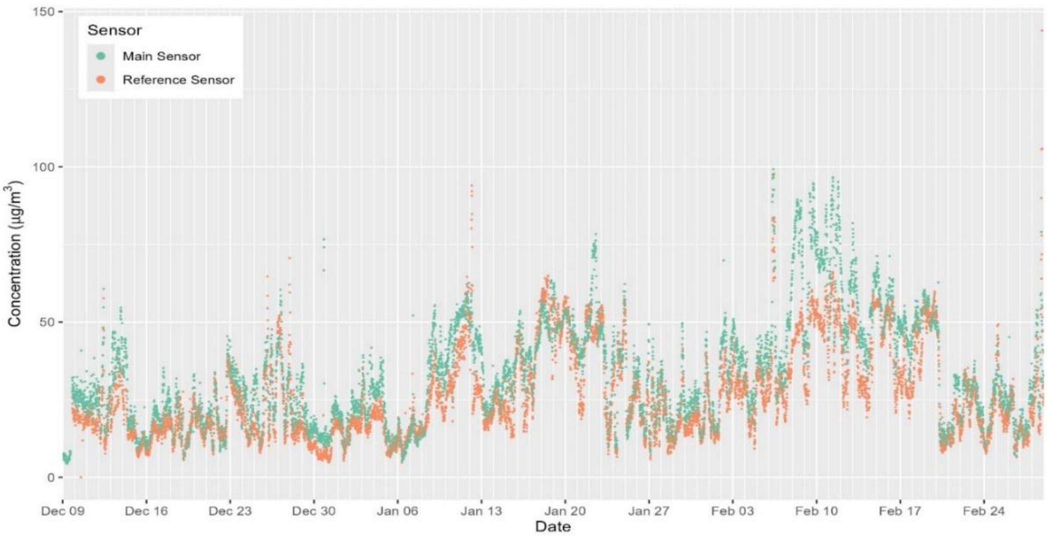

Figure 3: Concentrations of PM_{10} at main and reference sensors

NO_2

Concentrations of NO_2 measured at the Main sensor were higher than the Reference sensor for most (68%) of the study period, however the magnitude of the difference between Main and Reference sensors was less than for either $PM_{2.5}$ or PM_{10}. Fifteen outliers are omitted from Figure 4 to aid readability; they were included in the summary statistics reported in Table 2 and Table 3.

Figure 4: Concentrations of NO_2 measured at the main and reference sensors

CO

As with other pollutants, concentrations of CO measured at the Main sensor were higher than the Reference sensor for the majority (90%) of the study, although the difference was not as large as for the PM (see Figure 5, below). Of note, 31 outliers were removed from the plot to aid interpretation, although these were included in the calculations of summary statistics reported in Table 2 and Table 3.

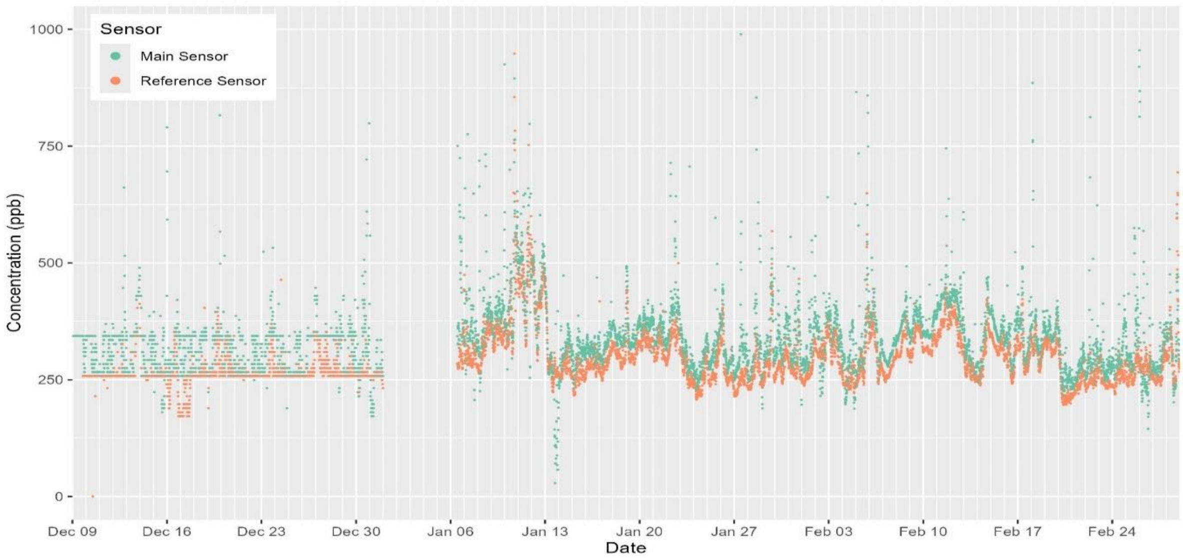

Figure 5: Concentrations of CO at the main and reference sensors

Comparison to DEFRA and WHO Standards

PM2.5

Figure 6, below, shows the daily mean concentrations of $PM_{2.5}$ obtained and compared to the threshold values set out in Table 1. The daily mean concentrations ranged from 2.98 to 70.2 µg/m^3 at the Main sensor, and from 2.42 to 43.8 µg/m^3 at the Reference sensor. This resulted in 22 days where concentrations at the Main sensor breached the WHO's threshold of 15 µg/m^3 and 10 breach days at the Reference sensor.

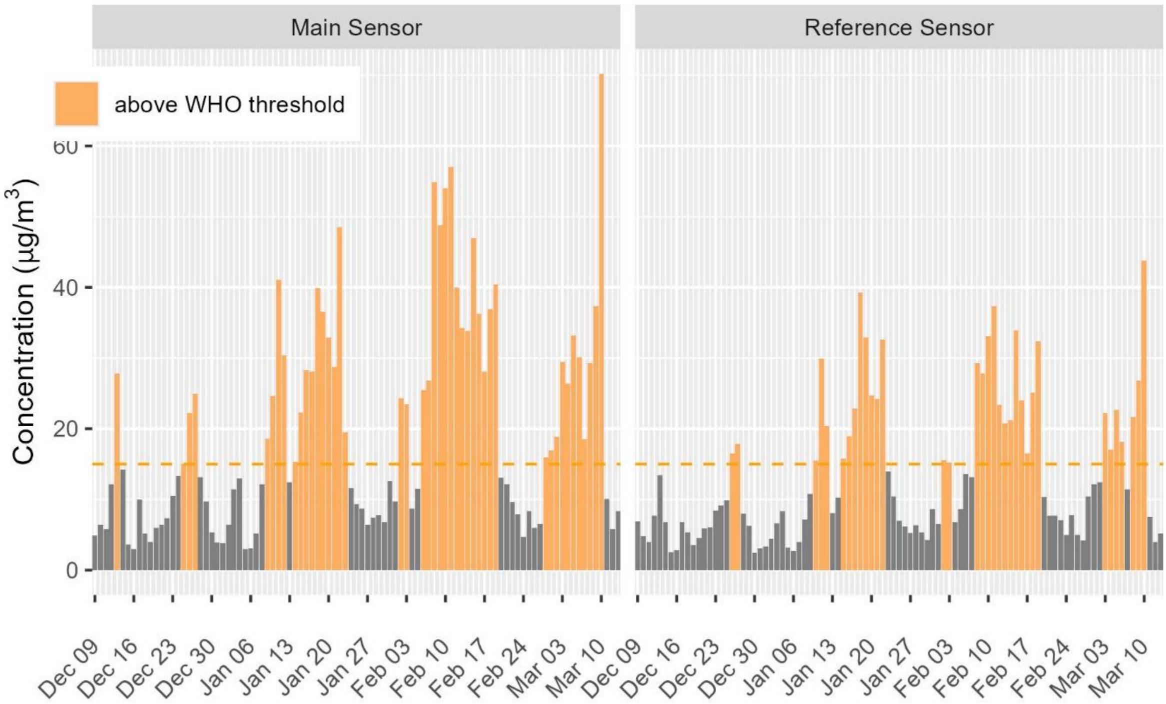

Figure 6: Mean concentrations of PM2.5 observed on each day. Orange bars represent days where the daily mean exceeded the WHO target, whilst DEFRA does not set a daily mean target.

Over the 95 days of data collection, the mean concentration of $PM_{2.5}$ at the Main sensor was 19.56 µg/m^3, just below the legally binding DEFRA annual mean threshold of 20 µg/m^3. At the Reference sensor, the mean concentration of $PM_{2.5}$ was 13.5 µg/m^3, well below the legally binding DEFRA threshold.

The guidance from WHO recommends a much lower annual limit of 5 µg/m^3; this was breached at both sensors.

PM10

Figure 7, below, shows the daily PM_{10} values obtained and compares them to the DEFRA and WHO daily mean thresholds (50 μg/m^3 and 45 μg/m^3 respectively). The daily mean concentrations ranged from 11.0 - 82.7 μg/m^3 at the Main sensor, and from 8.2 - 63.1 μg/m^3 at the Reference sensor.

For recordings at the Main sensor, the legally binding DEFRA threshold was breached on 15 days (16% of the total recording days), whilst the WHO daily threshold was breached on 22 days (23% of the total recording days). It should be noted that the DEFRA legislation makes allowance for up to 36 days where values breach the guidelines in each year. At the Reference sensor the recorded pollutant level breached the DEFRA and WHO thresholds on 7 (7%) and 10 (11%) days, respectively.

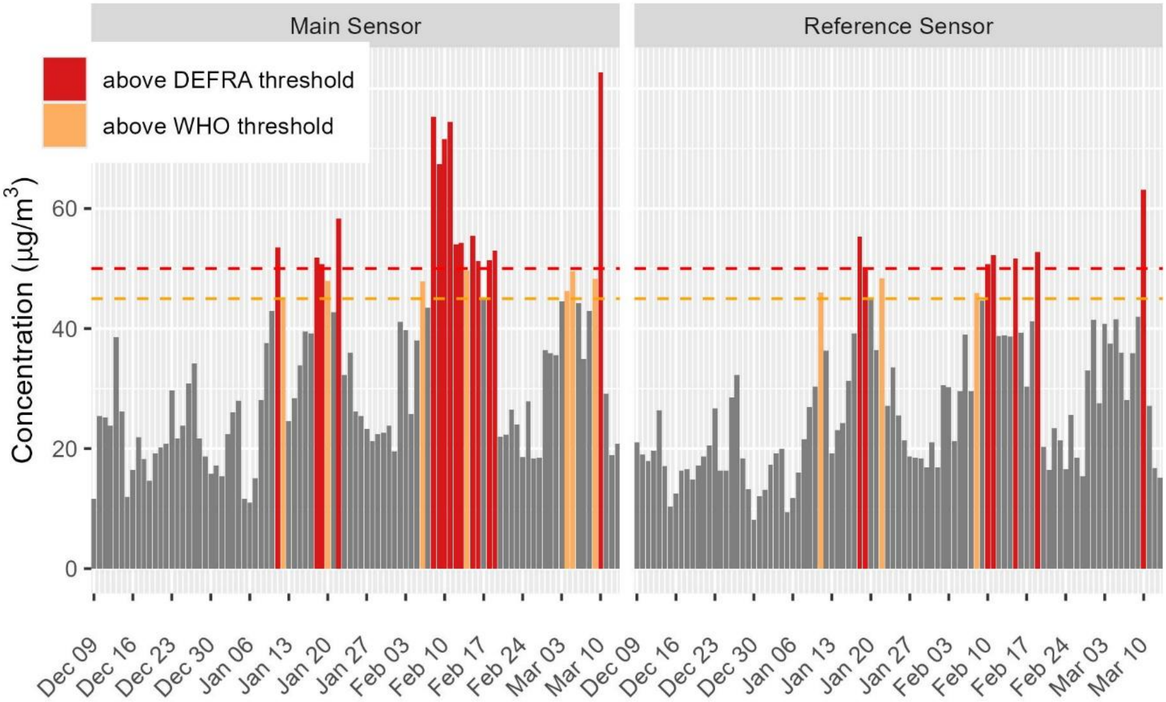

Figure 7: Mean concentrations of PM10 observed on each day. Red bars represent days where the daily mean concentration exceeded the DEFRA target, shown by the red line. Orange bars represent days where the daily mean exceeded the WHO target, but not the DEFRA target, shown by the orange line

The mean concentration of PM_{10} throughout the 95 days where data was collected was 33.8 μg/m^3 at the Main sensor, and 27.8 μg/m^3 at the Reference sensor. They remained below the DEFRA annual mean threshold of 40 μg/m^3, but breached the threshold recommend in WHO guidance of 15 μg/m^3.

NO_2

DEFRA do not set a daily mean threshold of NO_2, instead it provides hourly and annual mean NO_2 thresholds. During the reporting period, DEFRA's hourly mean NO_2 threshold of 200 μg/m^3 was not exceeded at any time.

The daily mean concentration of NO_2 was above the WHO limit of 25 μg/m^3 for all days (100%, n = 90) where data was available at both Main and Reference sensors, as seen in Figure 8, below. Concentrations measured ranged from 41.0 to 80.6 μg/m^3 at the Main sensor and 40.3 to 64.8 μg/m^3 at the Reference Sensor.

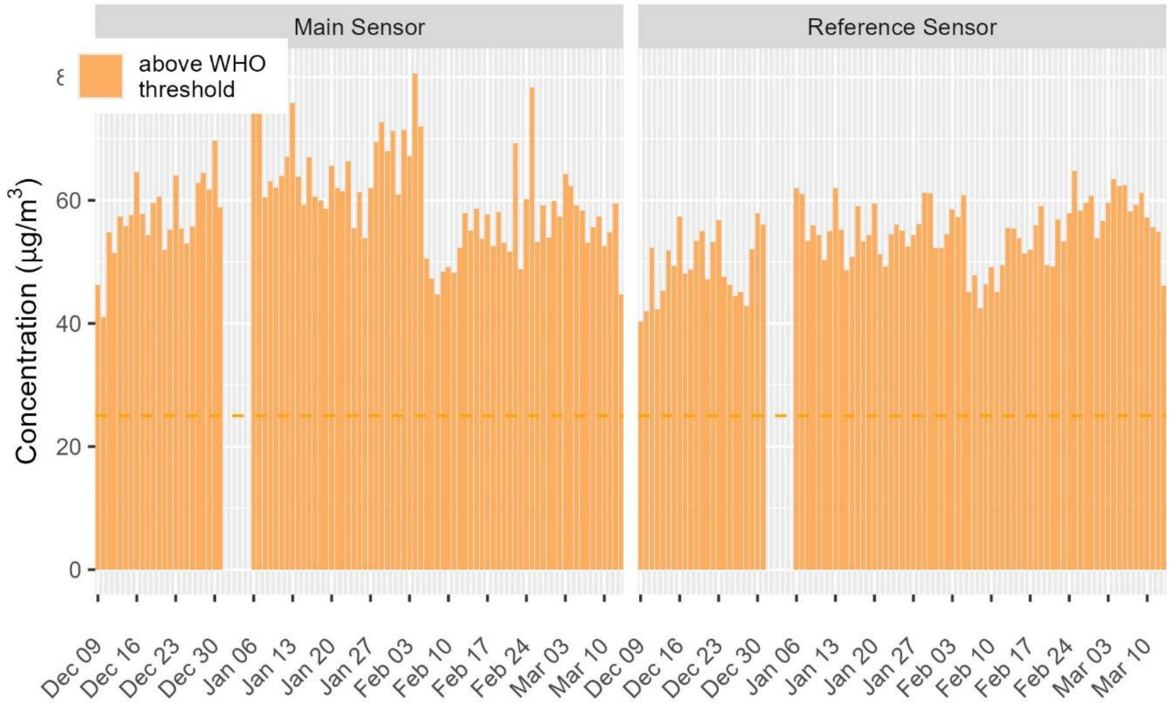

Figure 8: Mean concentrations of NO_2 observed on each day. Orange bars represent days where the daily mean exceeded the WHO target. Data is missing for 5 days at the start of January.

The mean concentrations for the whole study at the Main sensor (59.43 μg/m^3) and Reference sensor (53.79 μg/m^3) were above the annual mean thresholds set by WHO and DEFRA (10 μg/m^3 and 40 μg/m^3 respectively).

CO

CO levels remained below the DEFRA daily mean threshold (10 mg/m^3) and the WHO daily mean threshold (4 mg/m^3) throughout the 90 days of data collection. Daily mean concentrations remained between 0.29 and 0.63 mg/m^3 at the Main sensor and 0.25 and 0.53 mg/m^3 at the Reference sensor; the mean for the whole study was 0.38 mg/m^3 at the Main sensor and 0.33 mg/m^3 at the Reference sensor.

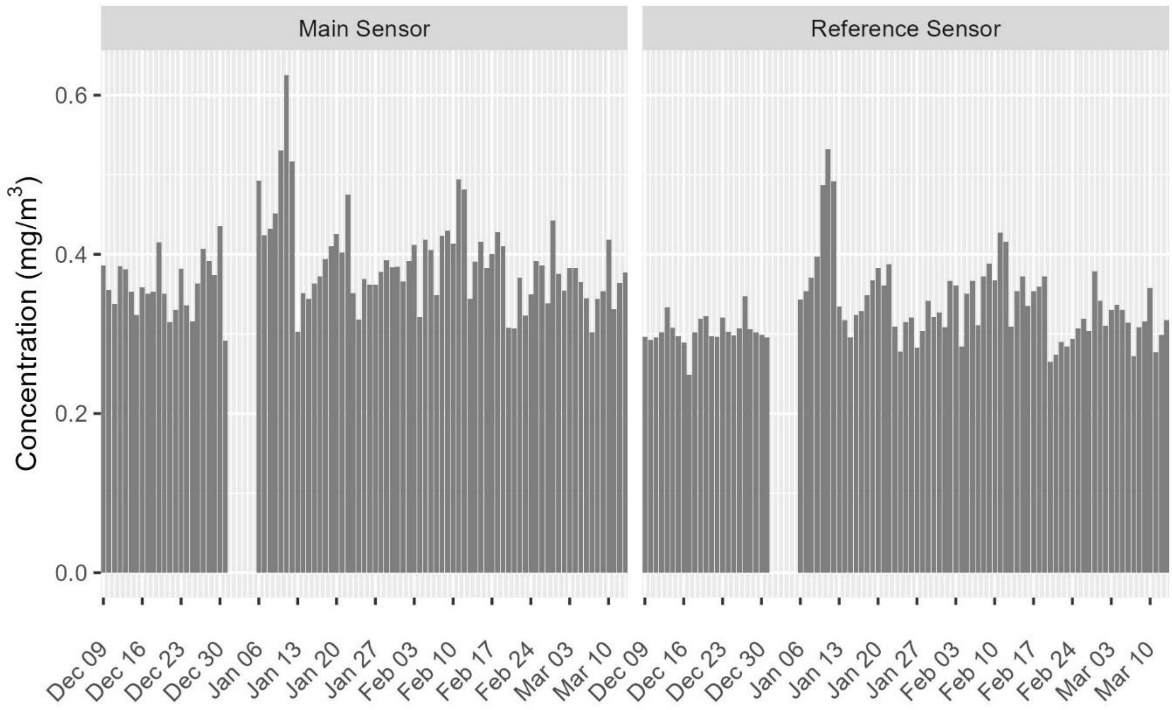

Figure 9: Mean concentrations of CO observed on each day.

Comparison between Main and Reference sensors

As shown above in Table 2, mean concentrations were higher at the Main sensor compared to the Reference sensor for all pollutants, particularly for particulate matter. A paired samples t-test was performed to compare each pollutant at the Main and Reference Sensors, which showed these differences to be statistically significant (Table 4).

	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	NO_2 (ppb)	CO (ppb)
t-value (df)	59.22 (4,477) $p<0.001$	52.16 (4,477) $p<0.001$	28.40 (4,213) $p<0.001$	38.60 (4,212) $p<0.001$

Table 4: Results of paired samples t-test comparing concentrations at the main and reference sensors

To visualise the distribution of the differences between the Main and Reference sensor values, the fractional difference between the concentrations at the sensors was calculated using the formula difference = (Main – Reference)/Main, and the result summarised in Figure 10, below. This shows that all pollutants were higher at the Main sensor for most of the study, but the magnitude of the difference was highest for $PM_{2.5}$.

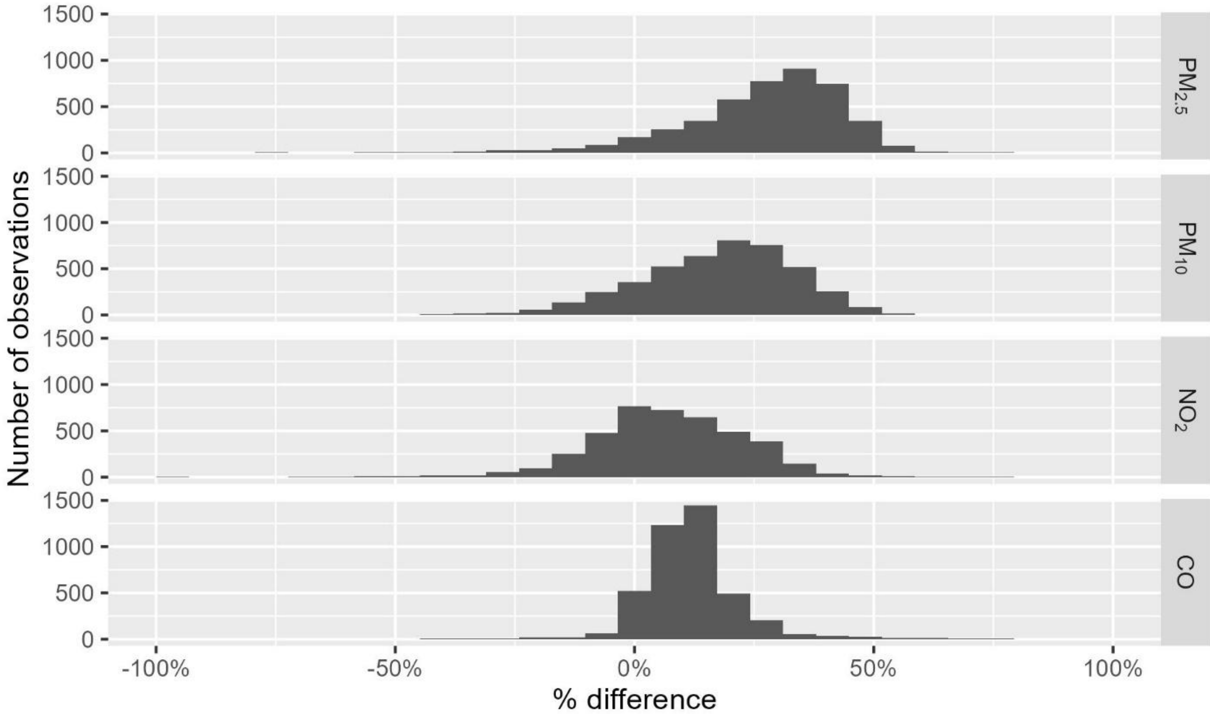

Figure 10: Histogram showing the distribution of percentage differences between the Main and Reference sensors. Values to the right indicate that the Main sensor was larger than the Reference.

Ambulance queue data

The number of vehicles outside CUH ED varied throughout the day, with a maximum of 26 vehicles observed and median of 3 vehicles outside. There were zero ambulances outside the ED for a total of 484 hours (13% of the total study time), and the longest continuous period where the ambulance bay was empty was three hours.

Comparing the time of day and day of week to number of ambulances present outside the ED showed that the lowest average occupancy was between 0500 and 0700 each day of the week. Otherwise, ambulance queuing activity remained consistent through each day (Figure 11, below).

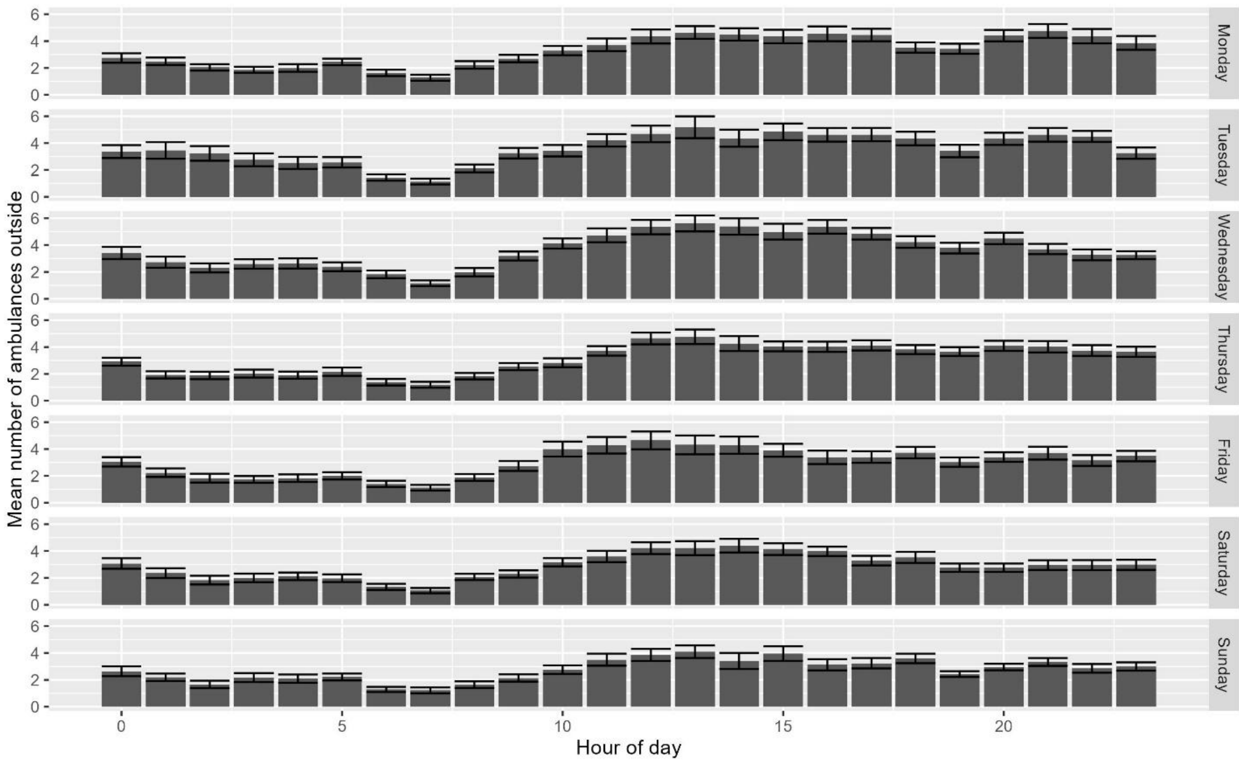

Figure 11: Mean number of ambulances outside ED grouped by hour and day of the week

Comparison between ambulance queue and air quality measurements

The number of ambulances queuing outside ED and the concentration of $PM_{2.5}$, PM_{10}, NO_2 and CO were compared using Spearman's Rank Correlation test. This showed that there was no correlation between the number of ambulances at the hospital and pollutant concentrations (Table 5), with a high degree of confidence in this finding. It is likely that the queue and pollution measurements exhibit more complex time-dependent relationships, but the scale of that analysis was beyond the scope of MAPA Pilot.

Pollutant	**Main Sensor**		**Reference Sensor**	
	Spearman's test Statistic	P - value	Spearman's test Statistic	P – value
$PM_{2.5}$	-0.23	2.2×10^{-16}	-0.21	2.2×10^{-16}
PM_{10}	-0.22	2.2×10^{-16}	-0.21	2.2×10^{-16}
NO_2	0.42	2.2×10^{-16}	0.13	2.2×10^{-16}
CO	0.06	1.1×10^{-4}	0.02	0.172

Table 5: Correlation between ambulance queue and pollution concentrations

Workstream 2: In-Ambulance Air Quality Monitoring

A total of 108 work shifts produced data that contributed to the results that follow. On occasion, data were not downloaded by the ambulance staff at the end of a shift for a variety of reasons, including lack of time available after finishing work or a sensor not recording data as intended. As a result, the number of shifts where data is available is different for each phase of ambulance activity. On several occasions, the concentration of PM measured exceeded 1000 µg/m^3. This is the greatest concentration the Atmotube Pro device can measure, therefore when this number is reported, actual PM concentration may have exceeded this value.

Table 6 and Table 7, below, summarise the mean, SD and peak concentrations for the pollutants of interest (PM_1, $PM_{2.5}$, PM_{10}, VOCs and CO), as recorded in the front and back of ambulances, along with selected average meteorological variables. Of note, the range of pollutant concentrations varied a long way from the mean, with peak concentrations of PM exceeding the device's measurement ability.

	PM_1 (µg/m^3)	**$PM_{2.5}$ (µg/m^3)**	**PM_{10} (µg/m^3)**	**VOCs (ppm)**	**CO (ppm)**	**Temperature (° C)**	**Humidity (%)**	**Pressure (mbar)**
Day (*n*=88 shifts)								
Mean	6.6	8.5	10.0	0.326	0	20	33	1016
SD	7.7	8.1	8.3	0.207	0	2	7	15
Peak	1000*	1000*	1000*	8.498	34	34	66	1040
Night (*n*=74 shifts)								
Mean	8.3	10.6	12.4	0.277	0	19	33	1014
SD	8.5	9.5	10.0	0.230	1	4	7	15
Peak	371.0	781.0	1000*	2.966	7	36	64	1040

*Table 6: Mean, standard deviation (SD) and peak concentrations of PM_1, $PM_{2.5}$, PM_{10}, VOCs and CO in the **front** of the ambulances, including selected mean meteorological variables.*

	PM_1 (µg/m^3)	**$PM_{2.5}$ (µg/m^3)**	**PM_{10} (µg/m^3)**	**VOCs (ppm)**	**CO (ppm)**	**Temperature (° C)**	**Humidity (%)**	**Pressure (mbar)**
Day (*n*=87 shifts)								
Mean	6.9	8.8	10.4	0.605	0	18	38	1016
SD	8.3	9.3	9.9	0.691	1	3	7	15
Peak	1000*	1000*	1000*	21.836	19	32	80	1041
Night (*n*=73 shifts)								
Mean	8.0	10.0	11.6	0.538	0	18	36	1014
SD	12.3	13.5	14.0	0.433	1	4	7	14
Peak	463.0	493.0	508.0	8.864	10	39	78	1044

*Table 7: Mean, standard deviation (SD) and peak concentrations of PM1, PM2.5, PM10, VOCs and CO in the **back** of the ambulances, including selected mean meteorological variables.*

Table 8 and Table 9 summarise the mean, SD and peak concentrations for the pollutants of interest, as recorded in the front and back of ambulances whilst at hospital. Ambulance crews were not certain to visit hospital during their shift; there were 188 hospital attendances during day shift hours, and 85 hospital attendances during night shift hours.

	PM_1 (μg/m³)	**$PM_{2.5}$ (μg/m³)**	**PM_{10} (μg/m³)**	**VOCs (ppm)**	**CO (ppm)**	**Temperature (° C)**	**Humidity (%)**	**Pressure (mbar)**
Day (*n*=77 shifts, *n*=188 hospital visits)								
Mean	6.1	7.9	9.5	0.321	0	20	31	1018
SD	7.8	8.4	8.6	0.333	1	3	7	13
Peak	181.0	196.0	205.0	5.766	12	34	60	1037
Night (*n*=35 shifts, *n*=85 hospital visits)								
Mean	10.6	13.4	15.4	0.295	0	20	31	1015
SD	16.5	17.7	18.0	0.259	0	3	7	13
Peak	153.0	165.0	168.0	1.312	3	28	64	1035

*Table 8: Mean, standard deviation (SD) and peak concentrations of PM1, PM2.5, PM10, VOCs and CO in the **front** of the ambulances, including selected mean meteorological variables, **whilst at hospital**.*

	PM_1 (μg/m³)	**$PM_{2.5}$ (μg/m³)**	**PM_{10} (μg/m³)**	**VOCs (ppm)**	**CO (ppm)**	**Temperature (° C)**	**Humidity (%)**	**Pressure (mbar)**
Day (*n*=77 shifts, *n*=188 hospital visits)								
Mean	6.5	8.5	10.1	0.650	0	19	36	1018
SD	10.3	11.8	12.9	0.799	1	4	8	13
Peak	710.0	853.0	945.0	21.836	3	32	70	1039
Night (*n*=35 shifts, *n*=85 hospital visits)								
Mean	9.1	11.3	12.9	0.557	0	19	36	1014
SD	11.3	12.2	12.6	0.613	1	4	7	13
Peak	110.0	155.0	201.0	5.577	5	31	57	1043

*Table 9: Mean, standard deviation (SD) and peak concentrations of PM1, PM2.5, PM10, VOCs and CO in the **back** of the ambulances, including selected mean meteorological variables, **whilst at hospital**.*

Table 10 and Table 11 summarise the mean, SD and peak concentrations for the pollutants of interest, as recorded in the front and back of ambulances whilst travelling, along with selected average meteorological variables.

	PM_1 (μg/m³)	$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	VOCs (ppm)	CO (ppm)	Temperature (° C)	Humidity (%)	Pressure (mbar)
Day (*n*=80 shifts, *n*=290 travelling statuses)								
Mean	6.9	8.7	10.2	0.267	0	20	34	1017
SD	9.1	10.0	10.4	0.241	0	3	8	14
Peak	330.0	372.0	401.0	2.150	5	31	61	1040
Night (*n*=42 shifts, *n*=145 travelling statuses)								
Mean	8.4	10.8	12.7	0.298	0	20	32	1014
SD	8.2	9.0	9.5	0.286	1	4	8	14
Peak	76.0	82.0	82.0	2.784	4	34	62	1039

*Table 10: Mean, standard deviation (SD) and peak concentrations of PM1, PM2.5, PM10, VOCs and CO in the **front** of the ambulances, including selected mean meteorological variables, **whilst travelling**.*

	PM_1 (μg/m³)	$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	VOCs (ppm)	CO (ppm)	Temperature (° C)	Humidity (%)	Pressure (mbar)
Day (*n*=80 shifts, *n*=290 travelling statuses)								
Mean	6.8	8.6	10.2	0.429	0	18	38	1017
SD	16.1	17.8	18.6	0.542	0	4	9	14
Peak	579.0	632.0	655.0	4.860	6	31	72	1041
Night (*n*=41 shifts, *n*=141 travelling statuses)								
Mean	5.7	7.5	9.0	0.395	0	19	35	1014
SD	5.3	5.9	6.1	0.397	1	4	8	13
Peak	55.0	60.0	62.0	3.439	5	35	58	1043

*Table 11: Mean, standard deviation (SD) and peak concentrations of PM1, PM2.5, PM10, VOCs and CO in the **back** of the ambulances, including selected mean meteorological variables, **whilst travelling**.*

Table 11 and Table 12 summarise the mean, SD and peak concentrations for the pollutants of interest, as recorded in the front and back of ambulances in the last 10 minutes of meal-break, along with selected average meteorological variables. This period was chosen as representative of the environmental conditions in the ambulance station garage area, where make-ready and other support staff work.

	PM_1 (µg/m³)	**$PM_{2.5}$ (µg/m³)**	**PM_{10} (µg/m³)**	**VOCs (ppm)**	**CO (ppm)**	**Temperature (° C)**	**Humidity (%)**	**Pressure (mbar)**
				Day (*n*=67 shifts)				
Mean	7.2	9.0	10.6	0.278	0	19	35	1017
SD	11.7	12.5	12.7	0.251	0	3	7	14
Peak	179.0	193.0	200.0	1.725	1	27	58	1036
				Night (*n*=29 shifts)				
Mean	13.2	16.2	18.3	0.233	0	20	30	1014
SD	19.6	20.7	20.6	0.155	0	5	9	14
Peak	77.0	83.0	84.0	0.774	2	28	49	1034

*Table 12: Mean, standard deviation (SD) and peak concentrations of PM1, PM2.5, PM10, VOCs and CO in the **front** of the ambulances, including selected mean meteorological variables, **whilst on meal break**.*

	PM_1 (µg/m³)	**$PM_{2.5}$ (µg/m³)**	**PM_{10} (µg/m³)**	**VOCs (ppm)**	**CO (ppm)**	**Temperature (° C)**	**Humidity (%)**	**Pressure (mbar)**
				Day (*n*=67 shifts)				
Mean	4.6	6.2	7.7	0.390	0	18	38	1017
SD	5.6	6.5	6.9	0.293	0	5	9	14
Peak	99.0	109.0	114.0	1.328	3	31	63	1037
				Night (*n*=28 shifts)				
Mean	9.5	11.4	12.9	0.464	1	20	33	1015
SD	14.8	15.9	16.2	0.484	2	7	10	13
Peak	68.6	74.2	76.1	1.886	6	32	56	1042

*Table 13: Mean, standard deviation (SD) and peak concentrations of PM1, PM2.5, PM10, VOCs and CO in the **back** of the ambulances, including selected mean meteorological variables, **whilst on meal break***

Comparison to DEFRA and WHO standards

Figure 12, below, shows mean concentrations of $PM_{2.5}$ during various phases of the ambulance shift. In one phase (the final 10 minutes of a meal break at the front of the ambulance at night) mean $PM_{2.5}$ concentrations were 16.2 μg/m^3, exceeding the WHO's 2021 24-hour Air Quality Guideline (AQG) threshold of 15 μg/m^3. Another night-time measurement (at the front of the ambulance while at the hospital) reached 13.4 μg/m^3, just below the threshold. However, if we consider the total number of shifts as a reasonable representation of typical, prolonged exposure inside the ambulance, then comparison to an annual threshold may be more applicable. In this context, all scenarios (range of 6.2 to 16.2 μg/m^3) exceeded the WHO's annual threshold of 5 μg/m^3.

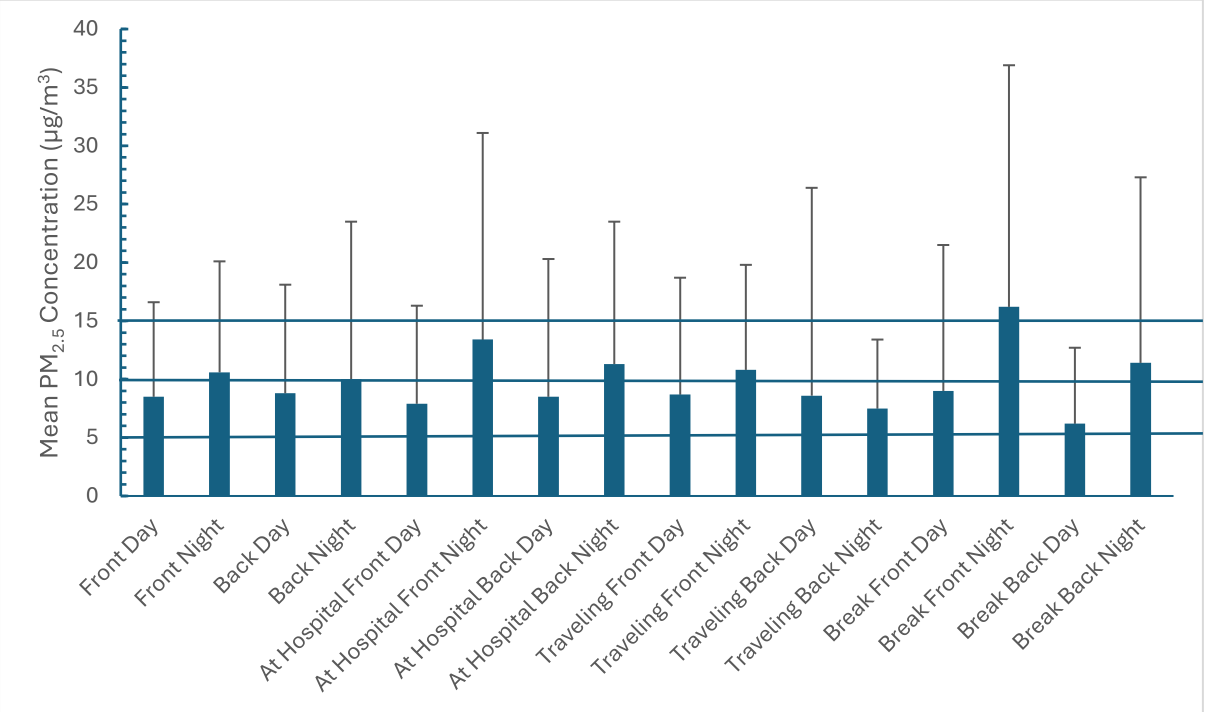

Figure 12: Mean concentrations of $PM_{2.5}$ for all scenarios in the front and back of ambulances. Error bars represent standard deviation of the mean. Horizontal threshold reference lines are added at 5 μg/m^3 and 15 μg/m^3 for the 2021 World Health Organisation's annual and 24-hour $PM_{2.5}$ threshold levels respectively, and at 10 μg/m^3 for the UK Government's Environment Act 2021 target for annual mean concentration to be met by the year 2040

For PM_{10}, neither DEFRA, nor WHO daily mean thresholds (50 μg/m^3 and 45 μg/m^3 respectively), were breached. The highest concentration was recorded during the final 10 minutes of a meal break at the front of the ambulance at night (18.3 μg/m^3). Additionally, a concentration of 15.4 μg/m^3 was measured in the back of the ambulance while waiting at the hospital during the daytime. Using the same reasoning as with $PM_{2.5}$

and comparing against WHO's more stringent annual threshold of 15 µg/m^3, the limit was exceeded during these two activity phases.

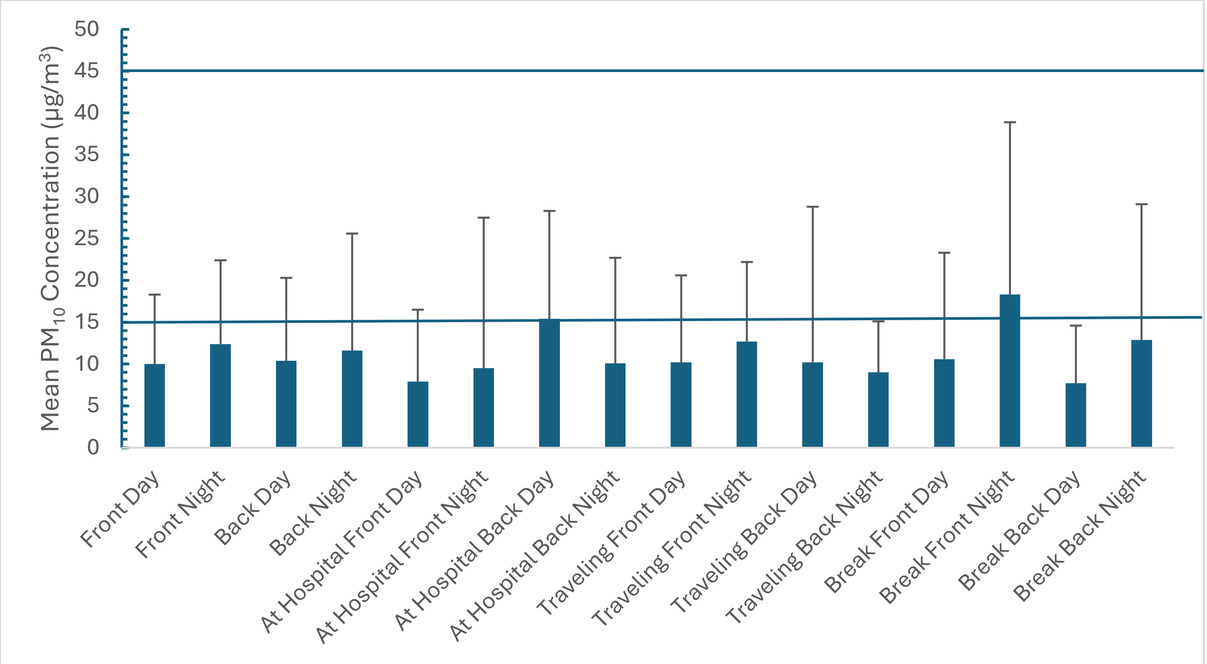

Figure 13: Mean concentrations of PM10 for all scenarios in the front and back of ambulances. Error bars represent standard deviation of the mean. Horizontal threshold reference lines are added at 15 µg/m^3 and 45 µg/m^3 for the 2021 World Health Organisation's annual and 24-hour PM10 threshold levels respectively.

In all cases but one, the mean concentration of CO was zero when rounded to a whole number. This is reflective of 12-hours of data being summarised to a single average value. However, a mean concentration of 1 ppm (or 1.15 mg/m^3) was recorded during the final 10 minutes of a meal break at the back of the ambulance at night.

Comparison between Workstream 1 and Workstream 2 (Ambulance Bay Monitoring vs In-Ambulance Monitoring)

One of the aims of MAPA Pilot was to inform future modes of air quality measurement in the ambulance environment. Data from Workstream 2 with the status 'At Hospital' at CUH was filtered and compared with Workstream 1 data collected from the Main reference sensor. This was, by its nature, quite a sparse dataset as shown using the example of PM_{10} in Figure 14, below, but still offers valuable insight into the consistency between the measurements taken inside and outside the ambulances.

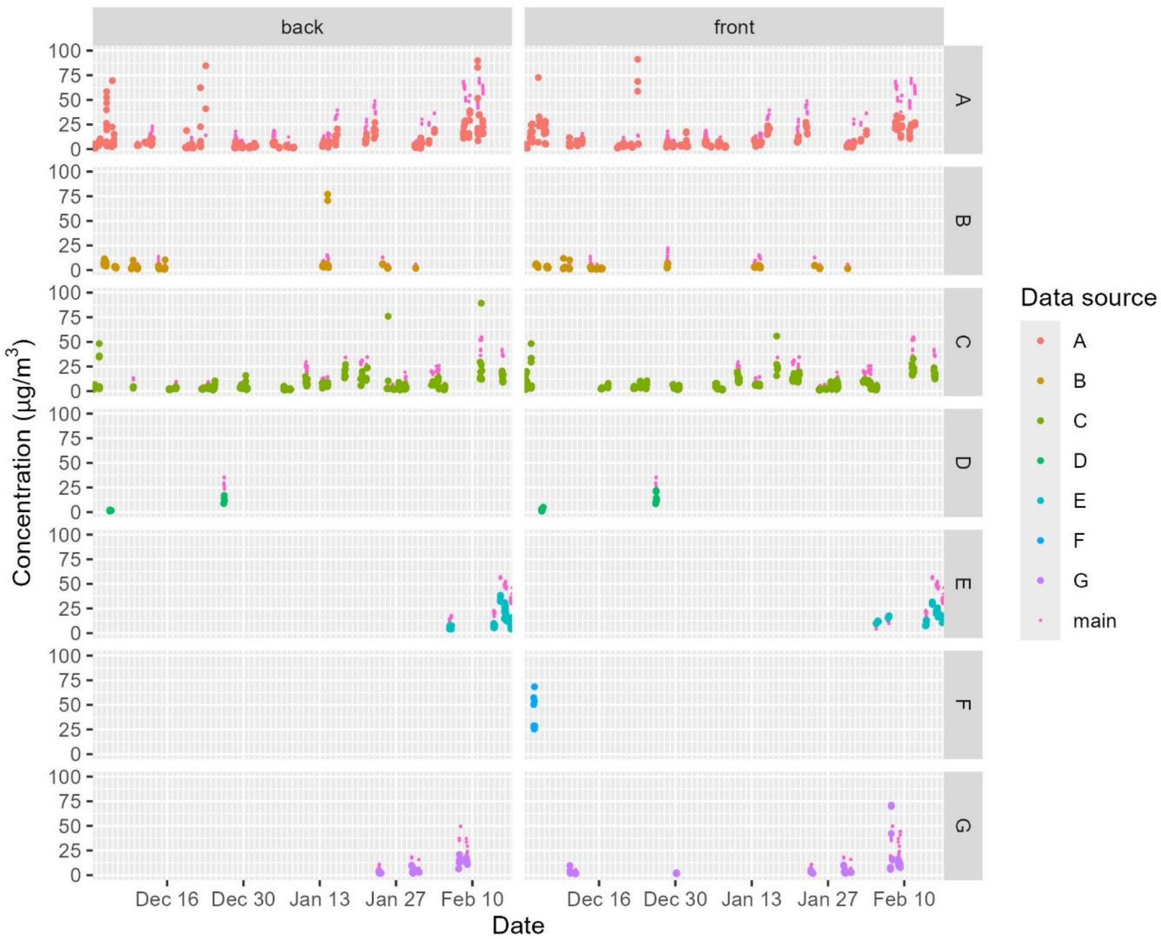

Figure 14: Concentrations of PM_{10} measured by staff (A - G) whilst they were outside CUH ED with comparison to the concentrations measured at the main sensor. NB: volunteer F withdrew after one day, however their data is included here.

Bland-Altman analysis[11] and ICC estimates[10] with 95% confidence intervals were calculated based on a mean-rating (k = 2), absolute-agreement, 2-way mixed-effects model. ICC values below 0.5 suggest poor reliability, those between 0.5 and 0.75 indicate moderate reliability, values falling between 0.75 and 0.9 indicate good reliability, and any value exceeding 0.9 demonstrates excellent reliability[16]. CO data was excluded from comparisons as the in-ambulance monitoring reported mean concentrations of CO as zero.

Data from both WS1 and WS2 contained some extremely high outlying values that skewed comparisons away from the mean. For the purposes of comparing results in the ambulance at the Main sensor, observations more than 3 standard deviations from the mean were removed. As described in Table 14, below, there was mixed agreement between the measurements in the ambulance and at the Main Sensor. For $PM_{2.5}$ the ICC scores show moderate reliability, albeit with wide confidence intervals, whilst for PM_{10} the ICC shows poor reliability with confidence intervals that cross 0.

Pollutant	**Sensor location**	**Data points**	**Ambulance Sensor Mean ± SD** μg/m³	**Main Sensor Mean ± SD** μg/m³	**ICC (95%CI lower bound, upper bound)**
$PM_{2.5}$	Front	812 (150 na, 30 outliers)	6.91 ± 6.19	13.4 ± 13.2	0.72 (0.25, 0.88)
$PM_{2.5}$	Back	749 (143 na / 50 outliers)	7.12 ± 11.1	13.6 ± 13.2	0.63 (0.37, 0.76)
PM_{10}	Front	806 (150 na / 36 outliers)	8.38 ± 6.43	25.9 ± 14.0	0.41 (-0.25, 0.75)
PM_{10}	Back	744 (143 na / 55 outliers)	8.20 ± 10.5	26.0 ± 14.2	0.37 (-0.31, 0.70)

Table 14: ICC values for $PM_{2.5}$ and PM_{10}. Data points report the number of data points used in analysis; na = points where one sensor did not record data, outliers (points more than 3 sd from the mean) were removed

Bland-Altman plots show the mean of each measurement for $PM_{2.5}$ and PM_{10} measured in the front and back of the vehicle against the bias score. Regression analysis found $P < 0.05$ in all cases, although correlation values (r) from the simple linear regression are not reported as this is not recommended for assessing comparability between two sets of data and can provide misleading results[12, 13](Giavarina, 2015; Doğan, 2018). As advised by Ludbrook[11] a $\log_{10}$ transformation was applied before creating the Bland-Altman plots.

Figure 15, below, shows these results for $PM_{2.5}$ in the front of the ambulance (bias score; 95% CI) -0.25; -0.76 to 0.26) and $PM_{2.5}$ in the back of the ambulance (-0.31; -0.85 to 0.22). Effectively, this reveals that the measurements in the front of the ambulance were a closer match to the Main sensor than those at the back of the ambulance.

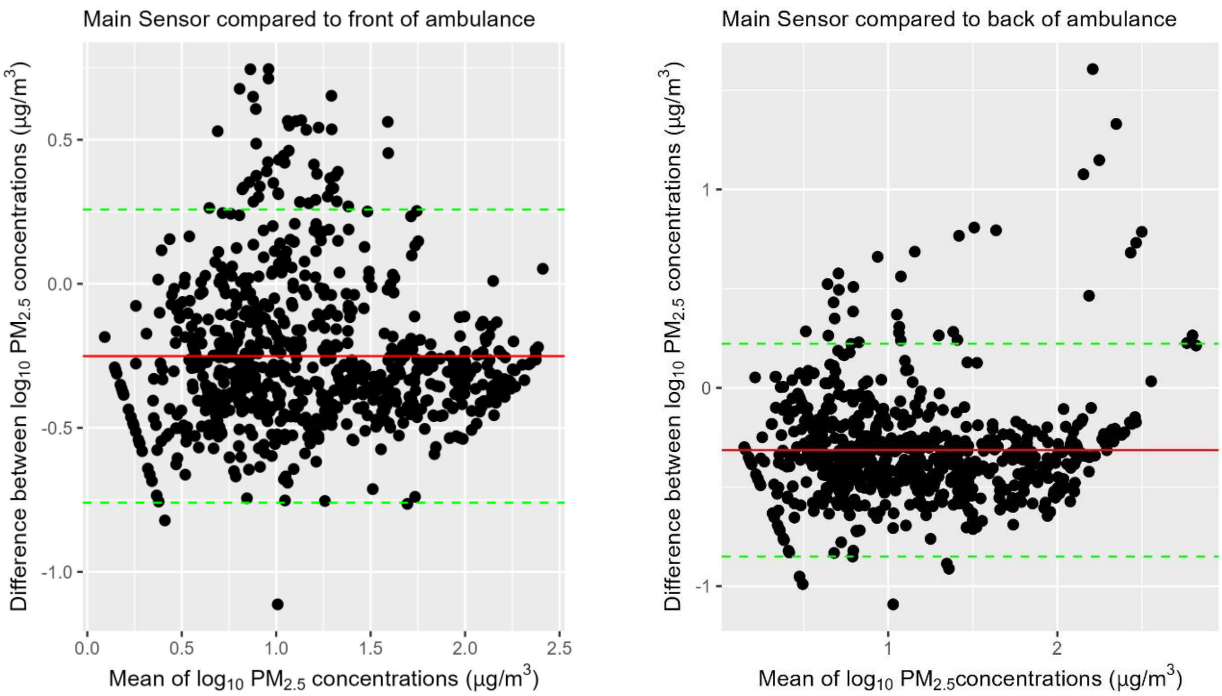

Figure 15: Bland Altman plot comparing $PM_{2.5}$ concentrations when measured in the front / back of the ambulance with the concentrations measured at the Main Sensor. Red line represents the bias score, the green lines represent the 95% confidence interval

Figure 16, below, shows the Bland-Altman plot comparing PM_{10} measured at the Main sensor with PM_{10} in the front of the ambulance (-0.53; -0.95 to -0.12) and PM_{10} in the back of the ambulance (-0.58; -1.03 to -0.14). This time, the analysis revealed that there was a closer match between the Main sensor and the back of the ambulance than between the Main sensor and the front of the ambulance.

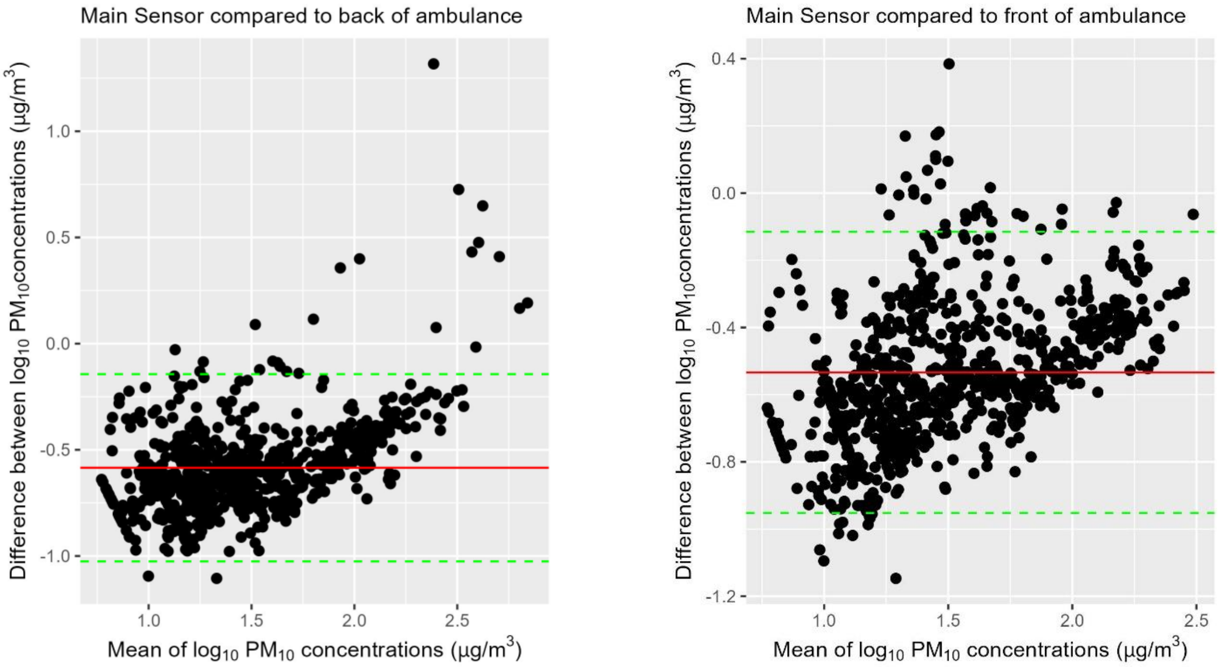

Figure 16: Bland Altman plot comparing PM_{10} concentrations when measured in the front / back of the ambulance with the concentrations measured at the Main Sensor. Red line represents the bias score, the green lines represent the 95% confidence interval

This analysis showed that measurements of $PM_{2.5}$ and PM_{10} were broadly similar when measured using the different devices in WS1 and WS2.

Staff feedback

All six of the staff participating throughout Workstream 2 provided feedback by completing a survey. The participants all gave similar feedback: they found the study important but highlighted significant challenges with data uploading. The process was time-consuming - largely due to slow computers and a cumbersome upload method which resulted in delays after shifts. Charging the Atmotube was inconvenient, especially during back-to-back shifts with limited plug sockets. While Atmotubes were relatively easy to use, the Dräger units were more difficult, with data downloading and sending being particularly tedious. To improve future use, participants suggested batch downloading data weekly and enabling uploads via an app. Some preferred the option to complete data uploads from home for a more relaxed experience.

Workstream 3: Staff CO Oximetry Measurements

A total of 160 measurements of CO saturations % were recorded on 9 different days during the study period. Participants gave some basic demographic information and reported their smoking status and respiratory health. The majority of participants were ambulance staff, and smokers were in a minority as shown in Table 15, below.

Age	Minimum	19
	Mean	36.5
	Standard Deviation	12.5
	Maximum	69
Staff types	CUH Staff (ED)	9
	CUH Staff (non-ED)	2
	Ambulance staff	149
Smoking status	Non-smoker	112
	Cigarettes	6
	Vape	35
	Vape & Cigarettes	7
Respiratory Health	No respiratory Conditions	143
	Asthma	14
	Other Respiratory Condition	1
	No answer	2

Table 15: Demographics of staff included in WS3

There were no incidences of CO saturations above the level of clinical significance (10%) and only 15 participants had CO saturations above 5%. The maximum time that a participant had spent in the ambulance bay was 10 hours. Of smokers, it was generally several hours since they had last smoked or vaped, as summarised in Table 16, below.

	CO Saturation (%)	**Time in ambulance bay (hours)**	**Time since last smoked / vaped (hours)**
Mean	2.5	2.6	5.79
SD	1.57	1.81	12.5
Maximum	8	10	72

Table 16: CO Saturation of participants in WS3

Before measuring CO saturations, participants reported on any new symptoms that had developed since arriving in the ambulance bay. Since none of the CO saturations measured were above a clinical threshold, clearly these symptoms were unrelated to acute CO poisoning. However, about a fifth (19%) of staff reported symptoms that started whilst in the ambulance bay. The most common symptoms were headache, fatigue and back pain as summarised in Table 17, below.

Number of different symptoms reported (n)	No symptoms	129
	One symptom	15
	Two symptoms	10
	Three Symptoms	4
	Four Symptoms	2
Symptoms reported (n)	Cough	2
	Dizziness	3
	Muscle Ache	6
	Back Pain	10
	Fatigue	14
	Headache	20

Table 17: Symptoms reported by participants.

Comparison to Ambulance Bay Monitoring

The study aimed to assess the impacts of CO exposure on ambulance staff by measuring their CO saturations. However, atmospheric CO data were only available for 5 of the 9 days during which CO saturations were collected (66 participants) due to the Main sensor data being compromised for one week. Pearson's product-moment correlation test was performed between the CO saturations measured in staff and those measured at the Main sensor. This showed small positive correlation ($r = 0.23$, 95% CI 0.03 – 0.42), however due to the small sample sizes it was not possible to comment on differences between subgroups.

Discussion

MAPA Pilot aimed to provide evidence to inform the need for further investigations into air quality in ambulance bays outside EDs. Workstream1 study results revealed higher concentrations of key air pollutants in the vicinity of one ambulance bay at one ED, described as a courtyard with partial canopy design. However, air pollution was observed at the Reference sensor, not just in the ambulance bay, showing that the air quality was not uniquely associated with ambulance activities.

The concentrations of all pollutants recorded at the Main sensor were higher than the Reference sensor, and this difference was statistically significant. The difference between the Main and Reference Sensor concentrations was higher for $PM_{2.5}$ and PM_{10} than for CO or NO_2. PM particles are heavy and tend to diffuse more slowly than gasses, so it is reasonable to presume they remain closer to the source of pollution for longer.

Workstream 2 results showed that in the ambulance, $PM_{2.5}$ concentrations were above the mean annual thresholds given by DEFRA and WHO, with other key pollutants showing peak values that may be of concern. In-ambulance monitoring provided information about the occupational exposure of ambulance staff, but did not consistently provide data on air pollution outside the ED of interest.

High peak concentrations of CO and PM were observed in the ambulances, in the same manner as similar studies conducted in taxis[14]. These peak concentrations were not observed at the Main sensor. It was beyond the scope of MAPA Pilot to fully investigate the source of these high values which therefore warrants further work.

The CO sensors in the ambulance bays measured concentrations in parts per billion, whilst the sensors used in ambulances measured in parts per million. This meant that the sensors used in WS1 were able to detect lower concentrations of CO (mean of 332 ppb) than those in WS2 (which registered as zero). Further work could consider using more sensitive mobile CO monitors.

Health Considerations

There has been a significant increase in evidence on the harmful health effects of air pollution, driven by advances in measurement techniques, exposure assessment, and a growing global database of air quality data[15]. Recent epidemiological studies have shown that even low levels of air pollution typical of high-income countries can negatively affect health, with adverse effects observed at concentrations lower than previously studied.

Particulate Matter can be absorbed in the lungs, causing irritation, respiratory diseases, blood pressure and cardiovascular effects. Toxicological studies indicate that PM_1 may pose greater risks than $PM_{2.5}$ in terms of cytotoxicity and inflammation[16]. However, current epidemiological evidence shows that PM_1 and $PM_{2.5}$ are similarly associated with adverse health outcomes, including cardiovascular disease, stroke, and respiratory conditions[17]. Standalone reference values, limits or thresholds do not currently exist for PM_1, therefore comparisons against benchmarks were not possible, although data on PM_1 concentrations was collected in WS2. NO_2 can have effects on blood pressure and cardiovascular systems; it has also been associated with increased mortality at the population level.

In WS1, daily levels of air pollution were recorded above the existing DEFRA legislation and WHO guidance thresholds for $PM_{2.5}$, PM_{10} and NO_2. However, most ambulance staff do not spend the whole of their shift in the ambulance bay. The WS2 data followed the staff exposure and did not show such high mean concentrations of pollutants, indicating that for most ambulance staff, the impact is not as high as first appears. Some ambulance staff work in the ambulance bay permanently, and further investigation into their exposure is warranted. For instance, a Hospital Ambulance Liaison Officer is responsible for managing the flow of patients in the queue outside an ED so they will spend 12-hour shifts in the ambulance bay and triage area of the ED.

Patients are not expected to repeatedly attend the ED, so should not be subjected to repeated exposure. The effects of an unwell patient being exposed to the levels of air pollution measured in the study are not clear and would benefit from further research.

Peak Concentrations

Of particular interest - especially given the physiological effects of acute exposure to CO - were the elevated peak concentrations observed in all phases of ambulance activity. In WS2, peak concentrations of CO reached 34 ppm (39.1 mg/m^3) in the front of the ambulance, and 19 ppm (21.85 mg/m^3) in the back of the ambulance (Table 6 and Table 7, above). Additionally, a peak concentration of 12 ppm (13.8 mg/m^3) was recorded in the front of the ambulance while waiting at ED during the day (Table 8, above). Further analysis is needed to determine the concentration profile surrounding those peak values.

A similar pattern was observed for $PM_{2.5}$ and PM_{10}, where very high peak concentrations were seen in the front and back of ambulances, both when waiting outside ED, and whilst travelling. Peak concentrations of 300 µg/m^3 are comparable to the highest concentrations reported during severe haze events in Beijing, China, more than ten years ago[18]. The Atmotube Pro device has an upper measurement limit of 1000 µg/m^3, therefore when this number is reported in Table 6 and Table 7, above, actual PM concentration may have exceeded this value. Notably, measurements in the 900's were recorded immediately before and after the 1000 µg/m^3 measurements, suggesting that true peak concentrations had indeed exceeded 1000 µg/m^3, albeit for a short period.

The artificial flattening of peak values may also have lowered the mean average concentrations reported.

In WS1, concentrations varied rapidly over time, but extreme peaks were not observed. PM_{10} levels, for example, peaked at 143 μg/m^3 (measured at the Reference sensor). Before drawing meaningful conclusions with all peak concentration values, further analysis is warranted to determine the profile of concentrations around those peak values to better understand their potential effect on human physiology.

Volatile Organic Compounds

Data on volatile organic compounds (VOCs) was collected in the in-ambulance monitoring, however comparison to any reference values was not attempted. The health effects of VOCs vary depending on the specific compound, its concentration, duration of exposure, and individual sensitivity. Since VOCs encompass a wide range of chemicals, there is no universal exposure threshold. However, indoor air quality research provides general guidance: concentrations below 300 μg/m^3 are typically considered safe, with health effects observed at higher concentrations.

Converting VOC concentrations from μg/m^3 to ppm (parts per million), as measured by Atmotube Pro devices, requires knowledge of each compound's molecular weight and assumes standard conditions (25°C, 1 atmosphere). Since total VOC (TVOC) measurements reflect a mixture of compounds, specific conversions are not possible without identifying individual VOCs.

Methodological Considerations

MAPA Pilot aimed to generate information that could be used to choose the most appropriate way of investigating the phenomenon of air quality around ambulance bays. Comparison between the data generated from WS1 and WS2 shows that the static pollution monitors collected robust and reliable data about the air quality in the ambulance bay outside an ED.

WS1 required the agreement and input from multiple stakeholders across different organisations (EEAST's research team, CUH's research team, CUH estates & facilities teams and EMSOL), which proved time-consuming in the setup phase of the project. Once installed, however, the sensors ran with little to no input from the research teams, with EMSOL providing maintenance within the agreed budget.

WS2 required only the input of the MAPA Pilot researchers and recruitment of a small number of operational ambulance staff. The data collection proved much more intensive, as the handheld monitors required charging and regular (near-daily) data-uploads. IT infrastructure problems created barriers for operational staff to engage with

MAPA Pilot as this work was in addition to their busy working day. Future projects could consider using a single sensor or methods that include automated uploading of data or recruiting ambulance support staff to manage the devices. Duggan (2023) used similar technology which automatically uploaded data which would fit with the preferences of the WS2 staff.

The data from the mobile sensors was rich and provided more detail on the occupational exposure of ambulance staff, but there was no way to guarantee that ambulances would travel to specific sites or locations. Location and activity data was available, with support from EEAST's informatics team to provide data from the CAD system. The analysis of agreement between the WS1 and WS2 data showed good levels of agreement, however the peak concentrations of PM measured in WS2 were not observed in WS1. This may be because the WS2 sensors were closer to the source of these high peak concentrations of PM – for example medical equipment such as nebulisers used in the ambulance.

For WS3, the RAD57 was a low-cost and sustainable way to measure baseline CO exposure. The device was already used within EEAST, was familiar to paramedic researchers, was non-invasive and required no additional consumables. The RAD57, however, is calibrated for clinical use and does not provide highly precise data on low-level exposure to CO.

Recommendations

MAPA Pilot has demonstrated a need for further investigation of air quality in ED ambulance bays and into the occupational exposure of ambulance staff to air pollution. Such future work is recommended to include:

- Further investigation of the data set presented in this report, with focus on:
  - the time dependent relationships between ambulance queue and concentrations of pollutants.
  - understanding the peak concentrations of PM and CO observed inside ambulances.

- Investigation of the effects of season and architecture on ambulance bay pollution, to understand air quality patterns over a 12-month period and in multiple hospitals.
  - There are a variety of ambulance bay architectural features: open parking bays, low-level access ramps, full or partial canopies, courtyards or other enclosed spaces, underground access, etc.
  - MAPA Pilot was conducted for 3 months during winter. Ambulance demand, hospital flow and the use of engines all vary considerably during the year.

- Investigation of the potential impacts of air pollution on the health of ambulance staff, other NHS staff and patients.

- Assembling a multi-professional stakeholder panel to develop solutions to eliminate, reduce, or mitigate the air pollution created outside ED.
    - The results of MAPA show that air pollution is produced in the ED ambulance bay, and solutions to this will involve a whole system approach between key stakeholders.

- In the short term, ambulance services may consider efforts to reduce engine idling, using publicity campaigns, new engine technology, providing electric hook-ups and reducing queuing outside ED.

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