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Article

An Examination of the Sensitivity of Sulfur Dioxide, Nitric Oxide, and Nitrogen Dioxide Concentrations to the Important Factors Affecting Air Quality Inside a Public Transportation Bus

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Abstract: The present study examined the sensitivity of sulfur dioxide (SO_2), nitric oxide (NO), and nitrogen dioxide (NO_2) concentrations to the important factors affecting air quality inside a public transportation bus. Additionally, this study quantified the in-bus contaminant concentrations in relation to the ranked statistically significant variables. The independent variables to which the monitored contaminant concentrations are the most sensitive to were determined using regression trees and the analysis of variance. A comprehensive one-year database, of the monitored contaminant concentrations and the independent factors that affect an indoor microenvironment (meteorology, monitoring periods, outdoor sources, and ventilation settings) was developed to study the sensitivity of monitored in-bus contaminants. SO_2 concentrations were extremely sensitive to the month, weather conditions, and heavy vehicles. NO concentrations were sensitive to the month/season, ventilation, and ambient temperature; while NO_2 concentrations were additionally sensitive to the monitoring period and the ambient mixing ratio. Quantified in-bus relationships revealed NO and NO_2 concentrations to be less than 0.6 ppm and 0.1 ppm, respectively. SO_2 concentrations of 0.4 ppm were observed in the fall-winter months, when the lead heavy vehicles were at a minimum density of 56 per hour; <0.4 ppm SO_2 concentrations remained for the rest of the year.

Keywords: indoor air quality; regression trees; analysis of variance; sulfur dioxide; nitric oxide; nitrogen dioxide; sensitivity analysis

1. Introduction

Indoor air quality (IAQ) is a major environmental concern, since people spend 90% of their time indoors and about 7% of their daily time is spent commuting, mostly between the workplace and their residences [1]. A comprehensive study of IAQ in relation to the sensitivity of in-vehicle contaminant concentrations is of utmost importance because people are exposed to high concentrations of traffic contaminants when they drive in heavy traffic, stand near idling vehicles, and spend time at places near roads that have high traffic, especially if the location is downwind of the road [2]. There are only a limited number of vehicular studies that used regression analysis to characterize the IAQ by monitoring sulfur dioxide (SO_2), nitric oxide (NO), and nitrogen dioxide (NO_2) concentrations [3–10]. According to the available literature on vehicular IAQ studies [3–10], the contaminant concentration buildup within a transit microenvironment was observed to be predominantly influenced by the indoor contaminant sources (such as the passenger density, emissions from various indoor components, *etc.*), ventilation settings, and outdoor air quality (affected by the test vehicle and lead vehicular exhaust emissions, and the ambient contaminant background concentrations in relation to different meteorological conditions). There are no in-vehicle sources for SO_2, NO, and NO_2 concentrations; the contaminant buildup within the vehicle compartment is primarily dependent on the ventilation settings and outdoor air quality.

The influence of ventilation settings (represented by the door and window positions) predominately depends on whether the monitored contaminants are directly-emitted from the indoor sources, or had contributions from outdoor emission sources and ambient background concentrations [3]. For the directly-emitted and the outdoor-generated indoor contaminants, such as the carbon dioxide (CO_2), the contaminant concentration buildup within the vehicle is mainly affected by the indoor source strength (passenger density) when there is not enough ventilation. With sufficient ventilating conditions, the contaminant buildup depends on the source strength as well as the amount of infiltrated outdoor-generated CO_2 concentrations [6,11]. For the outdoor-generated contaminants that infiltrated into the vehicle cabin, in-vehicle contaminant concentration buildup was inversely proportional to the wind speed, under sufficient ventilating conditions [11,12]. There is an accumulation of the outdoor-generated contaminants inside the vehicle cabin at low wind speeds, while at high wind speeds there is a dilution of the accumulated in-vehicle contaminants.

Outdoor-generated SO_2, NO, and NO_2 concentrations are directly proportional to the test vehicle and lead vehicular exhaust emissions, and the ambient background concentrations. With ample ventilating conditions, in-vehicle SO_2, NO, and NO_2 concentrations are directly proportional to the lead vehicular traffic, and there is also more self-pollution for the test vehicle when it operates at relatively low moving speeds, especially in the winter season when the roads are icy [5]. SO_2, NO, and NO_2 exhaust emission concentrations from heavy vehicles (public transport buses/garbage disposal trucks) in Toledo, Ohio, USA were higher during the idling mode of operation, compared to when they

were in transit [13–16]. The slow-moving traffic in combination with the increased idling times at traffic signals during the winter contribute to large amounts of local SO_2, NO, and NO_2 concentrations that are not normally experienced at other times. This is largely due to the relatively higher fuel consumption by vehicles in the winter (represented by low temperature and high humidity conditions) and the initial cold-start warm-up phase of the engine caused by low ambient temperatures, which result in higher vehicular exhaust emissions [13–16]. The lower ambient temperatures in the winter also inhibit the dispersion of SO_2, NO, and NO_2 exhaust emission concentrations, thereby accumulating the corresponding exhaust emission concentrations outdoors. Therefore, one can assume that the exhaust emission contributed SO_2, NO, and NO_2 concentrations vary positively with the ambient humidity and negatively with the ambient temperature.

Atmospheric SO_2 is removed by the gas-phase reaction, dissolution into clouds and rain, and deposition to the ground [17]. Consequently, atmospheric SO_2 concentrations vary negatively with the amount of precipitation. The gas-phase conversion mechanism of atmospheric SO_2 with the hydroxyl radical (OH) and the hydroperoxyl radical (HO_2) are represented by reaction equations R1 and R2, respectively [18–20]. Note that 'M' in reaction R1 refers to another molecule that serves to carry excess energy away from the reaction. Urban areas with colder climates, such as Toledo, Ohio, USA, experience higher atmospheric SO_2 concentrations during the late fall and winter because it is less reactive in these climates [21]. The rates of oxidation of atmospheric SO_2 concentrations are higher in the summer than in the winter and higher in the midday than in the nights, which indicate the negative and positive relationship of atmospheric SO_2 concentrations with the ambient temperature and the ambient humidity, respectively. Persistence of SO_2 concentrations indoors is limited due to its high reactive property with fresh emulsion paints, carpets, and wallpaper [22].

$$OH + SO_2 + M \rightarrow HSO_3 + M \quad \text{(R1)}$$

$$SO_2 + HO_2 \rightarrow SO_3 + OH \quad \text{(R2)}$$

Combustion of atmospheric nitrogen (N_2) with oxygen (O_2), dissociation of the atmospheric NO_2 in the presence of sunlight energy ($h\upsilon$), and rapid cooling of the vehicular exhausts on dilution in the atmosphere are the three primary mechanisms that yield high outdoor NO concentrations [20]. Combustion of atmospheric N_2 and dissociation of the atmospheric NO_2 are shown by the reactions, R3 and R4, respectively. Reaction R3 is a slow-occurring non-elementary process, where thermal NO formation is dependent on the reactions involving free radicals. At high temperatures, R3 moves to the right; at low temperatures, R3 moves to the left. Therefore, one can expect the atmospheric NO concentrations to vary positively with the ambient temperature and sunlight, and negatively with the ambient humidity.

$$N_2 + O_2 \leftrightarrow 2NO \quad \text{(R3)}$$

$$NO_2 + h\upsilon \rightarrow NO + O \quad \text{(R4)}$$

The major source of atmospheric NO_2 formation is the oxidation of NO as shown by reaction R5 [20,23]. Reaction R5 is a slow-occurring non-elementary process in the ambient air, which is important only when NO is greater than 1 ppm. Atmospheric oxidation of NO to NO_2 is based on the reactions with other oxidants such as ozone (O_3), HO_2, and other peroxy radicals, as indicated by the

reactions R6, R7, and R8, respectively. Reaction R6 occurs during the nighttime, when NO is oxidized by O_3 without sunlight [24]. During the daytime, some NO_2 disintegrates in the presence of sunlight to form NO and singlet oxygen (O) as shown by reaction R4; and on oxidation with the hydroxyl radical (OH), forms gaseous nitric acid as shown by reaction R9 [24]. Atmospheric NO_2 concentrations are more prevalent during midmorning than midday or afternoon, since sunlight breaks down NO_2 past midmorning [17]. Outdoor NO_2 concentrations are expected to be the highest, early in the mornings, due to exhaust emissions from the morning vehicular rush and the reaction of newly emitted NO with O_3 without sunlight to form NO_2. In the afternoon, outdoor NO_2 concentrations are the lowest, due to the photochemical dissociation of NO_2, as shown by the reaction R4. In the evenings and the nights, outdoor NO_2 concentrations are expected to be relatively higher than in the afternoon. The higher outdoor NO_2 concentrations are a result of vehicular exhaust emissions in the evening rush hours. The dominance of reaction R6 coupled with the low ambient temperatures inhibiting the dispersion of NO_2, leads to relatively higher outdoor NO_2 concentrations in the night than in the afternoon. Considering the above-mentioned factors, one can note that the atmospheric NO_2 concentrations are extremely sensitive to the time of day, sunlight, and humidity. Also, one can anticipate the outdoor NO_2 concentrations to be inversely proportional to the ambient temperature, the sunlight, the ambient humidity, and the precipitation (on relating the ambient temperature and the sunlight to the time of the day; the dominance of reaction R9 in the presence of OH, associated with the ambient humidity and the precipitation).

$$2NO + O_2 \rightarrow 2NO_2 \quad \text{(R5)}$$

$$O_3 + NO \rightarrow NO_2 + O_2 \quad \text{(R6)}$$

$$HO_2 + NO \rightarrow NO_2 + OH \quad \text{(R7)}$$

$$RO_2 + NO \rightarrow RO + NO_2 \quad \text{(R8)}$$

$$NO_2 + OH + M \rightarrow HNO_3 + M \quad \text{(R9)}$$

The objective of this study is to develop quantified relationships for the monitored SO_2, NO, and NO_2 concentrations inside one transit bus, by examining the association of monitored contaminant concentrations with a set of identified influential variables, and analyzing their behavior in reference to the atmospheric physiochemical interactions. In view of the fact that regression trees perform better than the conventional techniques, like regression, in determining the important factors affecting IAQ of a public transit bus [25], this study extends the work done by Kadiyala and Kumar [11,12] in establishing the sensitivity relationships for in-bus SO_2, NO, and NO_2 concentrations. Firstly, the important factors affecting the monitored in-bus contaminant concentrations were obtained from a comprehensive set of independent variables that affect an indoor environment, using the regression tree method, with CART® software. Secondly, the identified factors obtained from performing the regression tree analysis were further screened using the analysis of variance (ANOVA) to determine a subset of the statistically significant variables. The statistically significant variables identified from performing the ANOVA were ranked based on the *F* values computed using the SPSS® software. Thirdly, the relationships between the monitored in-bus gaseous concentrations and the identified statistically significant variables (obtained from the regression tree models developed in the first step)

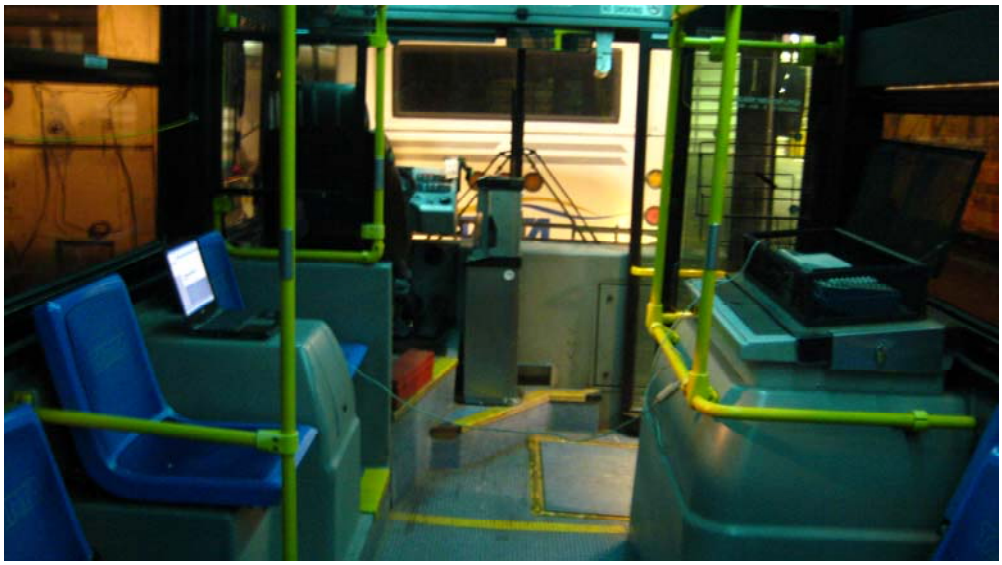
were quantified. The behavior of in-bus SO_2, NO, and NO_2 concentrations were analyzed further to compare the dynamics of in-bus pollution with atmospheric physics, to have a better understanding of the quantified relationships.

2. Methodology

2.1. Study Area

A 20% grade biodiesel (BD20) air-conditioned bus with 106 K miles was selected from the Toledo Area Regional Transit Authority (TARTA) 500 series fleet. The route selected for the study was Route 20, which runs between the TARTA garage and Meijer on the Central Avenue Strip [26]. The route selected is a standard two-lane (dual direction) asphalt urban road with a speed limit of 40 mph (65 kmph). For the most part, it has stop-and-go traffic resulting from the combination of heavy traffic, with traffic signals and bus stops. The BD20 test bus kept to the right lane for majority of the run, and the variation of in-bus concentrations with driving lane, roadway type, commuting mode, vehicle size, and the route selected, were eliminated with consistency in the test run throughout the testing period. The GPS unit, located inside the test bus, was used to track its location, when in transit. Continuous monitoring of SO_2, NO, and NO_2 gases inside the test bus were done simultaneously with two important indoor comfort parameters: indoor temperature (temp.) and indoor relative humidity (RH), on a one-second interval basis using the YES Plus air quality monitor [27], placed on an elevation within the vicinity of driver, as shown in Figure 1. A wired mesh box was provided to safeguard the instrument and the instrument drew power continuously from the bus. More details on the experimental setup and the test protocol, adopted by the researchers to monitor in-vehicle contaminants 24 hours a day 7 days a week, were documented elsewhere [6,7].

Figure 1. Yes Plus instrument setup and data collection.



The "Yes Plus" instrument is equipped with one microprocessor controlled circuit board with built-in temperature and humidity sensors, and is capable of handling 12 additional plug and play sensors. The instrument comes with a rechargeable nickel-metal hydride battery pack to support

18–24 hours of continuous operation time, and includes an internal, automatic sample pump for "active" sampling of the target environment with a flow rate of 0.5 liters per minute (LPM). Data collected in the preceding week were downloaded from the Yes Plus instrument to a laptop (Figure 1), prior to calibration of the gaseous sensors. The methodology associated with calibration of the gaseous sensors included the following steps. The researchers ensured that the batteries were fully charged (before starting the calibration) and a 20-minute warm up time was allowed for the instrument sensors to stabilize, so that accurate results were produced. The zero and span gas calibration was achieved by flowing the "zero gas" and the "span gas" (both acquired from CALGAZ [28] in cylinders) into the inlet port of the instrument with a cylinder regulator adjusted to a flow rate of 0.7 LPM, in accordance with the instrument supplier specification. The calibration is automated and the researchers only needed to specify the concentration of the span gas. Table 1 provides additional details on the Yes Plus instrument and the precision of gaseous sensors were mathematically computed using Equation (1).

$$\text{Precision} = [1 - (\text{maximum variation from span gas concentration}/\text{span gas concentration})]*100\% \quad (1)$$

Table 1. Yes Plus instrument sensor capabilities and calibration details.

	Temp.	RH	SO_2	NO	NO_2
Sensor					
Type	negative coefficient thermistor	thin film captive	electrochemical	electrochemical	electrochemical
Range (lower to upper detection limits)	23 °F to 131 °F (−5 °C to 55 °C)	0%–100%	0–20 ppm	0–100 ppm	0–10 ppm
Precision	---	---	99% (at 5 ppm)	99.8% (at 50 ppm)	98.2% (at 5 ppm)
Resolution (factory guaranteed, upper limit)	0.1 °C at 25 °C, --- (32 °F at 77 °F, ---)	2%, ---	<0.1 ppm, 0.01 ppm	<0.2 ppm, 0.01 ppm	0.1 ppm, 0.05 ppm
Long term drift	±33 °F (±0.5 °C)	±2%	<2% change per month	zero: 0.5 ppm equivalent change from −4 °F to 68 °F (−20 °C to 20 °C), 1 to 3 ppm equivalent change from 68 °F to 122 °F (20 °C to 50 °C)	<2% signal loss per month
Response time	<10 seconds	<10 seconds	$t_{90} \leq 25$ seconds from 0 to 10 ppm	$t_{90} \leq 20$ seconds from 0 to 50 ppm	$t_{90} \leq 25$ seconds
Calibration					
Calibration details	77 °F (25 °C) using digital RH/temperature calibration chamber	40% using digital RH/temperature calibration chamber	flow regulator, zero air gas, SO_2 span gas (5 ppm)	flow regulator, 99.99% N_2 gas for zero function, NO span gas (50 ppm)	flow regulator, zero air gas, NO_2 span gas (5 ppm)
Implemented calibration frequency (recommended)	once per year at the factory (once per year)	once per year at the factory (once per year)	once per week at TARTA (once for every six months)	once per week at TARTA (once for every six months)	once per week at TARTA (once for every six months)

2.2. Database Development

Database development included downloading data from the instrument, obtaining meteorological data, monitoring a hard drive that recorded the real-time video to obtain on-road variables, and designating time-related variables. Only the data collected between 6:00 a.m. and 11:00 p.m., over a period of one year (April 2007–March 2008) that represented the real-time transit conditions, were

considered for analysis in this study. Data downloaded from the Yes Plus instrument (indoor temp., indoor RH, SO_2, NO, and NO_2) on a one-second interval basis; meteorological variables (ambient temp., ambient RH, wind speed, sky condition, visibility, weather type, and precipitation) downloaded for the Toledo Express Airport station, from the National Climatic Data Center [29] on a one-hour interval basis; and real-time on-road variables monitored from the hard drive (outdoor sources such as the light vehicles (cars/SUVs) ahead, heavy vehicles (buses/trucks) ahead, and ventilation settings that were representative of the bus status (idle/run) and door position (open/close): run/close, idle/open, idle/close) on a one-minute interval basis were all averaged to one-hour for analysis. Time-related variables such as the month of the year, the season of the year, and the monitoring period (the time of day) were designated to the hourly averaged database. The different seasons used in this study are defined as spring (April 2007–June 2007); summer (July 2007–September 2007); fall (October 2007–December 2007); and winter (January 2008–March 2008). Taking into consideration that one only needs to change the temperature to alter the RH, the indoor RH and the ambient RH variables were replaced with the corresponding computed mixing ratio's (MR), *i.e.*, indoor MR and ambient MR. Missing variables in the database were a result of camera error, hard disk problems, and the amount of time required to record the observations on a one-minute interval basis. The database developed, from here on referred to as "complete database," includes only the hourly averaged data points with no missing values for any of the independent or dependent variables. The complete database had 2,172 hourly data points.

Table 2 presents a summary of the seasonal descriptive statistics such as the mean (μ), standard deviation (SD), minimum (min), quartile 1 (Q1), median (Med.), quartile 3 (Q3), and maximum (Max.). A prior study on the exposure of commuters to contaminant concentrations inside buses reported the average SO_2, NO, and NO_2 concentrations to be 0.020 ppm, 0.490 ppm, and 0.077 ppm, respectively [30]. The averaged SO_2 concentrations (refer to Table 2) in this study are much higher than the concentrations normally observed inside buses, while NO and NO_2 concentrations were not significantly different from the typical in-bus concentrations. Accumulated roadside SO_2 concentrations from vehicular exhaust emissions ranged between 0.5 ppm and 4 ppm [31–34]. Based on the consideration that there are no indoor sources for any of the monitored contaminant concentrations, the higher SO_2, NO, and NO_2 concentrations observed inside the TARTA test bus can be attributed to the corresponding roadside contaminant concentrations and ventilation settings. The average SO_2, NO, and NO_2 exhaust emission concentrations from Toledo area heavy vehicles, *i.e.*, the TARTA public transport buses and the City of Toledo garbage disposal trucks, in transit were observed to be 40 ppm, 600 ppm, 80 ppm, and 70 ppm, 400 ppm, 60 ppm, respectively [13–16]. In view of the relative difference between indoor and ambient parameters of the temperature (or the MR), and the average time for which the bus was in idle/open condition (refer to Table 2), one can observe that there was good ventilation in the summer, moderate ventilation in the fall and the spring, and reduced ventilation in the winter for the public transport test bus used in this study. Also, lead vehicular traffic was the highest in the fall season, followed by the winter, summer, and spring seasons.

Table 2. Seasonal descriptive statistics for different numeric variables considered in this study.

Variable	Season	μ ± SD	min	Q1	Med.	Q3	Max.
SO_2, in ppm	Fall (*n* = 570)	0.2 ± 0.1	0	0.1	0.2	0.2	0.7
	Spring (*n* = 613)	0.1 ± 0.1	0	0.1	0.1	0.2	0.7
	Summer (*n* = 695)	0.2 ± 0.1	0	0.1	0.2	0.2	0.7
	Winter (*n* = 294)	0.2 ± 0.1	0	0.1	0.1	0.2	1
NO, in ppm	Fall (*n* = 570)	0.3 ± 1.3	0	0.1	0.1	0.2	24.4
	Spring (*n* = 613)	0.4 ± 0.5	0	0.1	0.1	0.4	4.2
	Summer (*n* = 695)	0.3 ± 0.5	0	0	0.1	0.4	4.9
	Winter (*n* = 294)	0.5 ± 2.1	0	0	0.1	0.2	15
NO_2 in ppm	Fall (*n* = 570)	0.1 ± 0.01	0	0	0	0.1	0.2
	Spring (*n* = 613)	0.1 ± 0.02	0	0	0	0.1	0.5
	Summer (*n* = 695)	0.1 ± 0.01	0	0	0	0.1	0.1
	Winter (*n* = 294)	0.1 ± 0.3	0	0	0	0.1	3.1
Indoor temp., in °F (°C)	Fall (*n* = 570)	77.7 ± 4.1 (25.4 ± −15.5)	59 (15)	75.3 (24.1)	77.1 (25)	79.3 (26.3)	96.8 (36)
	Spring (*n* = 613)	76.8 ± 4.2 (24.9 ± −15.4)	59.6 (15.3)	74.4 (23.6)	76.4 (24.7)	78.4 (25.8)	95.3 (35.2)
	Summer (*n* = 695)	76.4 ± 8.4 (24.7 ± −13.1)	31.5 (−0.3)	74.6 (23.7)	76.4 (24.6)	78.3 (25.7)	104.4 (40.2)
	Winter (*n* = 294)	77.2 ± 6.8 (25.1 ± −13.9)	34.2 (1.2)	74.6 (23.7)	75.9 (24.4)	79.7 (26.5)	95.7 (35.4)
Indoor MR	Fall (*n* = 570)	21.1 ± 3.2	11	19.3	20.5	22.2	39.7
	Spring (*n* = 613)	20.6 ± 3.2	11.2	18.8	20	21.5	37.6
	Summer (*n* = 695)	20.8 ± 5.4	3.8	18.6	19.9	21.4	50.7
	Winter (*n* = 294)	20.6 ± 5.3	1	18.8	19.7	22.1	38
Ambient temp., in °F (°C)	Fall (*n* = 570)	60.4 ± 19.3 (15.8 ± −7)	14 (−10)	50.3 (10.1)	66 (18.9)	75 (23.9)	90 (32.2)
	Spring (*n* = 613)	59.7 ± 17.5 (15.4 ± −8.1)	13 (−10.6)	45.5 (7.5)	61 (16.1)	74 (23.3)	91 (32.8)
	Summer (*n* = 695)	75.8 ± 9.4 (24.3 ± −12.6)	36 (2.2)	69 (20.6)	77 (25)	83 (28.3)	95 (35)
	Winter (*n* = 294)	28.6 ± 13 (−1.9 ± −10.6)	2 (−16.7)	21 (−6.1)	28 (−2.2)	35 (1.7)	66 (18.9)
Ambient MR	Fall (*n* = 570)	8.2 ± 5.4	1.8	3.9	6.4	11.6	29.5
	Spring (*n* = 613)	18.8 ± 6.6	4.6	13.7	17.9	23.5	37.4
	Summer (*n* = 695)	19.8 ± 5.6	6.9	15.6	19.6	23.5	33.9
	Winter (*n* = 294)	3.9 ± 2.4	1	2.4	3.6	4.4	14
Wind speed, in mph (kmph)	Fall (*n* = 570)	7.5 ± 4.9 (12.1 ± 7.8)	0 (0)	5 (8.1)	7 (11.3)	10 (16.1)	30 (48.3)
	Spring (*n* = 613)	7.5 ± 5.6 (12 ± 9)	0 (0)	3 (4.8)	7 (11.3)	10 (16.1)	29 (46.7)
	Summer (*n* = 695)	6.3 ± 4.3 (10 ± 6.9)	0 (0)	3 (4.8)	6 (9.7)	8 (12.9)	24 (38.6)
	Winter (*n* = 294)	10.7 ± 5.5 (17.2 ± 8.8)	0 (0)	7 (11.3)	10 (16.1)	15 (24.1)	29 (46.7)

Table 2. *Cont.*

Variable	Season	μ ± SD	min	Q1	Med.	Q3	Max.
Precipitation, in inches (cms)	Fall (*n* = 570)	0.01 ± 0.06 (0.03 ± 0.15)	0 (0)	0 (0)	0 (0)	0 (0)	1.01 (2.57)
	Spring (*n* = 613)	0 ± 0.01 (0 ± 0.03)	0 (0)	0 (0)	0 (0)	0 (0)	0.22 (0.56)
	Summer (*n* = 695)	0.01 ± 0.05 (0.02 ± 0.13)	0 (0)	0 (0)	0 (0)	0 (0)	0.74 (1.88)
	Winter (*n* = 294)	0.01 ± 0.03 (0.03 ± 0.07)	0 (0)	0 (0)	0 (0)	0 (0)	0.24 (0.61)
Visibility, in statute miles (km)	Fall (*n* = 570)	8.3 ± 2.6 (13.4 ± 4.2)	0.8 (1.2)	6 (9.7)	10 (16.1)	10 (16.1)	10 (16.1)
	Spring (*n* = 613)	8.9 ± 2.3 (14.4 ± 3.8)	0 (0)	10 (16.1)	10 (16.1)	10 (16.1)	10 (16.1)
	Summer (*n* = 695)	8.9 ± 2.1 (14.4 ± 3.5)	0.5 (0.8)	9 (14.5)	10 (16.1)	10 (16.1)	10 (16.1)
	Winter (*n* = 294)	6.7 ± 3.8 (10.7 ± 6.1)	0 (0)	3 (4.9)	9 (14.5)	10 (16.1)	10 (16.1)
Light vehicles, in numbers per minute	Fall (*n* = 570)	0.4 ± 0.3	0	0.1	0.3	0.5	2
	Spring (*n* = 613)	0.2 ± 0.2	0	0.1	0.2	0.4	1.4
	Summer (*n* = 695)	0.3 ± 0.3	0	0.1	0.2	0.3	2
	Winter (*n* = 294)	0.3 ± 0.3	0	0.1	0.2	0.4	1.4
Heavy vehicles, in numbers per minute	Fall (*n* = 570)	0.2 ± 0.2	0	0	0.1	0.3	1
	Spring (*n* = 613)	0.1 ± 0.1	0	0	0.1	0.2	0.8
	Summer (*n* = 695)	0.2 ± 0.2	0	0	0.1	0.2	1
	Winter (*n* = 294)	0.2 ± 0.2	0	0	0.1	0.2	1
Run/close, in minutes per hour	Fall (*n* = 570)	38 ± 9	10	32	38	45	60
	Spring (*n* = 613)	42 ± 13	0	33	44	53	60
	Summer (*n* = 695)	40 ± 9	0	34	40	45	60
	Winter (*n* = 294)	37 ± 7	10	32	38	42	52
Idle/open, in minutes per hour	Fall (*n* = 570)	9 ± 7	0	4	8	14	33
	Spring (*n* = 613)	8 ± 8	0	2	6	12	34
	Summer (*n* = 695)	10 ± 7	0	5	9	14	32
	Winter (*n* = 294)	8 ± 6	0	3	7	11	27
Idle/close, in minutes per hour	Fall (*n* = 570)	13 ± 10	0	5	10	18	48
	Spring (*n* = 613)	10 ± 11	0	2	5	15	60
	Summer (*n* = 695)	10 ± 9	0	5	8	14	60
	Winter (*n* = 294)	15 ± 8	1	9	14	20	40

Some of the independent variables considered in this study such as the month and the season are not statistically independent of other variables. To better understand the association between different independent variables considered in this study, the Pearson correlation (R) matrix developed by SPSS® software was used. Time of the day was statistically independent of all other independent variables. Only a few statistically significant relationships were observed in the R-matrix that had moderate/strong correlations (moderate correlation: 0.4–0.8; strong correlation: 0.8–1.0) and are as follows:

- The month was strongly correlated (0.962) to the season and moderately correlated (0.414) to the ambient temperature. The season and the ambient temperature were moderately correlated (0.430).
- The indoor temperature and the indoor MR were strongly correlated (0.944).
- The ambient temperature and the ambient MR were moderately correlated (0.528).
- The run/close ventilating conditions were moderately correlated (−0.746) with the idle/close ventilating conditions.

3. Results and Discussion

First, the important factors affecting each monitored contaminant were short-listed using the regression tree method, with CART software, on the basis of "Score". CART software computes the variable importance "Score" as a measure that represents the improvement attributable to each independent variable in its role as a surrogate (alternative variable) to the primary split. The values of the improvements are summed up over each node and totaled, and are scaled relative to the best performing variable. The variable with the highest sum of improvements is scored 100, and all other variables are graded downward to zero. No restriction was specified for the number of nodes in the regression tree, so that mean responses obtained can account for all the variability in the output that can be captured by partitioning the dataset. Complete details of the developed regression tree models for in-bus SO_2, NO, and NO_2 gas concentrations were documented in the unpublished CART Report [35]. Next, the short-listed factors obtained from performing the regression tree analysis were screened with the ANOVA to determine a final subset of the statistically significant variables, based on the *F* values. Finally, the monitored in-bus gaseous concentrations were quantified in relation to the subset of statistically significant variables identified from performing the ANOVA on regression tree results. To better understand the quantified relationships between the monitored in-bus gaseous concentrations and the identified statistically significant variables, the 2 sample *t*-test was executed to compute the statistical significance of the difference in the means for both the dependent and the identified statistically significant independent variables, with MINITAB® 16 software. The difference in the computed means of any variable between two datasets is statistically significant when the computed *p*-value (p) ≤ 0.05.

3.1. Sulfur Dioxide

Based on the "Score" values computed by the CART software, the month, sky condition, ambient temperature, heavy vehicles, indoor temperature, indoor MR, run/close ventilating condition, weather type, ambient MR, season, light vehicles, idle/close ventilating condition, and precipitation were short-listed as the important factors that influenced in-bus SO_2 concentrations. From the short-listed factors, one can observe that CART accounted for all the moderate and strong correlations associated with the month. The month was the primary variable to which in-bus SO_2 concentrations were most sensitive, as it was selected as the first basis for splitting the data, and also selected in the subsequent nodes at lower level of the regression tree. Table 3 presents the sensitivity analysis results obtained from performing the ANOVA over regression tree results to study the relationships conditional on the month. The first dataset included data within the months April 2007 to July 2007, September 2007, November 2007, and January 2008, while the second dataset contained data from the months of

August 2007, October 2007, December 2007, February 2008, and March 2008. The large differences between the F values for the statistically significant (Sig.) input variables less than 0.05 indicate that the prioritization is robust. From Table 3, one can observe that only the ambient temperature and the ambient MR had a significant impact on both the datasets. The sky condition and the weather type had a significant effect on in-bus SO_2 concentrations in the first dataset, while the precipitation, heavy vehicles, and the idle/close ventilating conditions had a significant effect only in the second dataset.

Table 3. ANOVA results for the complete database SO_2 regression tree.

Variable	*F* Value	Sig.	Significant	Rank	Variable	*F* Value	Sig.	Significant	Rank
Month = Apr. 07 to July 07, Sep. 07, Nov. 07, Jan. 08					**Month = Aug. 07, Oct. 07, Dec. 07, Feb. 08, Mar. 08**				
Sky condition	13.792	<0.0001	Yes	1	Sky condition	0.008	0.930	No	------
Ambient temp.	1.745	<0.0001	Yes	3	Ambient temp.	1.311	0.049	Yes	4
Heavy vehicles	0.976	0.527	No	------	Heavy vehicles	1.789	0.001	Yes	3
Indoor temp.	1.162	0.477	No	------	Indoor temp.	1.427	0.503	No	------
Indoor MR	0.695	0.769	No	------	Indoor MR	------	------	------	------
Run/close	0.859	0.869	No	------	Run/close	1.019	0.444	No	------
Weather type	2.746	0.002	Yes	2	Weather type	1.193	0.301	No	------
Ambient MR	1.315	0.007	Yes	4	Ambient MR	1.793	0.003	Yes	2
Season	0.677	0.566	No	------	Season	2.258	0.106	No	------
Light vehicles	0.966	0.572	No	------	Light vehicles	0.816	0.868	No	------
Idle/close	0.894	0.845	No	------	Idle/close	1.276	0.039	Yes	5
Precipitation	1.047	0.402	No	------	Precipitation	2.938	<0.0001	Yes	1

Considering the complete database SO_2 regression tree and the ANOVA sensitivity analysis results, the month, ambient MR, ambient temperature, sky condition, precipitation, weather type, heavy vehicles, and idle/close ventilating conditions were ranked one to eight, respectively, that influenced the in-bus SO_2 concentrations. In view of the strong/moderate correlations between the independent variables considered in this study and *F*-values from Table 3, one can say the SO_2 concentrations inside the bus were extremely sensitive to the month, weather conditions (ambient MR, ambient temperature, sky condition, precipitation, weather type), and heavy vehicles.

Prior studies observed the outdoor SO_2 concentrations (vehicular exhaust emissions and atmospheric background concentrations) to vary negatively with the ambient temperature and precipitation, and positively with the ambient humidity; the outdoor SO_2 concentrations are higher during the late fall and winter months in colder places, such as Toledo, Ohio, USA [17–21]. On studying the optimal regression tree model developed with CART software, similar relationships were obtained for the in-bus SO_2 concentrations. This could mainly be a result of the lack of indoor SO_2 sources. To better understand the quantified relationships, this study categorized the in-bus SO_2 concentrations into three classes (at one-third range approximation): low (<0.4 ppm), medium (0.4–0.7 ppm), and high (>0.7 ppm) concentrations. Additional details on the quantified relationships for in-bus SO_2 concentrations are discussed in the subsequent sections.

3.1.1. Influence of the Month (Ambient Temperature) under Changing Ventilation Conditions

Low in-bus SO_2 concentrations were observed for both the combinations of (a) the spring-summer months dominated dataset, *i.e.*, Dataset 1; and (b) the fall-winter months dominated dataset, *i.e.*, Dataset 2. In-bus SO_2 concentrations were statistically significantly ($t = -7.27$, $p = 0.000$) higher in the fall-winter months dominated dataset ($\mu = 0.2$ ppm) when compared with the spring-summer months dominated dataset ($\mu = 0.1$ ppm). Table 4 presents a summary of the statistical significance of the difference between the computed means of the ranked numeric variables (obtained from performing the 2-sample *t*-test), using the two datasets. From Table 4, one can observe the precipitation and the heavy vehicles as statistically similar for the two datasets. The spring-summer months dominated dataset had significantly higher ambient temperature and ambient MR, and significantly lower idle/close ventilating conditions when compared with the fall-winter months dominated dataset. The following observations were made on studying the optimal SO_2 regression tree model:

- On an average, there was significantly higher in-bus SO_2 concentrations observed in the fall-winter months dominated dataset when compared with the spring-summer months dominated dataset.
- With significantly more idling time and reduced ventilation settings (idle/open ventilating conditions), the higher in-bus SO_2 concentrations observed in the fall-winter months dominated dataset can be attributed to have resulted from the greater infiltration of the higher outdoor SO_2 concentrations, normally observed in the late fall and winter.
- In-bus SO_2 concentrations (with no indoor sources) showed a negative relationship with the ambient temperature and the ambient MR, which was consistent with the behavior of outdoor-generated SO_2 concentrations.

Table 4. 2-Sample *t*-test results for the spring-summer months dominated dataset and the fall-winter months dominated dataset.

Variable	μ		Sig. (*t*-value, *p*-value)	Significant
	Spring-Summer Dataset	Fall-Winter Dataset		
Ambient temp. in °F (°C)	63.2 (17.3)	58.9 (14.9)	(3.51, 0.000)	Yes
Ambient MR	15.8	12.5	(6.94, 0.000)	Yes
Precipitation in inches (cms)	0.01 (0.02)	0.01 (0.02)	(−1.23, 0.219)	No
Heavy vehicles in numbers per minute	0.2	0.2	(0.47, 0.641)	No
Idle/close in minutes per hour	11	13	(−3.73, 0.000)	Yes

3.1.2. Influence of the Heavy Vehicles in the Fall-Winter Dominated Months

Medium and low in-bus SO_2 concentrations were observed in the fall-winter months dominated dataset. In-bus SO_2 concentrations were statistically significantly higher ($t = -3.06$, $p = 0.038$) when the heavy vehicle density >56/h or 0.94/min ($\mu = 0.4$ ppm), as compared with the case of heavy vehicle density ≤56/h or 0.94/min ($\mu = 0.2$ ppm) in the fall-winter months dominated dataset. Table 5 presents a summary of the statistical significance of the difference between the computed means of the ranked numeric variables (obtained from performing the 2-sample *t*-test) with the fall-winter months

dominated dataset, which was conditional on heavy vehicle classification. From Table 5, one can observe that there is statistically no significant difference between any of the ranked numeric variables. The following observation was made on studying the optimal SO_2 regression tree model:

- With statistically similar atmospheric parameters and ventilating conditions, in-bus SO_2 concentrations were strongly influenced by the lead heavy vehicular traffic in the fall-winter months and were shown to be positively related to the lead heavy vehicular traffic.

Table 5. 2-Sample *t*-test results for the fall-winter months dominated dataset classification conditional on the heavy vehicles.

Variable	μ		Sig. (*t*-value, *p*-value)	Significant
	Heavy Vehicles ≤ 56/h	Heavy Vehicles > 56/h		
Ambient temp. in °F (°C)	58.7 (14.9)	72.4 (22. 5)	(−1.41, 0.230)	No
Ambient MR	12.5	12.1	(0.20, 0.855)	No
Precipitation in inches (cms)	0.01 (0.02)	0.03 (0.08)	(−1.11, 0.331)	No
Idle/close in minutes per hour	13	14	(−0.21, 0.845)	No

3.1.3. Influence of the Weather Type, the Ambient MR, and the Precipitation on Days with Broken/Broken-Overcast Sky Conditions in the Spring-Summer Months

For the spring-summer months dominated dataset with broken/broken-overcast (BKN/BKN-OVC) sky conditions, low in-bus SO_2 concentrations were observed throughout the year, irrespective of the weather type, precipitation amounts, and ventilating settings. In-bus SO_2 concentrations were statistically significantly lower ($t = -3.07$, $p = 0.003$) on days with haze, rain, thunderstorm, and mist weather types ($\mu = 0.1$ ppm), when compared with days having fog and normal weather conditions ($\mu = 0.2$ ppm). Table 6 presents a summary of the statistical significance of the difference between the computed means of the ranked numeric variables (obtained from performing the 2-sample *t*-test), for the spring-summer months dominated dataset with BKN/BKN-OVC sky conditions, which are conditional on the weather type classification. From Table 6, one can observe the ambient temperature, heavy vehicles, and idle/close ventilating conditions are statistically similar for the two datasets. The spring-summer months dominated dataset with BKN/BKN-OVC sky conditions had significantly higher ambient MR and precipitation on days with haze, rain, thunderstorm, and mist weather types when compared to the days when the weather is foggy or normal. The ambient MR was directly proportional to the precipitation. Based on the above-mentioned conditions and upon studying the optimal SO_2 regression tree model, the following observations were made:

- For statistically similar ventilating conditions and heavy vehicular traffic, significantly lower in-bus SO_2 concentrations were observed on days with haze, rain, thunderstorm, and mist weather types, when compared with the foggy and normal weather type days, in the spring-summer months dominated dataset with BKN/BKN-OVC sky conditions.
- In-bus SO_2 concentrations (with no indoor sources) showed an inverse relationship with the precipitation and the ambient MR. These relationships are in accordance with the relationships exhibited by atmospheric SO_2 concentrations, considering outdoor SO_2 concentrations also vary negatively with the precipitation.

Table 6. 2-Sample *t*-test results for the spring-summer months dominated dataset with BKN/BKN-OVC sky conditions classification conditional on the weather type.

Variable	μ		Sig. (*t*-value, *p*-value)	Significant
	Haze, Rain, Thunderstorm, Mist	Fog, Normal		
Ambient temp. in °F (°C)	67.4 (19.7)	65.4 (18.6)	(1.40, 0.165)	No
Ambient MR	18.8	15.5	(3.28, 0.002)	Yes
Precipitation in inches (cms)	0.03 (0.07)	0.01 (0.01)	(2.34, 0.023)	Yes
Heavy vehicles in numbers per minute	0.03	0.03	(0.10, 0.923)	No
Idle/close in minutes per hour	11	11	(−0.33, 0.740)	No

3.2. Nitric Oxide

CART software short-listed the month, ambient MR, wind speed, ambient temperature, time of the day, run/close, idle/close, idle/open, light vehicles, indoor temperature, indoor MR, season, and weather type as the influential variables affecting in-bus NO concentrations. The month was the most important factor to which in-bus NO was sensitive, since it was selected as the first basis for splitting the data. Table 7 presents the sensitivity analysis results obtained from performing the ANOVA over NO regression tree results to study the relationships conditional on the month. The first dataset included data with the months May 2007 to November 2007, referred as the summer dominated dataset. The second dataset contained data with the months April 2007 and December 2007 to March 2008, referred as the winter dominated dataset. From Table 7, one can observe the run/close and the idle/close ventilating conditions to be influential in both the cases. The season and the ambient temperature additionally influenced the summer dominated dataset, while the winter dominated dataset was also influenced by the idle/open ventilating conditions.

Table 7. ANOVA results for the complete database NO regression tree.

Variable	*F* Value	Sig.	Significant	Rank	Variable	*F* Value	Sig.	Significant	Rank
Month = May. 07 to Nov. 07					Month = Apr. 07, Dec. 07 to Mar. 08				
Ambient MR	0.925	0.795	No	------	Ambient MR	0.130	1.000	No	------
Wind speed	0.602	0.919	No	------	Wind speed	1.508	0.071	No	------
Ambient temp.	1.710	<0.0001	Yes	2	Ambient temp.	0.802	0.878	No	------
Time of the day	0.854	0.624	No	------	Time of the day	0.841	0.639	No	------
Run/close	1.401	0.005	Yes	4	Run/close	7.930	<0.0001	Yes	1
Idle/close	1.536	<0.0001	Yes	3	Idle/close	2.090	<0.0001	Yes	3
Idle/open	1.112	0.212	No	------	Idle/open	3.748	<0.0001	Yes	2
Light vehicles	0.543	1.000	No	------	Light vehicles	0.910	0.695	No	------
Indoor temp.	0.409	0.983	No	------	Indoor temp.	11.621	0.231	No	------
Indoor MR	0.354	0.907	No	------	Indoor MR	------	------	------	------
Season	6.427	0.002	Yes	1	Season	0.811	0.445	No	------
Weather type	1.067	0.384	No	------	Weather type	0.247	0.981	No	------

Considering the complete database NO regression tree and the results of the ANOVA sensitivity analysis, the month, run/close, idle/close, season, idle/open, and ambient temperature were ranked from one to six, respectively, to which in-bus NO concentrations were sensitive.

Prior studies indicated that atmospheric NO concentrations (formed by the oxidation of atmospheric N_2) varied positively with the ambient temperature, while NO concentrations from the vehicular exhaust emissions varied negatively with the ambient temperature [20]. Thus, the variation of outdoor NO concentrations largely depends on the formation mechanism. In colder places, such as Toledo, Ohio, USA, vehicular NO exhaust emission concentrations form the dominant part of the outdoor NO concentrations, due to NO formation by rapid cooling of the vehicular exhaust emissions and inhibition of NO dispersion at lower temperatures. Accordingly, outdoor NO concentrations are expected to be the highest in the winter months. Based on the developed NO complete database regression tree model, in-bus NO concentrations were categorized into three classes (at one-third range approximation): low (<8 ppm), medium (8–16 ppm), and high (>16 ppm) concentrations to better understand the quantified relationships. Additional details on the quantified relationships for in-bus NO concentrations are discussed in the subsequent sections.

3.2.1. Influence of the Month/Season (Ambient Temperature) under Different Ventilation Levels

Low NO concentrations were observed inside the test bus cabin throughout the year, regardless of the dataset classification, which was conditional on the month. In-bus NO concentrations were statistically significantly ($t = -2.18$, $p = 0.030$) higher in the winter months dominated dataset ($\mu = 0.6$ ppm) when compared with the summer months dominated dataset ($\mu = 0.3$ ppm). Table 8 presents a summary of the statistical significance of the difference between the computed means for the ranked numeric variables (obtained from performing the 2-sample *t*-test), for the two datasets, conditional on the month. From Table 8, one can observe the ambient temperature, run/close, and idle/open conditions were significantly higher in the summer-dominated dataset, while the idle/close conditions were significantly higher in the winter-dominated dataset. The following observations were made in consideration of the above-mentioned conditions, as well as studying the optimal NO regression tree model:

- In-bus NO concentrations always remained low, irrespective of the month/season.
- Even with significantly reduced ventilation settings in the winter months dominated dataset, significantly higher in-bus NO concentrations were observed. This was possibly due to accumulation of the higher outdoor NO concentrations under limited ventilating conditions in winter months. Note that the lead vehicular traffic was also greater in the winter when compared to other seasons (refer to Table 2).
- In the summer months dominated dataset, there was good ventilation that caused the dilution of accumulated in-bus NO concentrations. There was also a possibility of increased dispersion of the outdoor NO concentrations, normally associated with higher ambient temperatures, which could have contributed to less in-bus NO concentration buildup.
- In-bus NO concentrations (with no indoor sources) have shown a negative relationship with the ambient temperature, considering that the ambient temperature is a function of the month/season.

Table 8. 2-Sample *t*-test results for the summer-dominated dataset and winter-dominated dataset.

Variable	μ		Sig. (*t*-value, *p*-value)	Significant
	Summer Dataset	Winter Dataset		
Run/close in minutes per hour	41	38	(4.77, 0.000)	Yes
Idle/close in minutes per hour	10	15	(−7.77, 0.000)	Yes
Idle/open in minutes per hour	9	8	(4.77, 0.000)	Yes
Ambient temp. in °F (°C)	70.1 (21.2)	42.6 (5.9)	(25.80, 0.000)	Yes

3.3. Nitrogen Dioxide

The time of day, month, idle/close, ambient MR, light vehicles, season, run/close, ambient temperature, and idle/open conditions were short-listed by the CART software, to which in-bus NO_2 concentrations were sensitive. The time of day was observed to be the most sensitive factor, as it was selected as the first basis for splitting the data. Table 9 presents the sensitivity analysis results obtained from performing the ANOVA, which were conditional on the time of day. The first dataset included data monitored between 6:00 a.m. and 7:00 a.m. The second dataset contained data monitored between 7:00 a.m. and 11:00 p.m. From Table 9, one can note the ambient MR was significant in both the datasets. The first dataset was also influenced by the idle/close and run/close ventilating conditions, while the second dataset was additionally influenced by the month, season, and ambient temperature.

Table 9. ANOVA results for the complete database NO_2 regression tree.

Variable	*F* Value	Sig.	Significant	Rank	Variable	*F* Value	Sig.	Significant	Rank
Time of day = 6:00 a.m. to 7:00 a.m.					**Time of day = 7:00 a.m. to 11:00 p.m.**				
Month	1.123	0.355	No	------	Month	40.636	<0.0001	Yes	1
Idle/close	1,314.106	<0.0001	Yes	1	Idle/close	0.164	1.000	No	------
Ambient MR	215.640	0.005	Yes	2	Ambient MR	1.533	<0.0001	Yes	4
Light vehicles	0.073	1.000	No	------	Light vehicles	0.333	1.000	No	------
Season	0.806	0.494	No	------	Season	16.999	<0.0001	Yes	2
Run/close	102.393	<0.0001	Yes	3	Run/close	0.157	1.000	No	------
Ambient temp.	0.345	1.000	No	------	Ambient temp.	1.772	<0.0001	Yes	3
Idle/open	0.145	1.000	No	------	Idle/open	0.173	1.000	No	------

Considering the complete database NO_2 regression tree and results of the ANOVA secondary analysis, in-bus NO_2 concentrations were most sensitive to the time of day, ambient MR, idle/close, run/close, month, season, and ambient temperature, ranked in ascending order.

Prior studies observed outdoor NO_2 concentrations were highest, early in the mornings (as a consequence of the exhaust emissions from morning vehicular rush and reaction of the newly emitted NO with O_3 without sunlight to form NO_2), while ambient temperature was inversely related to outdoor NO_2 concentrations [24]. On studying the optimal NO_2 regression tree model, similar relationships were observed for the in-bus NO_2 concentrations. This shows the strong influence of outdoor NO_2 concentrations on in-bus NO_2 concentrations, with no indoor sources. To better

understand the quantified relationships, NO_2 concentrations inside the bus were categorized into three classes (at one-third range approximation): low (<1 ppm), medium (1–2 ppm), and high (>2 ppm) concentrations. More details on the quantified relationships for in-bus NO_2 concentrations are discussed in the subsequent sections.

3.3.1. Influence of the Time of Day under Different Ventilation Levels

Low in-bus NO_2 concentrations were observed throughout the year, despite the time of day. In-bus NO_2 concentrations were statistically significantly ($t = -1.97$, $p = 0.049$) higher in the early morning dataset ($\mu = 0.1$ ppm), *i.e.*, between 6:00 a.m. and 7:00 a.m., when compared with rest of the day dataset ($\mu = 0$ ppm), *i.e.*, between 7:00 a.m. and 11:00 p.m. Table 10 presents a summary of the statistical significance of the difference between the computed means for the ranked numeric variables of the two time of day datasets (obtained from performing the 2-sample *t*-test). From Table 10, one can observe the ambient temperature to be statistically similar for the two datasets. The higher ambient temperatures associated with warm days/afternoon were leveled with the lower ambient temperatures associated with cold days/evening and nights. Consequently, this resulted in more or less equivalent ambient temperatures for the early morning and rest-of-the-day datasets. The early morning dataset had significantly lower ambient MR and idle/close ventilating conditions, and significantly higher run/close ventilating conditions when compared with rest-of-the-day dataset. The following observations were made upon studying the optimal NO_2 regression tree model:

- In-bus NO_2 concentrations always remained low regardless of the time of day.
- With equivalent idle/open ventilating conditions, significantly higher in-bus NO_2 concentrations were observed early in the mornings when compared with rest-of-the-day NO_2 concentrations inside the bus. This result could be primarily due to the infiltration of higher outdoor NO_2 concentrations (normally associated with the early mornings).

Table 10. 2-Sample *t*-test results for the early morning and rest of the day datasets.

Variable	μ		Sig. (*t*-value, *p*-value)	Significant
	Early Morning Dataset	Rest-of-the-Day Dataset		
Ambient MR	10.1	14.8	(−7.93, 0.000)	Yes
Idle/close in minutes per hour	10	12	(−1.99, 0.049)	Yes
Run/close in minutes per hour	42	40	(2.28, 0.025)	Yes
Ambient temp. in °F (°C)	61.9 (16.6)	61 (16.1)	(0.38, 0.707)	No

3.3.2. Influence of the Month/Season (Ambient Temperature) under Different Ventilation Levels

Low NO_2 concentrations were observed inside the bus compartment, regardless of the month. In-bus NO_2 concentrations were statistically significantly ($t = -2.91$, $p = 0.004$)) higher in the winter-spring months dominated dataset ($\mu = 0.1$ ppm) when compared to the summer-fall months dominated dataset ($\mu = 0$ ppm). The winter-spring months dominated dataset included the observations from May 2007, June 2007, December 2007, February 2008, and March 2008, while the summer-fall dominated dataset included the months April 2007, July 2007 to November 2007, and January 2008. Table 11 presents a summary of the statistical significance of the difference between the computed means for the ranked

numeric variables (obtained from performing the 2-sample *t*-test) for the two datasets classified on the basis of the month. From Table 11, one can observe the ambient MR and run/close ventilating conditions to be statistically similar for the two datasets. The winter-spring dataset had significantly higher idle/close ventilating conditions and significantly lower ambient temperature, when compared to the summer-fall dataset. The following observations were made upon studying the optimal NO_2 regression tree model:

- Significantly higher in-bus NO_2 concentrations were observed in the winter-spring months (with lower ambient temperatures) when compared with the summer-fall months (with higher ambient temperatures).
- In-bus NO_2 concentrations were negatively related to the ambient temperatures. As there are no NO_2 sources inside the bus, this relationship holds true, considering a similar relationship existed between the ambient temperature and outdoor NO_2 concentrations.

Table 11. 2-Sample *t*-test results for rest of the day datasets conditional on the month.

Variable	μ		Sig. (*t*-value, *p*-value)	Significant
	Summer-Fall Dataset	Winter-Spring Dataset		
Ambient MR	15.1	14.3	(1.76, 0.078)	No
Idle/close in minutes per hour	11	12	(−2.84, 0.005)	Yes
Run/close in minutes per hour	39	40	(−0.57, 0.570)	No
Ambient temp. in °F (°C)	67.8 (19.9)	51.2 (10.7)	(15.20, 0.000)	Yes

4. Validation of the Methodology

This study validated the methodology by using the ANOVA as a secondary analysis to the regression tree results that helped determine a subset of statistically significant variables. Results obtained from using the complete database were compared with the results obtained from using the test database (90% of the hourly data points from the complete database) at two stages. In the first stage, the important variables short-listed from using the complete and test databases (using CART software) were compared. In the second stage, the statistically significant subsets of important variables (identified from using the ANOVA on regression tree results) were compared to see the consistency in the methodology. More detailed information on the validation results were documented in an unpublished CART report [35]. The following observations summarize the validation results on using the two databases:

- The regression tree primary splitting criterion remained unchanged, irrespective of the database considered.
- Regression tree analysis performed well in determining a set of important factors affecting each monitored in-bus contaminant concentration, considering that the short-listed factors (primary variable included) obtained from using the complete database were also attained from using the test database.
- In addition to the complete database short-listed factors, a few other variables (with very low scores) affected the test database.

- The ANOVA ranking results were consistent for both the databases, considering the same set of variables were determined to be statistically significant.
- The additional factors short-listed by the regression trees, using the test database, were observed to be not statistically significant.

5. Conclusions

The sensitivity of SO_2, NO, and NO_2 concentrations to the statistically significant factors affecting in-bus air quality was studied. Regression trees and the ANOVA were used to accomplish the research objectives of quantifying the in-bus SO_2, NO, and NO_2 concentration relationships, using a comprehensive one-year database of the independent variables and the monitored contaminant concentrations. SO_2 concentrations inside the bus compartment were extremely sensitive to the month, weather conditions, and heavy vehicles. In-bus NO concentrations were sensitive to the month/season, ventilation settings, and ambient temperature; while NO_2 concentrations inside the bus were influenced by the time of day, ambient MR, idle/close, run/close, month/season, and ambient temperature. NO and NO_2 concentrations inside the bus remained low throughout the year, irrespective of the conditions. Medium in-bus SO_2 concentrations were observed only in the fall-winter months, when the lead heavy vehicular density was a minimum of 56 per hour. For the remainder of the year, the in-bus SO_2 concentrations remained low. It should be noted that this study is based on the data collected inside a single transit bus and that, while it illustrates a technique for interpreting the data, the results may not be generalizable. Considering the closeness of monitored SO_2, NO, and NO_2 concentrations to the Yes Plus instrument lower detection limits, an experimental framework that can incorporate more number of test buses must be designed and the proposed methodology of quantification implemented to achieve the generalized quantitative in-bus relationships.

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