Analysis of Real-time Particulate Monitoring in Career, Volunteer, and Mixed Career-Volunteer Fire Stations

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Introduction

The goal of this study was to use real-time monitoring equipment to assess aerosol particulate matter exposure to workers at fire-station facilities across a wide range of municipalities, and to use site-categorization techniques and analysis to attempt to determine whether there were any identifiable patterns in exposure levels from site to site.

A total of 23 fire station facilities in the states of KY and TN participated. These facilities were categorized in numerous ways. For purposes of this presentation, we consider the type of workforce (career, volunteer, or mixed), by the type of vehicle bay (pull-through or back-in), and whether the station possessed an exhaust control system (detachable ventilation hoses for engine exhaust) of the type recommended by the NFPA [1].

Fire Station	Dept. Type	Bay Type	Vent Type	n
A1	C	P	V	240
A2	C	P	V	240
A3	C	P	V	240
A4	C	P	V	240
A5	C	P	V	240
A6	C	P	N	93
B1	C	P	N	240
B2	C	P	V	240
B3	V	B	N	140
C	M	P	N	240
D	M	B	V	240
E	M	P	V	240
F	M	P	V	240
G	M	P	V	240
H	M	B	N	240
I	M	P	N	240
J	M	B	V	240
K	M	P	N	240
L	C	B	N	240
M1	M	P	N	120
M2	M	B	N	87
N	M	P	V	240
O	V	P	N	169

Key 1

Dept Type	C	Career
	V	Volunteer
	M	Mixed
Bay Type	P	Pull-through
	B	Back-in
Vent Type	V	Ventilation Hoses
	N	No Ventilation Hoses

Methodology

The primary instrument used for this study is TSI's DustTrak DRX Aerosol Monitor 8533, a gravimetric sampling device capable of measuring both the mass and size fraction of aerosol particulate. Though the DustTrak's ability to measure size fraction allowed us to gather data for PM1, PM2.5, PM4, and PM10, for purposes of this presentation, we are focusing on PM2.5, as we found this to be the size fraction of PM that had the clearest regulatory context and richest body of existing literature for comparison.

We chose a sampling period of 4 hours. The DustTrak was programmed to report mass concentration and size fraction at 60 second intervals over the course of this 4-hour period. This ability to report point-samples, rather than extrapolating TWA from cumulative sampling, is the feature that distinguishes this sampling method from the standard method of measuring particulate exposure in sites of this type, NIOSH method 5040 [2].

On some occasions, equipment errors or facility availability prevented us from sampling for the full 240 minutes. These cases are indicated in the n column of Table 1.

The DustTrak device was placed inside the vehicle bay of each facility, in an interior corner outside the direct exhaust trajectory of any fire engine, at a height within the breathing zone (chest-to-chin height) of workers inside the bay. The sampling period was initiated prior to morning shift-change at each facility, and start-time thus varied according to when each department initiated their shift-change. Morning shift-change was chosen for the beginning of the sample period because most fire departments (including all of those that participated in this study) idle their engines early in the morning shift for maintenance purposes, providing some level of uniformity in activity level at each station.

Though this methodology considers aerosolized particulate matter of nonspecific chemical composition, past research [3] on firefighter exposures has indicated diesel and gas exhaust from the operation of firefighting apparatus as a primary cause of elevated particulate levels in fire station facilities. This is why our categorizations revolve around the use of the vehicle bay, and why the morning shift-change engine idling period was considered of relevance.

Results

As previously indicated, we are fixating on PM2.5 results for purposes of this presentation. More particularly, we are utilizing the mass-concentration value of 12 µm/m^3, or 0.012 mg/m^3, which is the most recent EPA-recommended air-quality standard for PM2.5 [4].

Because our data-set was very large (up to 240 samples for each of 4 different particle size fractions, across 23 sampling sites), this presentation primarily considers the data as represented by descriptives and percentile methods. Table 2 gives the mean, median, TWA, and maximum PM2.5 concentrations at each of the 23 participating sites, as well as Standard Deviation of each site's samples as an indicator of consistency. Table 3 compares these descriptives to the 0.012 mg/m^3 reference value , as well as summarizing comparisons of the raw data to this same reference value.

Table 2

Fire Station	Mean PM2.5	Median PM2.5	TWA PM2.5	STDev PM2.5	Max PM2.5
A1	0.01247	0.012	0.00600	0.00610	0.043
A2	0.01135	0.012	0.00600	0.00323	0.022
A3	0.02406	0.024	0.01200	0.00304	0.036
A4	0.01112	0.01	0.00500	0.00353	0.032
A5	0.01074	0.01	0.00500	0.00464	0.055
A6	0.02684	0.026	0.01400	0.00877	0.104
B1	0.03040	0.03	0.01500	0.00779	0.124
B2	0.02807	0.027	0.01400	0.00470	0.045
B3	0.05146	0.038	0.01500	0.06801	0.591
C	0.02456	0.024	0.00200	0.00777	0.138
D	0.02530	0.023	0.01300	0.00711	0.079
E	0.02430	0.022	0.01200	0.00500	0.041
F	0.01981	0.019	0.01000	0.00583	0.04
G	0.02341	0.023	0.01200	0.00399	0.041
H	0.01653	0.015	0.00800	0.00533	0.03
I	0.04179	0.028	0.02100	0.05182	0.592
J	0.01888	0.016	0.00900	0.01038	0.051
K	0.00960	0.009	0.00500	0.00263	0.03
L	0.01782	0.018	0.00900	0.00302	0.035
M1	0.07417	0.017	0.01900	0.20840	1.56
M2	0.01930	0.013	0.00300	0.02081	0.115
N	0.04892	0.029	0.02400	0.03601	0.134
O	0.0192	0.004	0.01000	0.03607	0.173

Key 2

Highest in set	TWA PM2.5	Time-weighted Average of PM2.5 measurements
Lowest in set	STDev PM2.5	Standard Deviation of PM2.5 measurements

Table 3

Fire Station	Mean^0.012 mg	Med^0.012 mg	TWA^0.012 mg	T^ 0.012 mg	T% ^ 0.012 mg
A1	Yes	Yes	No	135	56.25%
A2	No	Yes	No	122	50.83%
A3	Yes	Yes	Yes	240	100.00%
A4	No	No	No	81	33.75%
A5	No	No	No	37	15.42%
A6	Yes	Yes	Yes	92	98.92%
B1	Yes	Yes	Yes	240	100.00%
B2	Yes	Yes	Yes	240	100.00%
B3	Yes	Yes	Yes	140	100.00%
C	Yes	Yes	No	240	100.00%
D	Yes	Yes	Yes	240	100.00%
E	Yes	Yes	Yes	240	100.00%
F	Yes	Yes	No	240	100.00%
G	Yes	Yes	Yes	240	100.00%
H	Yes	Yes	No	188	78.33%
I	Yes	Yes	Yes	240	100.00%
J	Yes	Yes	No	175	72.92%
K	No	No	No	34	14.17%
L	Yes	Yes	No	240	100.00%
M1	Yes	Yes	Yes	117	97.50%
M2	Yes	Yes	No	61	70.11%
N	Yes	Yes	Yes	239	99.58%
O	Yes	No	No	30	17.75%

Key 3

Mean^0.012 mg	Indicates whether the mean mass concentration of PM2.5 exceeds 0.012 mg/m^3
Med^0.012 mg	Indicates whether the median mass concentration of PM2.5 exceeds 0.012 mg/m^3
TWA^0.012 mg	Indicates whether the TWA mass concentration of PM2.5 exceeds 0.012 mg/m^3
T^ 0.012 mg	Number of individual samples that exceed 0.012 mg/m^3
T% ^ 0.012 mg	Percentage of individual samples that exceed 0.012 mg/m^3 (needed due to varied n)

Hypotheses & Statistical Tests

This project has been constructed in an attempt to enable the use of categorical variables for statistical comparison. Our goal was to see whether a sufficiently large sample size would allow us to isolate these variables and, applying them as bounds to set up binary comparisons, attempt to identify factors affecting exposure level.

For this presentation, we applied this approach to 3 different categorical variables to produce 3 different hypotheses:

1. PM2.5 concentrations of >0.012µm/m^3 are not significantly more likely to be recorded at stations without ventilation hose systems than at stations with ventilation hose systems.
2. PM2.5 concentrations of >0.012µm/m^3 are not significantly more likely to be recorded at non-career fire stations than they are at career fire stations.
3. PM2.5 concentrations of >0.012µm/m^3 are not significantly more likely to be recorded at stations with back-in vehicle bays than at stations with pull-through vehicle bays.

By combining site datasets according to the characterizations in Table 1, we set up binary datasets that could be applied to chi-square tests:

Table 4 (p calculated through IBM SPSS)

Hypothesis	Chi-square	p	Significant at p < 0.5?	Retain Null
1	2.0871	0.14855	No	Yes
2	103.8611	<0.00001	Yes	No
3	1.1655	0.280334	No	Yes

Conclusions & Discussion

As indicated in Table 4, we found no statistically-significant relationship between PM2.5 levels >0.012 and the presence of emissions-control ventilation systems, or between PM2.5 levels >0.012 mg/m^3 and vehicle bay type. We did, however, find what appeared to be a statistically-significant relationship between these PM2.5 levels and the type of workforce, with career departments being more likely to record PM2.5 concentrations of >0.012 mg/m^3.

This may be due to the typically higher activity levels at career fire stations, something that was evaluated as part of this study but not within the scope of the statistical tests from Table 4.

Future Research Direction

In addition to further developing the large dataset assembled for this study, we believe we have demonstrated that the methods used in this study are reproducible across a wide variety of sites, and that this is a viable method of analyzing exposure risk factors at potential aerosol-producing sites. Given time, more sites can be added to the dataset, increasing the reliability of any conclusions drawn from this type of categorical analysis.

Sources

1. National Fire Protection Association (2018). NFPA 1500 Standard on Fire Department Occupational Safety, Health, and Wellness Program.
2. Birch, E. (1996), Diesel Particulate Matter (as Elemental Carbon), *NIOSH Method of Analytical Methods* (4).
3. Hwang, J., Taylor, R., Cann, C., Golla, J., Gilbert, W. (2019). Assessment of Ambient Air Diesel Particulates in Fire Departments Using Different Exposure Metrics: Pilot Study, *Fire Safety Journal*, 106, pp 155-162.
4. U.S. Environmental Protection Agency (2012), Revised Air Quality Standards for Particle Pollution and Updates to the Air Quality Index (AQI), *The National Ambient Air Quality Standards for Particle Pollution* .

Acknowledgements

Special thanks are due to the personnel and administrators of the Airport-Sorgho Fire Department, Bardstown Fire Department, Bowling Green Fire Department, Campbellsville/Taylor County Fire Rescue, Central City Fire Department, Danville Fire Department, Daviess County Fire Department, Franklin-Simpson Fire Rescue, Glasgow Fire Department, Leitchfield Fire Department, Portland Fire Department, Princeton Volunteer Fire Department, Russellville Fire Department, Springfield Fire Department, and the Zoneton Fire Protection District.