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Exposure Assessment on Volatile Organic Compounds (VOCs) for Tollway Station Workers via Direct and Indirect Approaches

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Abstract: Exposure Assessment on Volatile Organic Compounds (VOCs) for Tollway Station Workers via Direct and Indirect Approaches: Ching-Chang LEE, *et al.* Department of Environmental and Occupational Health, Medical College, National Cheng Kung University—The present study was set out to assess the exposure levels of volatile organic compounds (VOCs) for tollway station workers via direct and indirect approaches. For direct approach, personal samplings were conducted on 25, 30 and 31 booth attendants of a tollway station during the dayshift (08:00 AM–16:00 PM), nightshift (16:00 PM–24:00 AM), and late-nightshift (24:00 AM–08:00 AM), respectively. For each collected sample, five target VOCs including benzene, toluene, xylene, ethylbenzene and methyl tertiary-butyl ether (MTBE) were analyzed. Results show that at least four of the exposure profiles of the five target VOCs for the booth attendants on any given workshift were log-normally distributed. The above results suggest that the booth attendants on any given workshift can be regarded as a similar exposure group (SEG). The exposure levels for both the dayshift and the nightshift booth attendants were quite similar, but were significantly higher than those for the late-nightshift booth attendants. A similar tend was found in the vehicle flow rates. The above results indicate that the difference in VOC exposure levels for the booth attendants on the three workshifts could be due to the intrinsic difference in the vehicle flow rates. After conducting linear regression analyses, we found that the vehicle flowrates were able to explain the variation in VOC exposure levels up to 40%–52%. It is concluded that the vehicle flow rates can be used as an indirect indicator for predicting the booth attendants' VOC exposure levels.
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Both gasoline vapor emissions and motor vehicle exhausts have been recognized as important sources of exposure of both occupational and non-occupational groups to volatile organic compounds (VOCs). Among various kinds of VOCs, BTEX (the acronym for benzene, toluene, ethylbenzene and xylene) are the four most intensively investigated compounds because of their high content in gasoline fuel and engine exhaust. In addition to BTEX, methyl tertiary-butyl ether (MTBE) has also been intensively investigated. This is because MTBE has being widely used as an additive in gasoline fuel to reduce the emissions of both carbon monoxide and hydrocarbons from motor vehicle engines. Table 1 summarizes the results of 13 studies associated with either gasoline vapor emissions or motor vehicle exhausts for both occupational and non-occupational groups exposure to VOCs[1–13]. It can be seen that the exposure levels associated with gasoline vapor emissions (such as workers in car repair shops[9]), petroleum refineries[10], dispatch tank trucks[11], and gas service stations[12, 13]) were higher than those associated with motor vehicle emissions (such as bus/car commuters[4, 5]), roadside pedestrians, cyclists and car drivers[1–3, 6]), traffic police officers, roadside storekeepers and parking-lot attendants[7]). Nevertheless, the concentrations in the environments associated with motor vehicle emissions were still found to be much higher than those in the general ambient environments[1–3]).

To date, the freeway transportation system has been widely used in many developed and developing countries, and its vehicle flow rates have increased dramatically in recent years. For example, the vehicle flow rates on a main freeway in Taiwan were found to have increased from 1.39×10^8 vehicles/yr in 1985 to 4.24×10^8 vehicles/yr in 1998. But to the best of our knowledge, VOC exposure levels for tollway station workers have never been assessed. Therefore, the objective of the present study was to assess VOC exposure levels for tollway station workers via the personal sampling approach. But, because direct measuring of VOC exposure levels in the field is costly and labor consuming, the present study also set out to develop an indirect method for predicting VOC exposure levels. In epidemiological studies, measuring the traffic density has been used as an indirect method for assessing residents' exposure levels[14–17]. Therefore, the above approach was adopted and examined in the present study. The results obtained from this study would provide a basis for tollway station managers to introduce an effective control strategy for reducing the exposure levels of tollway station workers under various traffic conditions.

Methods and Materials

1. The selected tollway station

In this study, a tollway station with 20 vehicle lanes was selected. Beside each vehicle lane, one collecting booth ($L \times W \times H$ = 1.5 m $\times$ 1.0 m $\times$ 2.1 m) was installed for collecting either cash or prepaid tickets from vehicle drivers. 5 booths called bus/truck lane booths were therefore installed beside the bus/truck lanes for collecting either cash or prepaid tickets, and 5 booths called car lane/cash-collecting booths were installed beside the car lanes for collecting cash, and 10 booths called car lane/ticket-collecting booths were also installed beside the car lanes for collecting prepaid tickets. The tollway stations were operated for three workshifts per day, called the dayshift (from 08:00 AM to 16:00 PM), nightshift (from 16:00 PM to 24:00 AM), and late-nightshift (from 24:00 AM to 08:00 AM), respectively. During any given workshift, all booth attendants were requested to perform their tasks rotationally at two to three collecting booths.

Table 1. VOC exposure contents for various groups

Exposure groups	VOCs concentration						Ref
	Benzene	Toluene	Ethylbenzene	Xylene	MTBE	Unit	
Car/driver	3.64	12.33	2.03	9.65	–	ppb	1
Sidewalk/pedestrian	2.13	8.17	1.36	6.34	–	ppb	
Roadside/motorcyclist	106.58	225.20	43.55	139.63	–	ppb	2
Car/driver	77.74	158.96	25.81	92.40	–	ppb	
Bus/driver	50.16	97.35	17.74	56.22	–	ppb	
Roadside/motorcycle commuter	45.45	117.24	17.05	45.62	–	ppb	3
Roadside/car commuter	42.32	98.41	49.08	38.25	–	ppb	
Car/commuter	9.59	26.53	2.10	11.91	–	ppb	4
Bus/commuter	6.33	20.16	1.59	9.15	–	ppb	
Car/commuter	24.86	–	–	–	16.72	ppb	5
Bus/commuter	4.98	–	–	–	5.92	ppb	
Roadside/cyclist (city route)	7.21	15.92	–	9.22	–	ppb	6
Roadside/cyclist (rural route)	< 2.51	3.45	–	<1.84	–	ppb	
Roadside/car driver (city route)	23.20	61.76	–	28.34	–	ppb	
Roadside/car driver (rural route)	7.84	22.28	–	11.52	–	ppb	
Roadside/pedestrian (city route)	6.58	18.04	–	9.45	–	ppb	
Roadside/traffic police officer	7.59	33.16	1.77	6.27	–	ppb	7
Parking garage/attendant	12.73	45.62	2.76	9.72	–	ppb	
Roadside/storekeeper	5.24	46.68	0.90	3.32	–	ppb	
Roadside/underground storekeeper	6.24	52.25	1.66	4.29	–	ppb	
Tank barge/coastguard	< 0.1–0.5	–	–	–	1.30–22.0	ppm	8
Repair shop/machanic	0.15	–	–	–	–	ppm	9
Petroleum refinery/employee	–	–	–	–	0.58	ppm	10
Dispatch tank truck/driver	0.05	0.27	0.04	0.14	1.44	ppm	11
Service station/customer	–	–	–	–	0.92	ppm	12
Service station/operators	0.05	–	–	–	0.30	ppm	13

2. Sampling strategy

A total of 25, 30 and 31 booth attendants on the dayshift, nightshift, and late-nightshift were selected for this study. Method 1615 which is suggested by the US National Institute of Occupational Safety and Health (NIOSH) was adopted to assess booth attendants' VOC exposure levels[18]. The sampling system consisted of a sorbent tube (SKC charcoal tube, 100 mg/50 mg, SKC Inc., Eighty-Four, PA) and a low-flow sampling pump (Model 222–3, SKC Inc., Eighty-Four, PA). The sampling flow rate was specified as approximately 150 m*l*/min. The VOC sample was taken from the breathing zone of each selected booth attendant. In order to collect enough for the quantitative analysis, the sampling time for each VOC sample lasted for approximately 16 h during the same work shift on two consecutive sampling days. After a sample was collected, the sorbent tube was stored at –20°C in a refrigerator before analysis. All collected samples were analyzed within 14 d.

During any given workshift, the traffic at any given collecting booth was measured by using a pneumatic tube which was laid across the given vehicle lane and connected to an automatic data logger. This allowed us to calculate vehicle flow rates for each individual collecting booth during each of the three workshifts. It is known that each booth attendant was requested to perform his/her task rotationally at 2 to 3 collecting booths during a workshift, and the personal sample was conducted on two consecutive days during the same workshift. Each booth attendant was required to perform his/her task at 4 to 6 collecting booths while a VOC sample was taken. We have carefully recorded the time which booth attendant spent at each collecting booth. This allowed us to calculate the time-weighted average vehicle flow rate for each collected VOC sample.

3. Sample Analysis and Quality Assurance/Quality Control

For each collected sample, five target VOCs (including benzene, ethylbenzene, toluene, xylene and MTBE) were analyzed by means of a gas chromatograph with a frame ionization detector (GC/FID; Hewlett Packard, Model 5890 series II, Delaware, NY)[18]. VOCs Mix 2 (Supelco, 4–8167, Bellefonte, PA) was used to prepare the stock solution for establishing calibration curves (with $R^2 > 0.995$) for the five target VOCs. 7 duplicate analyses were performed at the lowest concentration of the calibrating curve for each target VOC, and the method detection limit (MDL) of the target VOC was determined as three times the magnitude of the resultant standard deviation. This study yielded MDLs for benzene, toluene, ethylbenzene, xylene and MTBE as 0.0095μg, 0.021μg, 0.018μg, 0.0096μg and 0.028 μg, respectively. 3 duplicate analyses were performed for 3 known concentrations to assess the accuracy of the analytical method for each target VOC. This study yielded relative standard deviations (RSD) for the five target VOCs which were consistently less than 15%. Desorption efficiency for each target VOC was determined by analyzing three sorbent tubes (each spiked three known concentrations to the front section of the sorbent tube for one day). We found desorption efficiencies for the five target VOCs were greater than 85%. Both the front and rear sections were analyzed for each collected sample, we found the VOC content in the rear section was less than 10% in magnitude of that in the front section (i.e., no break-through was detected). To ensure the quality of the sampling, one field-blank sample was taken for every 10 VOC samples, and no contamination (i.e., < MDLs) was found in any field-blank sample. In addition, 10 duplicate samples were taken from 10 booth attendants in order to test the precision of the sampling and the analytical techniques adopted in the present study. We found the RSDs for the five target VOCs were less than 20%.

4. Data analyses

For each workshift booth attendant, we examined the log-normality, range, and average exposure level in order to describe their exposure profiles associated with the five target VOCs. The log-normality was examined by means of the W-test as suggested by Gilbert[19]. We calculated the minimum-variance-unbiased-estimate arithmetic mean (AM_{MVUE}) to describe the average exposure level, since the AM_{MVUE} has been proved o be an effective estimate for exposure profiles with various sample sizes and geometric standard deviations (GSDs)[20–21]. Full calculating procedures for AM_{MVUE} were described in a study conducted by Attfield and Hewet[22]. In order to predict exposure levels for booth attendants' on the three workshifts, we conducted linear regression analyses to find the relationships between their AM_{MVUE}s and their corresponding vehicle flow rates.

Results and Discussion

1. VOC exposure levels for booth attendants on the three workshifts

As shown in Table 2, we found at least four of the exposure profiles of the five target VOCs for any given workshift booth attendant were log-normally distributed. The above results suggest that each workshift booth attendant can be regarded as in a similar exposure group (SEG), but it is true that the VOC in the exhaust from bus/truck vehicle engines could be different from those from car engines, since different types of gasoline fuel and vehicle engines were involved in the above two types of vehicles. But it should be noted that each booth attendant was required to perform his/her task at 4 to 6 collecting booths while a VOC sample was taken. Based on the above scenario, the differences on the pollution sources involved in the VOC samples collected during

Table 2. Estimated VOCs exposure levels for dayshift, nightshift and late-nightshift booth attendants

unit: ppb

VOCs	Statistics	Booth attendants		
		Dayshift (n=25)	Nightshift (n=30)	Late-nightshift (n=31)
MTBE	Range	1.63–9.86	1.96–8.83	1.20–5.32
	AM_{MVUE}	5.12	5.52	2.84
	95 % C.I.	4.43–6.11	4.92–6.33	2.55–3.22
	Log-normality	Yes	Yes	Yes
Benzene	Range	2.05–8.87	2.11–9.84	1.42–5.16
	AM_{MVUE}	5.43	5.97	3.24
	95 % C.I.	4.77–6.34	5.30–6.86	2.93–3.63
	Log-normality	Yes	Yes	Yes
Toluene	Range	9.97–31.13	8.29–35.40	4.37–18.49
	AM_{MVUE}	20.21	22.48	11.39
	95 % C.I.	18.23–22.76	20.33–25.22	10.30–12.79
	Log-normality	Yes	No	Yes
Ethylbenzene	Range	1.50–4.60	1.48–7.06	0.72–2.26
	AM_{MVUE}	2.97	3.75	1.54
	95 % C.I.	2.70–3.30	3.39–4.23	1.41–1.70
	Log-normality	Yes	Yes	Yes
Xylene	Range	3.10–12.22	3.12–16.08	1.93–6.41
	AM_{MVUE}	7.64	9.36	4.21
	95 % C.I.	6.79–8.78	8.39–10.67	3.81–4.72
	Log-normality	Yes	Yes	No

any given workshift might become insignificant. Therefore, we regarded the booth attendants on any given workshift as an SEG which could be theoretically feasible. Based on this, the exposure profiles for each of the three workshifts' booth attendants were examined separately in the present study.

As shown in Table 2, we found the exposure levels for the dayshift booth attendants (AM_{MVUE} for benzene, toluene, ethylbenzene, xylene and MTBE = 5.43, 20.21, 2.97, 7.64 and 5.12 ppb, respectively) were not significantly different from that for the nightshift booth attendants (=5.97, 22.48, 3.75, 9.36 and 5.52 ppb, respectively) (all p-values > 0.05; non-parametric Mann-Whitney test). On the other hand, the exposure levels for the above two types of booth attendants were found to be significantly higher than those for the late-nightshift booth attendants (= 3.24, 11.39, 1.54, 4.21 and 2.84, respectively) (all p-values < 0.05; non-parametric Mann-Whitney test). The above results suggest that more attention should be paid to both the dayshift and nightshift booth attendants, rather than to late-nightshift booth attendants.

2.Significance of VOC exposure levels for booth attendants on the three workshifts

To help the toll-way station managers to assess the significance of the booth attendants' exposure levels, it is important to compare the results obtained in the present study to those associated with both vehicle engine exhausts and gasoline vapor emissions for both occupational and not-occupational groups (see Table 1). We found the AM_{MVUE}s range for the booth attendants on the three workshifts (=3.24–5.97, 11.39–22.48, 1.54–3.75, 4.21–7.64 and 2.84–5.52 ppb for benzene, ethylbenzene, toluene, xylene and MTBE, respectively) (Table 2) were lower than those directly associated with gasoline vapor emissions, such as car-repair workers (benzene = 0.15 ppm)[9], petroleum refinery workers (MTBE = 9.58 ppm)[10] and gas station workers (MTBE and benzene = 0.30 and 0.05 ppm, respectively)[13] (see Table 1). Nevertheless, the exposure levels found in this study were quite comparable with those directly associated with vehicle engine exhausts, such as car commuters (= 9.59, 26.53, 2.10 and 11.91 ppb for benzene, toluene, ethylbenzene and xylene, respectively)[4], bus commuters (= 6.33, 20.16, 1.59 and 9.15 ppb, respectively)[4], traffic police officers

Table 3. Vehicle flowrates for booth attendants on the three workshifts: the dayshift (08:00–16:00), nightshift (16:00–24:00) and late-nightshift (24:00–08:00)

Type of Workshift	Vehicle flowrate (vehicles/shift)		
	Mean	Range	n
Dayshift	4007	2008–7451	25
Nightshift	3885	2014–6777	31
Late-nightshift	2314	1145–4102	32

(= 7.59, 33.16, 1.77 and 6.27 ppb, respectively)[7], parking-lot attendants (= 12.73, 45.62, 2.76 and 9.72 ppb, respectively)[7], roadside ground floor storekeepers (= 5.24, 46.68, 0.90 and 3.32 ppb, respectively)[7] and roadside underground storekeepers (= 6.24, 52.25, 1.66 and 4.29 ppb, respectively)[7] (see Table 1). Nevertheless, the results of the present study were still much higher than those found in the general ambient environments in Taiwan (=0.23–0.45, 0.83–1.45, 0.18–0.25 and 0.33–0.74 ppb for benzene, toluene, ethylbenzene and xylene, respectively)[1–3] indicating that the booth attendants' exposure levels might not be negligible.

3.Predicting VOC exposure levels for booth attendants on the three workshifts

Table 3 shows the ranges and the mean values for the vehicle flowrates for the booth attendants on the three workshifts. For the dayshift booth attendants, we found their vehicle flowrates were not significantly different from those for the nightshift booth attendants (p-values > 0.05; non-parametric Mann-Whitney test). On the other hand, we found the vehicle flowrate for the late-nightshift booth attendants was significantly lower than those corresponding for both dayshift and nightshift booth attendants (all p-values < 0.05; non-parametric Mann-Whitney test). Obviously the trend found in the vehicle flowrates was consistent with the trend found in VOC exposure levels for the booth attendants on the three workshifts. Based on this, it is expected that VOC exposure levels for booth attendants could be strongly affected by their vehicle flowrates.

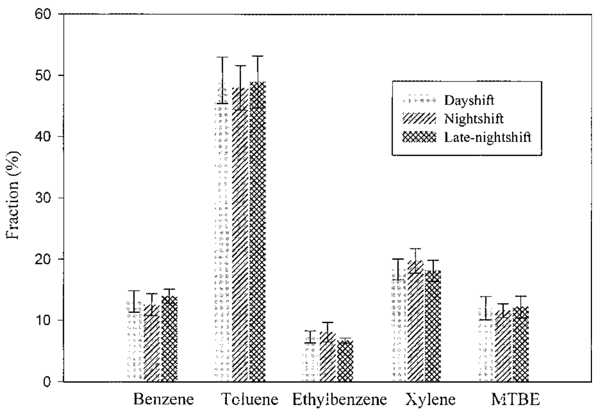


Fig. 1. The fractions (mean ± standard deviation) of the five target VOCs, benzene, ethylbenzene, toluene, xylene, and MTBE, with respect to their totals for booth attendants on the three workshifts

Figure 1 shows the fractions of the five target VOCs with respect to their total VOC content (= bezene + toluene + ethylbenzene + xylene + MTBE) for booth attendants on the three workshifts. For each of the five target VOCs , we found the fractions were not significantly different for the booth attendants on the three workshifts (all p-values > 0.05; non-parametric Mann-Whitney test). The above results further confirm that the differences in the pollution sources for the booth attendants on the three workshifts might not be significant. Therefore, it is expected that the VOC exposure levels for the booth attendants on the three workshifts could be mainly due to the intrinsic difference in vehicle flowrates. Based on this, we conducted linear regression analyses to examine the relationship between the estimated AM_{MVUE}s for the five target VOCs (Y; ppb) and their corresponding vehicle flowrates (X; vehicles/shift) for the booth attendants on the three workshifts. This study yielded the following regression results (Fig. 2):

Benzene:

$$Y= 8.27 \times 10^{-4}X + 1.74 \ (R^2=0.52, n=86) \quad (1)$$

Toluene:

$$Y= 2.71 \times 10^{-3}X + 7.69 \ (R^2=0.47, n=86) \quad (2)$$

Ethylbenzene:

$$Y= 4.41 \times 10^{-4}X + 1.08 \ (R^2=0.40, n=86) \quad (3)$$

Xylene:

$$Y= 1.23 \times 10^{-3}X + 2.40 \ (R^2=0.49, n=86) \quad (4)$$

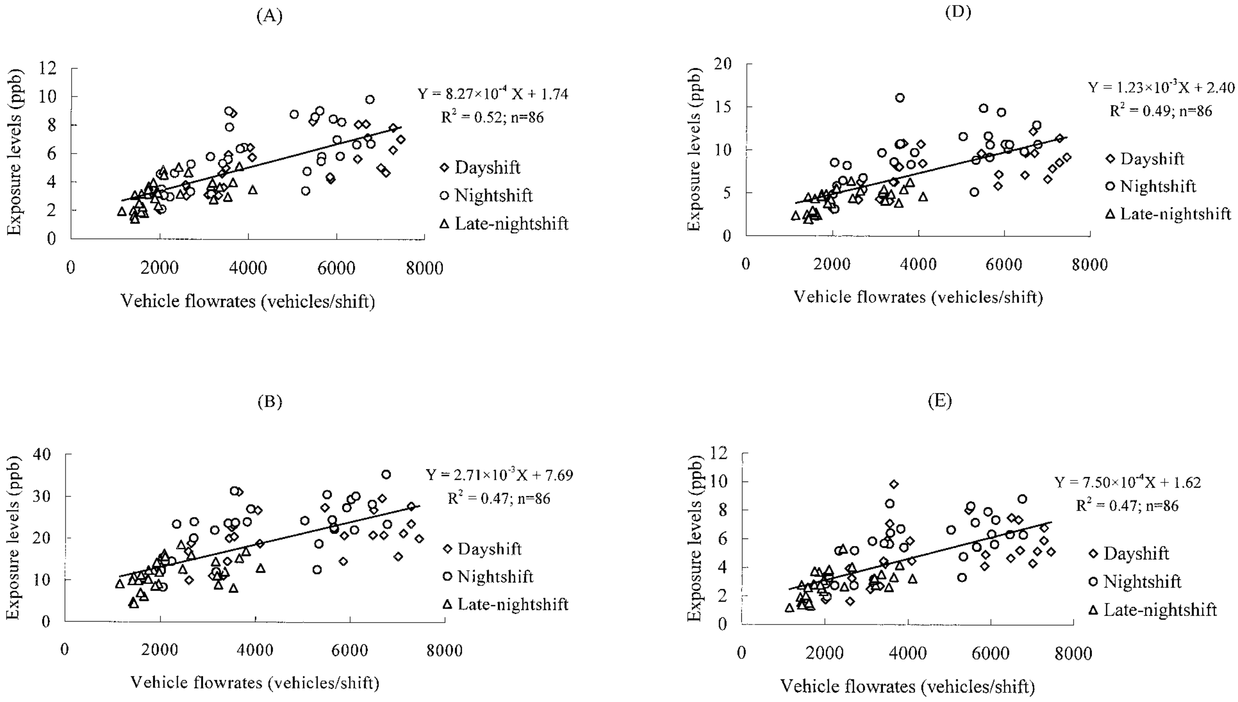
MTBE:

$$Y= 7.50 \times 10^{-4}X + 1.62 \ (R^2=0.47, n=86) \quad (5)$$

All regression coefficients (i.e., the slopes of these regression equations) were found to have positive values indicating that an increase in the vehicle flowrate would lead to an increase in the VOC exposure level. All R^2 values fell to the 0.40–0.52 range indicating that vehicle flowrates were able to explain the variations in exposure levels of booth attendants for the five target VOCs. Based on these, it is concluded that the vehicle flowrate can be used as an indirect indicator for predicting the booth attendants' VOC exposure levels. The results of the present study might be used a basis for toll-way station managers to assess the exposure levels for booth attendants under various conditions with different vehicle flowrates.

Conclusions

In this study we found that booth attendants on any given workshift can be regarded as a similar exposure group (SEG). The VOC exposure levels for both dayshift and nightshift booth attendants were quite similar, but



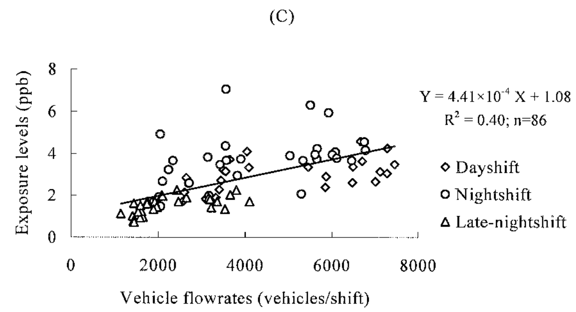


Fig. 2. Relationships between VOC exposure levels and vehicle flowrates for booth attendants on the three workshifts (A: Benzene, B: Toluene, C: Ethylbenzene, D: Xylene, E: MTBE)

both were significantly higher than that for the late-nightshift booth attendants. The VOC exposure levels obtained in the present study for booth attendants were significantly lower than the exposure groups that were directly related to gasoline vapor emissions, but were comparable with those exposure groups with similar emission sources (i.e., motor vehicle emissions). After conducting linear regression analyses, we found the vehicle flowrate can be used as an indirect indicator in predicting the booth attendants' VOC exposure levels. Therefore, it is concluded that the results of this study would provide a useful basis for tollway station managers to assess VOC exposures for booth attendants under various traffic conditions in the future.

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