Comparisons of the Vehicular Emission Exposure Levels of Respirable Particulate Matter for Three Types of Commuters: Bus, Car and Bicycle

by

Lisa Kirkham

B.Sc., Simon Fraser University, 2003

PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
Bachelor of Technology in Environmental Health

BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
May 2008

Table of Contents

Abstract:

Previous studies implicate vehicular emissions as possible causes for asthma and asthmatic attacks in children, as well as elevated risks of adverse pregnancy outcomes, certain cancers, cardiovascular disease and even death. Due to the negative health effects associated with vehicular emissions particulate matter air pollutants were analyzed in an effort to establish which mode of transportation provides the least amount of vehicular emission exposure. The results determined the mode of transportation which has the least negative impact upon public health. The exposure levels of airborne particulate matter were examined between three types of commuters, those that traveled within the automobile environment by both car and bus and those that traveled in the outdoor environment by bicycle. Respirable particulate matter is an indicator species for both other harmful gases and ultra fine air particulates of vehicular emissions and therefore was chosen as the vehicular pollutant to be examined in the study. The DustTrak™ Aerosol Flow Monitor 8520 continuously sampled the exposure levels within the breathing zone of the researcher for the three modes of transportation during multiple, 3 hour, Wednesday evening rush hour intervals on the Stanley Park Causeway, in Vancouver B.C, during the month of January 2008. The results of the primary analysis of mean exposure levels were 0.0307, 0.0240 and 0.0175 mg/m^3 for bus, bicycle and car respectively. The particulate matter exposure levels were then analyzed utilizing Kruskal-Wallis One-Way ANOVA, Scheffe's Multiple Comparison Test and Tukey-Kramer Multiple-Comparison Test which determined the probability level as less than 0.000000 and therefore the null hypothesis, there is no difference between exposure levels from vehicular emissions for commuters travelling by bus, car or bicycle, was rejected and a statistically significant difference between the three exposure levels was found. Although the particulate exposure levels were well below the maximum levels established by Health Canada, from the perspective of public health the car was the safest method of transportation with respect to particulate matter exposure levels.

Introduction:

Many options are available for commuters with respect to the daily modes of transportation. Although most commuters understand the obvious safety hazards that exist with each transportation option they may not understand which mode of transportation is the safest with respect to air pollutant exposure. In an effort to establish which mode of transportation has the lowest air pollutant exposure this study examines automobile exhaust exposure for two types of commuters, those travelling as automobile occupants, specifically those travelling by both car and bus, and those travelling outside of vehicles, specifically cyclists.

Although several studies have examined the implications of individual occupational exposure due to vehicular emissions few have investigated daily commuter exposures. Of the studies that investigated everyday pollutant exposure from vehicular exhaust very few compared commuter ambient air emission levels within or on different modes of transportation. Instead, research has been limited to one independent form of transportation such as cyclist exposure in Copenhagen (Vinzents et al. 2005). From a public health perspective it is essential to assess pollution exposure associated with different modes of transportation in order to minimize the impact placed upon public health.

Literature Review:

Exposure of individuals to in-vehicle emissions is very significant due to the exposure levels within the vehicle as compared to the external environment. A study examining the occupational exposure of police officers within patrol cars concluded roadsides in close proximately to freely moving traffic maintain levels of air pollution much lower than those experienced within the vehicle (Riediker et al. 2004). Vehicles represent a "microenvironment" of potentially high exposure levels of air pollutants from vehicular emissions (Riediker et al. 2004). However, currently no studies have determined which type of vehicle, such as car or bus, has the least amount of in-vehicle air pollutants.

Exposure to automobile exhaust is highest nearest to the source. Therefore cyclists and pedestrians account for a significant level of exposure of the general public due to their close proximity to the road while commuting. Furthermore, an additional factor that must be considered when comparing cycling and walking to other forms of transportation is an increase in both heart rate and lung capacity that must be induced to travel. The increase in lung capacity and ventilation rate of a physically active individual increases the internal dose of pollutant received by that individual (Daigle et al. 2003). The result is higher exposure levels and altered lung deposition of air pollutants in those individuals utilizing physically demanding modes of transportation over those individuals utilizing modes of transport that enable the commuter to remain stationary (Vinzents et al. 2005, Daigle et al. 2003, Bräuner et al. 2007).

The major air pollutants from automobile exhaust exist in various forms. Nitrous oxides (NO_X), carbon monoxide (CO), sulphur oxides (SO_X), unburned hydrocarbons, other organic compounds, polycyclic aromatic hydrocarbons (PPAH), and particulate matter are the most widely reported air pollutants associated with vehicular emissions (Brugge et al. 2007, Ferguson et al. 2004). Diesel exhaust is a significant contributor to coarse, fine and ultrafine particulate matter (UFP) some of which result from chemical reactions of other pollutants, including sulphur dioxide and nitrogen oxides (Cohen 2000). $PM_{2.5}$ and PM_{10} refer to particulate matter with aerodynamic diameters of 2.5 and 10 um, respectively while ultrafine particulates posses a diameter in the range of 0.0005 to 0.1 microns (Brugge et al. 2007, Delfino et al. 2005). Diesel exhaust also contains relatively high levels of various polynuclear aromatic hydrocarbons (PAHs) such as the carcinogen benzo(*a*)pyrene (BaP) (Penn et al. 2005, Marr et al. 2004, Brugge et al. 2007). The volatile organic compound 1,3-Butadiene is an additional emission of vehicular exhaust and thus contributes to urban air pollution (Cohen 2000). Additionally, various aldehydes, such as formaldehyde and acetaldehyde, are released into the air as the result of the combustion of both gasoline and diesel fuels (Cohen 2000). The aldehydes are also of concern with respect to alternative fuels, such as methanol and oxygenated fuels containing the additive methyl tertiary butyl ether, for the combustion of these fuels result in the production of greater aldehyde emissions and a further increased level of air pollution (Cohen 2000). Black carbon (BC) or "soot carbon" is an impure form of elemental carbon which has been found to be associated with vehicular emissions (Brugge et al. 2007). Each pollutant, both individually and in combination with others, contributes to the overall degradation of air quality and overall population health.

Vehicle emissions are significant contributors to urban air pollution (McDonald et al. 2004). Known toxins found in vehicle emissions enter into the atmosphere thereby causing air pollution. Therefore it is of little surprise that numerous studies have concluded an association between population exposure to air pollution from vehicular emissions and both acute and long term adverse health effects (McDonald et al. 2004, Pope and Dockery 2006, Ferguson et al. 2004). Pulmonary and cardiovascular diseases as well as cancer, asthma and even mortality have been linked to traffic exhaust related exposure (Pope and Dockery 2006, Ferguson et al. 2004).

Known carcinogens are released from vehicular emissions on a daily basis (Cohen 2000). The Environmental Protection Agency of the United States has determined diesel exhaust as "likely to be carcinogenic to humans by inhalation" (Brugge et al. 2007). Diesel exhaust, formaldehyde and 1,3-Butadien in particular are classified as "probable human carcinogen[s]" by IARC classification 2A (Cohen 2000). Furthermore, associations have been made between lung cancer and both particulate matter and nitrogen dioxide (Brugge et al. 2007). Extensive epidemiological research established cancer as a proven result of long term exposure to many localized sources of air pollution (Cohen 2000). Of significance to this report are those areas with high vehicular traffic.

When examining the effects of ultrafine particulate matter upon DNA it was found that controlled exposure to ultrafine particulate matter is associated with oxidative DNA damage (Bräuner et al. 2007, Penn et al. 2005). Oxidative damage is considered to be an important initial event in carcinogenesis (Garshick et al. 2004). Therefore oxidative DNA damage, the consequence of exposure to the respirable ultrafine particulates found in vehicle emissions, specifically those derived from diesel exhaust, potentially results in both mutations and cancer (Vinzents et al. 2005, Garshick et al. 2004, Cohen 2000, Brugge et al. 2007).

In recent epidemiological research, outdoor air pollution has been implicated as a major precursor for both cardiovascular hospital admissions and mortality (Delfino et al. 2005). Associations exist between black carbon and decreased heart rate variability as well as between nitrogen dioxides and cardiopulmonary mortality (Brugge et al. 2007). Additionally, numerous studies have implicated both fine and ultrafine particles found in air pollution as significant precursors to cardiovascular diseases (Delfino et al. 2005, Penn et al. 2005). Short-term exposure to particulates exacerbates existing pulmonary and cardiovascular disease while long-term, repeat exposures increase the risk for both cardiovascular disease and death (Brugge et al. 2007). However, the exact mechanisms by which these events occur remain a theory (Delfino et al. 2005).

The high surface area of particulate matter, especially that of ultrafine particulates, enable the transportation of a large number of adsorbed or condensed toxic air pollutants, which have been implicated as a contributor to pro-inflammatory effects, into the target sites of the lungs (Delfino et al. 2005, Bräuner et al. 2007). The chemical composition in combination with small particle size and high reactivity enables the particulates to posses a high pulmonary toxicity and deposition efficiency (Delfino et al. 2005, Bräuner et al. 2007). These particulates once inhaled deposit in the lung, translocate through the epithelium of the terminal bronchioles and alveoli, and continue into the systemic circulation thereby reaching the heart or more distal organs (Penn et al. 2005, Bräuner et al. 2007). Previous studies have confirmed that ultrafine particulates from automobile exhaust cause systemic oxidative damage (Bräuner et al. 2007). Therefore, it is theorized that acute changes observed in the cardiovascular system are a result of inflammation and oxidative stresses acquired from the exposure of target sites, including the lungs, vasculature or heart, with the redoxactive components in ultrafine particulates (Delfino et al. 2005, Vinzents et al. 2005). Of particular concern is the everyday exposure levels encountered in close proximity to roads of high traffic volume. The resultant exposure levels of ultrafine particulates are high enough to cause the aforementioned systemic oxidative stress (Bräuner et al. 2007). This is significant with respect to this study as it is the everyday stresses which ultimately affect the general population.

Currently there is no proven evidence to link air pollution and an increase in adverse birth outcomes. However, there is sufficient evidence to link a causal relationship between particulate air pollution and postneonatal period respiratory deaths (Šrám et al. 2005). Additionally, although further testing needs to occur, the evidence points to causality for air pollution and decreased birth weights (Šrám et al. 2005).

Air pollutant exposure has been theorized to induce or aggravate asthma as well as increase the permeability of the airways to other allergens to which asthmatics are susceptible (Ferguson et al. 2004). Studies have linked air pollutant exposure, specifically that of carbon monoxide, sulphur dioxide, nitrogen dioxide and particulate matter, to asthmatic incidences (Yu et al. 2002, Ferguson et al. 2004). Nitrogen dioxide exposure is significant with respect to asthma due to its ability to increase cell membrane permeability, decrease ciliary beat frequency, increase the response of asthmatics to inhaled allergens, cause bronchoconstriction and bronchial hyper-reactivity as well as cause inflammation and damage to the airway epithelium (Ferguson et al. 2004, Devalia et al. 1993). Furthermore, examination of epidemiological studies suggests an association between air pollution levels and the exacerbation of asthma.

Previous studies indicated the odds ratios for asthma and other asthmatic symptoms increased in subjects exposed to heavy lorry traffic (Ciccone et al. 1998). Additionally, a direct correlation was proven between heavy traffic and an increase in childhood asthma-related hospital admissions (Edwards et al. 1994). Other data suggests an association between increased hospitalization of individuals due to asthma related illnesses and proximity of the individuals' homes to road traffic (Edwards et al. 1994, Lin et al. 2002). Studies in both Paris and Israel show emissions of nitrogen oxides influence asthma related emergency room hospitalization (Garty et al. 1998, Dab et al. 1996). These studies and others have shown an association between the increased potential for asthma and an increase in air pollution, specifically that of vehicle emissions. Asthma is a common disease for which the incidence rate is rapidly growing due to the increase in vehicle related air pollution (Ferguson et al. 2004).

Air quality is of particular concern to those most susceptible individuals of the population. Studies have indicated that children and the elderly are more at risk for adverse health outcomes from air pollution than the general population. As well, new evidence suggests an association between elevated risks of adverse pregnancy outcomes and air pollution (Šrám et al. 2005). Those with previously existing cardiovascular health problems represent yet another negatively impacted group (Brugge et al. 2007). As these groups are the least motile of the population exposure to automobile emissions while occupying vehicles will be of more concern to these groups than exposure from other forms of transportation, specifically cycling or walking. This is of particular significance in this study with respect to the potentially higher in-vehicle exposure levels to the most susceptible. These most vulnerable members of society have an even greater need for public health protection from the everyday exposures of air pollutants.

The Canadian guidelines for maximum acceptable outdoor exposure limits of Total Suspended Particulates are 120 $\mu g/m^3$ for 24 hours (Health Canada 2006).

Table of National Ambient Air Quality Objectives & Guidelines in Canada				
Pollutant	**Averaging Time**	**Maximum Desirable Level**	**Maximum Acceptable Level**	**Maximum Tolerable Level**
Sulphur dioxide (SO_2)	annual 24 hours 1 hour	11 ppb 57 ppb 172 ppb	23 ppb 115 ppb 334 ppb	--- 306 ppb ---
Total Suspended Particulate (TSP)	annual 24 hours	60 µg/m3 ---	70 µg/m3 120 µg/m3	--- 400 µg/m3
Carbon Monoxide (CO)	8 hours 1 hour	5 ppm 13 ppm	13 ppm 31 ppm	17 ppm ---
Nitrogen Dioxide (NO_2)	annual 24 hours 1 hour	32 ppb --- ---	53 ppb 106 ppb 213 ppb	--- 160 ppb 532 ppb
Ozone (O_3)	annual 24 hours 1 hour	--- 15 ppb 51 ppb	15 ppb 25 ppb 82 ppb	--- --- 153 ppb

(Health Canada 2006)

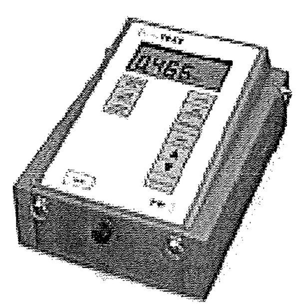
As human exposure to vehicular emissions contributes to overall population health decline it is imperative that extensive investigations be made into everyday commuting patterns. Comparisons of pollutant exposures among different modes of transportation have not been studied extensively thus far. As North Americans utilize cars, buses and bicycles for the sole purpose of transportation it is essential that these comparisons be made to determine which mode of transport is the healthiest, with respect to air quality, for commuters. The purpose of this study was to establish if there is a significant difference in the concentrations of pollutants from vehicular emissions, specifically particulate matter (PM10) levels, between three different modes of transportation, those travelling by car and bus, and those travelling outside of vehicles on bicycles, within the Stanley Park Causeway during typical rush-hour exposures in an effort to establish which mode of transportation has the greatest negative impact upon public health.

Methods and Materials:

Air particulates are one of the most significant contributors to adverse health effects caused by vehicular emissions and, therefore, were chosen as the air pollutant of interest for this study (Delfino et al. 2005, Penn et al. 2005, Bräuner et al. 2007, Brugge et al. 2007, Cohen 2000). Air particulates with an aerodynamic diameter of 10 μm (PM_{10}) were analyzed as they are an indicator species for both other harmful gases, such as nitrous oxides, and ultra fine air particulates of vehicular emissions (Yu et al. 2002, Brugge et al. 2007). As all species originate from a common source, vehicular emissions, they are highly inter-correlated and, as such, inferences about other vehicular pollutants may be made from the particulate matter data (Brugge et al. 2007).

Alternatively, the emissions of gases could have been analyzed as this data enables extrapolation to other roads and studies as well. Carbon monoxide was initially chosen as the indicator gas to be sampled for this study. However, after initial sampling the gas emissions in the atmosphere were found to be negligible and, therefore, carbon monoxide was excluded from the study. Additionally, nitrogen dioxide or sulphur dioxide could have been examined as they too are indicator species for traffic related pollution, however, due to both the instrument and financial limitations of BCIT, neither were chosen (Raaschou-Nielsen et. al 2001).

The DustTrak™ Aerosol Flow Monitor 8520 was the sampling instrument chosen due to its capabilities to sample PM_{10} (TSI Inc. 2007). Additionally, its ease of operation and availability to the analyst were other factors that lead to its selection. Its portability, light weight and compact design elements were important instrument considerations as the researcher had to incorporate the sampling device onto her person. This was especially important when testing exposure levels upon the bicycle as the size of the instrument was a safety concern. Other



(TSI Inc. 2007)

instruments designed for particulate matter sampling could have been employed but were not in part because of the availability of analytic resources at BCIT and also due to budgetary constraints. Alternatively, the PHD Ultra or P-Trak® could have been selected had gas emissions been the species sampled (Biosystems 2005).

The instrument has been assessed by the Canadian Standards Association, and as such, its safety as a sampling instrument is assured. The instrument sampled utilizing the cyclone mode; the atmosphere under study was forced through vents in the sensor compartment cover at a rate of 1.7 Litres per minute (TSI Inc. 2007). As cyclone operation monitors only the atmosphere immediately surrounding the inlet the instrument was located within the breathing zone of the subject to adequately represent the atmospheric exposure concentrations under question. Therefore, with each sampling occurrence the apparatus was attached to the subject just below the mouth, upon the chest, to ensure that accurate representation of exposure levels were obtained.

To account for both the validity and reliability of the results the instrument was calibrated before its use. The DustTrak™ is factory calibrated to the respirable fraction of *ISO 12103-1. A1 Test Dust* however, to increase the accuracy of the results, the instrument was further calibrated before its use in this study (TSI Inc. 2007). First, a High-Efficiency Particulate Air (HEPA) filter was placed on the unit to clean the air of any pre-existing particulate matter. After cleaning, the instrument read particulate matter at less than 0.001 mg/m^3; the unit was then placed in "zeroing mode" so as to accept the result (TSI Inc. 2007). The calibration was performed by an expert technician of BCIT so as not to add additional confounding variables to the results.

The instrument results were highly specific due to the use of the size selective cyclone. As the particulate laden air is forced into the cyclone the larger massed particulates become trapped whereas the smaller particulates remain in the air stream and pass through for measurement; therefore, the cyclone enabled measurement of only those particulate concentrations of interest with respect to particulate size (TSI Inc. 2007).

For this study vehicular emissions within or on vehicles utilized by the majority of the population in Vancouver, British Columbia were examined as these modes of transportation provide the most representative exposure levels to the average occupant. The three methods of transportation chosen for analysis were bus, commuter vehicle and bicycle. More specifically, "Translink" buses leading from Vancouver to West Vancouver, a compact, 1997 Chevy Cavalier and an 18 speed bicycle were the modes of transportation from which comparisons of exposure levels to the occupant were made. In each of the bus and car the windows were kept shut to maintain a constant internal environment between samples; this consistency removed confounding variables and increased the accuracy of the results. Additionally, bus air intake was out of the control of the sampler and, as such, is considered to be constant between samples as it is presumed that bus drivers would operate bus air intakes similarly if not identically. Car air intake, however, was within the control of the sampler and therefore was set on "low" as it is assumed that this is the normal operation of most vehicles and was mandatory with respect to safety purposes during rainy, winter nights in Vancouver.

Exposure levels of pedestrians were excluded from the study as cyclists would theoretically receive similar outdoor exposure levels as pedestrians; the breathing zone for a cyclist is within a similar vertical range as a pedestrian and therefore the differences in outdoor exposure would not be significant. Additionally, the amount of air intake due to physical exertion was not considered in this experiment.

The roadway selected, upon which all comparisons of exposure levels between the different modes of transportation were examined, was the Stanley Park Causeway from the park entrance up to, but not including, the First Narrows Lion's Gate Bridge (see Appendix A). The location was selected due to its ability to provide continuous, uninterrupted travel for all vehicles, as no additions or subtractions of vehicles occurred due to a lack of entrances or exits, thereby ensuring all sample points along the route had similar emission levels. This lack of intersections was also significant with respect to the second reason for the choice of site location; the route itself was utilized by all three forms of transportation, buses, cars and bicycles, which could not deviate from the direct route due to the aforementioned lack of entrances or exits. This was very important when analyzing results as all vehicular emissions were sampled from the same source thereby eliminating confounding variables. Additionally, the length of the road was a significant factor as it enabled a greater number of sampling intervals thereby resulting in an increased number of samples and data accuracy.

The physical properties of the location were also taken into consideration when deciding upon the suitability of the location for the study. The location was walled in by a forest on either side of the roadway trapping much of the exhaust and vehicular emissions. Therefore, much of the emissions remained at ground level thereby duplicating the vehicular emissions trapped by buildings on other roadways. This will enable inferences to be made between this study and recent or future studies.

Alternative roadways were considered but not selected as the site offered more significant advantages to the study than other sites. Alternative roadways did not possess a route which enabled an identical traffic pattern for all three methods of transportation; many roadways enabled bus and automobile routes that were the same but did not include an identical route followed by cyclists. The safety of the cyclist was also a consideration as the Stanley Park Causeway offered a sidewalk for cyclists. Additionally, other roadways did not offer a route in which constant, non-deviating travel occurred for such a long period of time nor did they offer the topography which contained the vehicular emissions. Consistency of the samples was imperative to the accuracy of the results and therefore other sites were dismissed due to their inability to provide a consistent route.

A sample size of minimum 30 is necessary to achieve normal distribution of data thereby providing more statistically accurate results (Heacock and Chiodo 2005). Due to the lack of funding, time constraints and practicability for one person the sampling occurred over three periods for all transportation modes studied. Data was collected every minute for as long as feasible within each sampling period. The measurement obtained at the end of each minute interval was the average of the exposure levels obtained during the entire minute interval. The averaging was necessary to eliminate outliers and lessen the impacts of any deviations from the norm. Additionally, the sampling was performed by one solitary individual to prevent the sampling discrepancies that exist between operators. As one operator results in greater precision when sampling the validity and reliability of the data were thereby ensured thus resulting in a more accurate representation of exposure levels.

Confounding variables were taken into consideration with respect to the time of sampling. The sampling occurred during the most similar time periods as possible; all samples were taken on Wednesdays during peak night time rush hour traffic, between the hours of 15:00 and 18:00. The time and day of the week were chosen to maximize the vehicular traffic on the road thereby maximizing the levels of vehicle emissions. It was assumed that sampling on Fridays or Mondays would have resulted in an under representation of emissions due to the commuting patterns of part time employees and/or students. Evening was chosen as the period of sampling as often morning traffic is more temporally separated whereas evening traffic is often more condensed. The sampling was carried out on three consecutive Wednesday evenings, January 9, 16 and 23, 2008, to ensure similar temperatures and weather patterns so as not to confound the data; sampling periods were as similar as possible to ensure a greater accuracy of the results (see Appendix B). Sampling for both the car and bus exposure was completed over the course of two days, January 9 and 16, and January 16 and 23 respectively, whereas sampling for the bicycle exposure occurred during one day, January 23, 2008.

The researcher sampled the entire length of the causeway during the specified three hour time interval. If during the sampling period the researcher came to the end of the causeway with additional time the alternate direction was sampled. The DustTrak™ was not turned off during the sampling period rather, the sampling was continuous and time was used as a determinate for the data points utilized.

The ethics of this study were considered as the author was the sole subject and was therefore aware of all dangers associated with the study, including traffic related injuries and vehicular emission exposure. As the commuting population is exposed to these risks everyday the author's decision to expose herself to these risks was not a concern due to the low level of risk.

Results and Analysis:

The data was sampled in mg/m^3 and therefore is of the continuous, numerical data type (Heacock and Chiodo 2005). In the primary analysis the means of exposure levels for bus, bicycle and car were 0.0307, 0.0240 and 0.0175 mg/m^3 respectively (see Appendix C). Additionally, the middle observation, the median, values were 0.025, 0.024 and 0.016 mg/m^3 respectively. These

Group	**Count**	**Mean (mg/m^3)**	**Median (mg/m^3)**
Car	57	0.0175	0.0160
Bicycle	42	0.0240	0.0240
Bus	42	0.0307	0.0250

results indicate that the levels were well below the Canadian national permitted levels for air quality standards (Health Canada 2006). Additionally, from these two descriptive statistical analyses it is apparent that the exposure levels for the car exposure group differed from those of the other two exposure groups. However, further comparisons had to be made to determine what, if any, statistically significant differences existed between the exposure groups. Therefore, statistical analysis of traffic related exposure to particulate matter was carried out utilizing an Analysis of Variance Table, Kruskal-Wallis One-Way ANOVA, Scheffe's Multiple Comparison Test and Tukey-Kramer Multiple Comparison Test (Heacock and Chiodo 2005). NCSS was utilized for all analyses of the study (J. Hintze 2001).

When examining the Tests of Assumptions it was determined that the assumptions were not met thereby indicating a non-normally distributed sample range (see Appendix C). As a result of the non-normality the parametric results were invalid; additionally, the data did not have equal variances. Therefore the results of the parametric ANOVA could not be used to make inferences from and, as such, the results were inferred from the non-parametric Kruskal-Wallis One-Way ANOVA, Scheffe's Multiple Comparison Test and the Tukey-Kramer Multiple Comparison Test.

The data was analyzed using a Kruskal-Wallis One-Way Analysis of Variance Test to determine if between the three methods of transportation, bus, car and bicycle, significantly different exposure levels occurred. A selected probability value of 0.005 reduced the potential for alpha errors (see Appendix B). From the analysis of the Kruskal-Wallis One-Way ANOVA the probability level was less than 0.000000 and therefore the null hypothesis, there is no difference between exposure levels from vehicular emissions for commuters travelling by bus, car or bicycle, was rejected (see Appendix C). As a result, there was a statistically significant difference in exposure levels between the commuter groups. As the Kruskal-Wallis One-Way ANOVA could not be utilized to determine which exposure group differed significantly the data was further analyzed utilizing the Scheffe Multiple Comparison Test and the Tukey-Kramer Multiple Comparison Test to establish which method of transportation was significantly different from the others (Heacock and Chiodo 2005).

Utilizing both the Tukey-Kramer Multiple Comparison Test and the Scheffe Multiple Comparison Test multiple analyses were made from the data (J. Hintze 2001). From analysis of both the Scheffe Multiple Comparison Test and the Tukey-Kramer Multiple Comparison Test it was determined that every exposure group was statistically significantly different from all other exposure groups (see Appendix C). That is, there was a statistically significant difference between the vehicular emission exposures received by all three methods of transportation.

Group	**Count**	**Mean (mg/m^3)**	**Different From Groups**
Car	57	0.0175	Bus, Bicycle
Bicycle	42	0.024	Car, Bicycle
Bus	42	0.0307	Car, Bus

The higher the power of a test the greater the ability of that test to detect differences in the study. A power exceeding 80% ensures the test is valid; therefore as the power in this study was greater than 99.9% the test reflects reality (see Appendix C).

Discussion:

The results indicated a statistically significant difference in particulate matter exposure levels between all transportation methods; the car had the smallest exposure of particulates whereas the bus had the highest. Therefore, from the perspective of public health, the car was the safest method of transportation with respect to particulate matter exposure. All three particulate matter exposure levels, for bus, car and bicycle, were well below the Canadian standards for both permitted maximum 1 and 8 hour exposure levels and were therefore acceptable exposure levels

(Health Canada 2006). From these findings it is evident that all three transportation methods had exposure levels of particulate matter deemed as safe by Health Canada.

Although the results of the study indicated that particulate matter exposures were well within maximum allowable levels from the perspective of public health the exposures pose the potential to cause harm. Exposure to air pollution contributes to the cumulative, long term exposure of the public to adversely affective pollutants thereby resulting in an increased risk for disease (Beeson et al. 1998). Therefore the exposure levels pose a risk to public health.

The results of this study were important in that they complied with other findings indicating all three transportation methods as having particulate matter exposure to the individual. However, contradictory to other findings, the results were not high enough to warrant concern when compared to Canadian maximum allowable levels (Riediker et al. 2004, Vinzents et al. 2005). In the future, the results of this study may impact public health policy, with respect to air quality and maximum allowable particulate levels, but does not seem likely to impact policy or legislation at this current point in time.

As time passes our attitudes towards public health change; that which is currently deemed to be the acceptable level of particulate matter exposure may change as our views of what is "safe" change. Therefore maximum permissible levels are all most certain to decrease in the future as a result of public pressure to change. However, for now these exposure levels are well below the acceptable limits and as such it is the responsibility of the public to determine which mode of transportation is most appropriate based on their individual perceptions of risk.

Limitations:

The low particulate matter exposure levels could have been due to a number of factors including the lack of diesel vehicles, the cold temperatures and the continuous nature of the route during the sampling periods. Diesel vehicles are known to contribute particulate matter pollution and therefore a reduction in the number of these vehicle types on the route utilized would have had a reduced effect on the particulate matter exposure levels (Cohen 2000). Since the route selected had a limitation on the size of vehicle permitted to utilize the route this may have negatively impacted the levels of particulate materials sampled thereby resulting in much lower levels than would be sampled on other roads (Government of British Columbia 2004, Transport Canada 2006). Furthermore, the cold temperatures experienced during the sampling period may have resulted in a reduction of particulate matter as higher ambient temperatures may produce higher levels of particulate matter. Additionally, a further potential cause to the low exposure levels could have been the continuous nature of the route. The lack of vehicles stopping and restarting could have a negative impact on the levels of particulate materials released into the environment.

Further limitations of the study include the restriction of available sampling instruments as well as the in-vehicle sampling positions. Due to the limitations of sampling instruments the study was not able to measure ultra fine particulate matter which is the particulate matter of greatest concern to public health. As well, when the research was conducted within the bus the sampling occurred consistently at the front of the bus, due in part to limitations of seating and for consistency between sampling periods. This area of the bus may have had higher exposure levels due to the proximity to the door; perhaps as the door opened at each stop the particulate matter was able to enter and accumulate at this front location. Further studies must be made to investigate all aforementioned limitations of the study.

Recommendations:

For future studies it is recommended that particulate matter exposure levels be examined for routes which permit all traffic including those vehicles of over 13,000 kg gross vehicle weight.

Additionally, in order to assess the impact of temperature on the exposure levels further research should be conducted during warmer temperatures and compared to the exposure levels obtained during this study. Comparisons will ascertain what impact temperature has, if any, on the particulate levels obtained during the research. Furthermore, future studies should investigate as to the effects of continuous versus interrupted travel on the level of air particulate matter. Further study is also necessary to determine what difference exists, if any, between exposure levels for particulates at different locations within the bus environment. Additional studies should also examine for variation of particulate levels within the internal environment of the car. Most importantly a future examination must be made to determine the exposure levels of ultra fine particulate matter between the three exposure types.

Conclusion:

A major source of air pollution in urban areas is vehicular emissions. Population exposure to air pollutants, including nitrous oxides, carbon monoxide, sulphur oxides, unburned hydrocarbons, polycyclic hydrocarbons, aldehydes, polynuclear aromatic hydrocarbons, black carbon and particulate matter, may lead to adverse public health outcomes in the form of pulmonary and cardiovascular diseases as well as cancer, asthma, adverse pregnancy outcomes and even mortality. From this study it was determined that the particulate matter exposure levels were significantly different between the three methods of transportation, bus, car and bicycle; the car transportation had the lowest particulate exposures whereas the bus had the highest. Therefore the method of transportation that was the safest, with respect to air quality and public health, was the car. Although no exposure level was deemed to be a risk to public health, as determined by the standards of Health Canada, any exposure to air pollutants from vehicular exhaust contributes to cumulative lifetime exposure and therefore adversely affects the state of public health. From this study it is clear that additional research is necessary to establish the safest mode of transportation with respect to air quality and public health.

References:

Beeson, W., Abbey, D. and Knutsen, S. (1998). Long-term Concentrations of Ambient Air Pollutants and Incident Lung Cancer in California Adults: Results from the Adventist Health Study on Smog. *Environmental Health Perspectives*, 106(12): 813–823.

Biosystems. (January 12, 2005). Reference Manual PHD Ultra Multigas Detector. Retrieved November 11, 2007 from http://www.biodownloads.com/files/manuals/13-037.pdf

Bräuner, E.V., Forchhammer, L., Møller, P., Simonsen, J., Glasius, M., Wåhlin, P., Raaschou-Nielsen, O.,[3] and Loft, S. (2007). Exposure to Ultrafine Particles from Ambient Air and Oxidative Stress–Induced DNA Damage. *Environmental Health Perspectives*, 115(8): 1177–1182.

Brugge, D., Durant, J.L., and Rioux, C. (2007). Near-Highway Pollutants in Motor Vehicle Exhaust: A review of Epidemiologic Evidence of Cardiac and Pulmonary Health Risks. *Environmental Health*. 6:23.

Ciccone G., Forastiere F., Agabiti N., Biggeri A., Bisanti L., Chellini E., Corbo G., Dell'Orco V., Dalmasso P., Volante T.F., Galassi C., Piffer .S, Renzoni E., Rusconi F., Sestini P., Viegi G., SIDRIA Collaborative Group. (1998). Road Traffic and Adverse Respiratory Effects in Children. *Occupational and Environmental Medicine*, 55:771–778.

Cohen, A.J. (2000). Outdoor Air Pollution and Lung Cancer. *Environmental Health Perspectives*, 108(Suppl 4): 743-750.

Dab W., Medina S., Quenel P., Le Moullec Y., Le Tetre A., Thelot B., Monteil C., Lameloise P., Pirard P., Momas I., Ferry R., Festy B. (1996). Short Term Respiratory Health Effects of Ambient Air Pollution: Results of the APHEA Project in Paris. *Journal of Epidemiology and Community Health,* (50):S42–S46.

Daigle C.C., Chalupa D.C., Gibb F.R., Morrow P.E., Oberdörster G., Frampton M.W., et al. (2003). Ultrafine Particle Deposition in Humans During Rest and Exercise. *Inhalation Toxicology*, (15):539–552.

Delfino, R.J., Sioutas, C., and Malik, S. (2005). Potential Role of Ultrafine Particles in Associations between Airborne Particle Mass and Cardiovascular Health. *Environmental Health Perspectives*, 113(8): 934–946.

Devalia J.L., Sapsford R.J., Cundell D.R., Rusznak C., Campbell A.M., Davies R.J. (1993) Human Bronchial Epithelial Cell Dysfunction Following In-Vitro Exposure to Nitrogen Dioxide. *European Respiratory Journal*.6:1308–1316.

Edwards J., Walters S., Griffiths R.K. Hospital Admissions for Asthma in Preschool Children: Relationship to Major Roads in Birmingham, United Kingdom. (1994). *Archives of Environmental Health*. 49:223–227.

Ferguson, E.C., Maheswaran, R., and Daly, M. (2004). Road-traffic pollution and asthma – using modelled exposure assessment for routine public health surveillance. *International Journal of Health Geography*, 3(24).

Garshick, E., Laden, F., Hart, J.E., Rosner, B., Smith, T.J., Dockery, D.W., and Speizer, F.E. (2004). Lung Cancer in Railroad Workers Exposed to Diesel Exhaust. *Environmental Health Perspectives*, 112(15): 1539–1543.

Garty B.Z., Kosman E., Ganor E., Berger V., Garty L., Wietzen T., Waisman Y., Mimouni M., Waisel Y. Emergency Room Visits of Asthmatic Children, Relation to Air Pollution, Weather and Airborne Allergens. (1998). *Ann Allergy, Asthma Immunology.*, 81:563–570.

Government of British Columbia. (2004). Transportation Act; Provincial Public Undertakings Regulation. Retrieved November 12, 2007 fromhttp://www.qp.gov.bc.ca/statreg/reg/T/Transportation513_2004/513_2004.htm

Heacock, H. and Chiodo, V. (2005). Course Manual ENVH 8400 Research Methods. British Columbia Institute of Technology, Burnaby, British Columbia.

Health Canada. (2006). Environmental and Workplace Health. Regulations Related to Health and Air Quality. Retrieved November 13, 2007 from http://www.hc-sc.gc.ca/ewh-semt/air/out-ext/reg_e.html

Hintze, J. (2001). NCSS and PASS. Number Cruncher Statistical Systems. Kaysville, Utah. Retrieved on November 5, 2007 from www.ncss.com

Lin S., Munsie J.P., Hwang S., Fitzgerald E., Cayo M.R. (2002). Childhood Asthma Hospitalization and Residential Exposure to State Route Traffic. *Environmental Research Section A.*, 88:73–81.

Marr, L.C., Grogan, L.A., Wohrnschimmel, H., Molina, L., and Molina, M.J. (2004). Vehicle Traffic as a Source of Particulate Polycyclic Aromatic Hydrocarbon Exposure in the Mexico City Metropolitan Area. *Environmental Health Perspectives*, 38(9): 2584–2592.

McDonald, J.D., Eide, I., Seagrave, J.C., Zielinska, B., Whitney, K., Lawson, D.R., and Mauderly, J.L. (2004). Relationship between Composition and Toxicity of Motor Vehicle Emission Samples. *Environmental Health Perspectives*, 112(15): 1527–1538.

Penn, A., Murphy, G., Barker, S., Henk, W., and Penn, L. (2005). Research Combustion-Derived Ultrafine Particles Transport Organic Toxicants to Target Respiratory Cells. *Environmental Health Perspectives*, 113(8): 956–963.

Pope, C.A., and Dockery, D.W. (2006). Health Effects of Fine Particulate Air Pollution: Lines That Connect. *Journal of Air Waste Management Association*, 56:709–742.

Raaschou-Nielsen O, Hertel O, Thomsen BL, Olsen JH. Air pollution from traffic at the residence of children with cancer. *American Journal of Epidemiology.* 2001;**153**:433–443

Riediker, M., Devlin, R.B., Griggs, T.R., Herbst, M.C., Bromberg, P.A., Williams, R.W., and Cascio, W.E. (2004). Cardiovascular Effects in Patrol Officers are Associated with Fine Particulate Matter from Brake Wear and Engine Emissions. *Particle and Fibre Toxicology*, 1: 2.

Šrám, R.J., Binková, B., Dejmek, J., and Bobak, M. (2005). Ambient Air Pollution and Pregnancy Outcomes: A Review of the Literature. *Environmental Health Perspectives*, 113(4): 375–382.

Transport Canada. (2006). Surface Infastructure Programs-Bridges. Retrieved April 05, 2008 from http://www.tc.gc.ca/programs/surface/bridges/lionsgate.htm

TSI Inc. (2007). Model 8520 DustTrak™ Aerosol Monitor Operation and Service Manual. Retrieved February 22, 2008 from http://www.tsi.com/Product.aspx?Pid=11

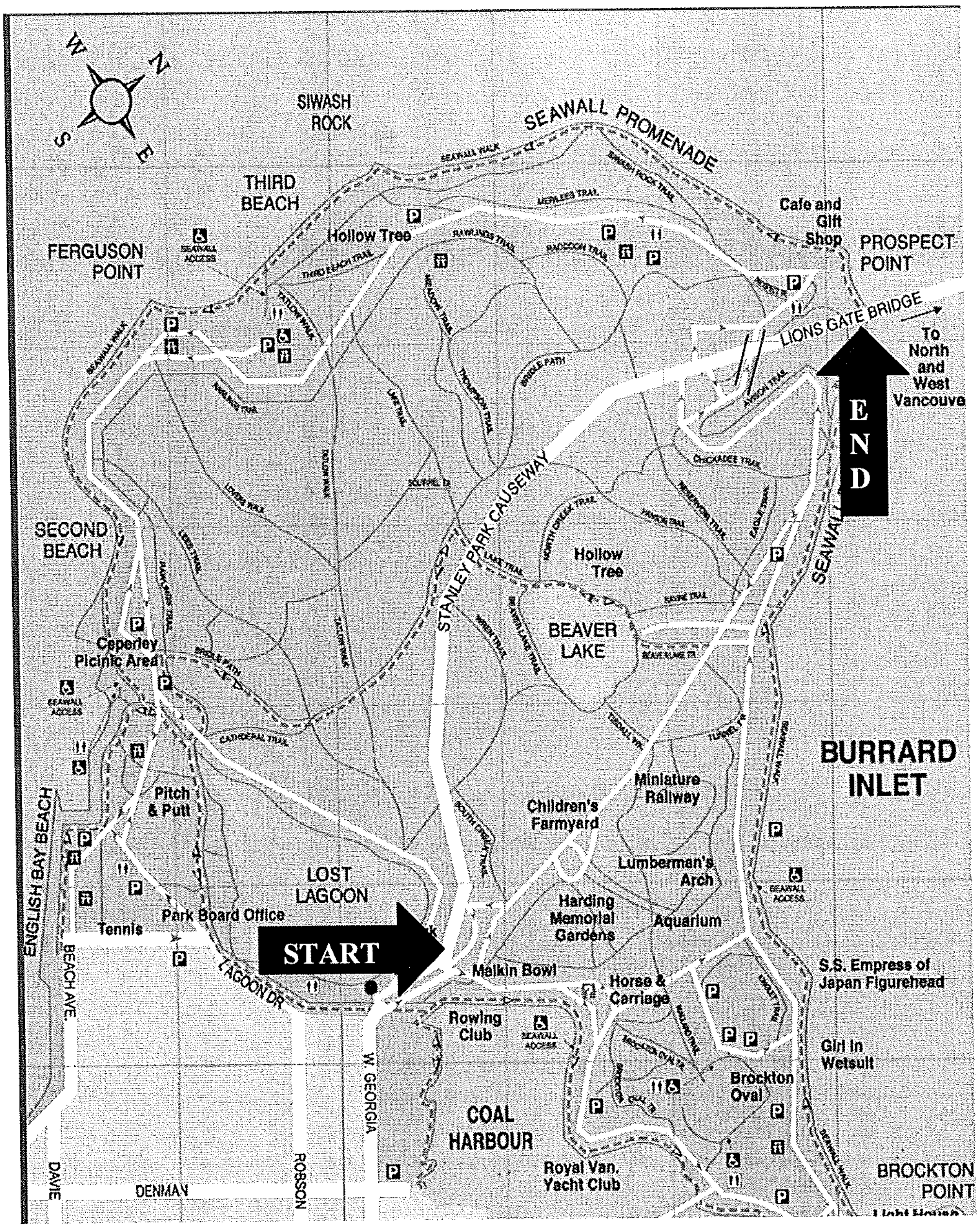
Vinzents, P.S., Møller, P., Sørensen, M., Knudsen, L.E., Hertel, O., Jensen, F.J., Schibye, B., and Loft, S. (2005). Personal Exposure to Ultrafine Particles and Oxidative DNA Damage. *Environmental Health Perspectives* , 113(11): 1485–1490.

www.visitorschoice.com. (2004). Visitor's Choice Vancouver. Retrieved November 13, 2007 from http://www.biv.com/vc/map04-stanleypark.asp

Yu, O., Sheppard, L., Lumley, T., Koenig, J.Q., and Shapiro, G.G. (2000). Effects of Ambient Air Pollution on Symptoms of Asthma in Seattle-Area Children Enrolled in the CAMP Study. *Environmental Health Perspectives*, 108(12): 1209-1214.

Appendix A:

Selected Route:



(www.visitorschoice.com 2004)

Appendix B:

Weather Conditions

January 09, 2008: Some cloud cover; precipitation experienced from 17:30 to 19:00; temperatures of 5-2°C
January 16, 2008: Some cloud cover; no precipitation; 2.2-0 °C
January 23, 2008: Clear with no cloud cover; no precipitation; 3-0 °C

Data:

Car			Bus			Bicycle		
Date	Time	mg/m^3	Date	Time	mg/m^3	Date	Time	mg/m^3
01/09/2008	16:12	0.017	01/16/2008	16:54	0.031	01/23/2008	17:41	0.02
01/09/2008	16:13	0.015	01/16/2008	16:55	0.025	01/23/2008	17:42	0.017
01/09/2008	16:14	0.014	01/16/2008	16:56	0.023	01/23/2008	17:43	0.024
01/09/2008	16:33	0.012	01/16/2008	17:11	0.048	01/23/2008	17:44	0.026
01/09/2008	16:34	0.014	01/16/2008	17:12	0.033	01/23/2008	17:45	0.026
01/09/2008	16:35	0.014	01/16/2008	17:13	0.026	01/23/2008	17:46	0.024
01/09/2008	17:02	0.023	01/16/2008	17:14	0.02	01/23/2008	17:47	0.019
01/09/2008	17:03	0.025	01/16/2008	17:22	0.015	01/23/2008	17:48	0.019
01/09/2008	17:04	0.027	01/16/2008	17:23	0.024	01/23/2008	17:49	0.025
01/09/2008	17:05	0.019	01/16/2008	17:24	0.023	01/23/2008	17:50	0.02
01/09/2008	17:20	0.012	01/16/2008	17:25	0.022	01/23/2008	17:51	0.029
01/09/2008	17:21	0.014	01/16/2008	17:42	0.024	01/23/2008	17:52	0.018
01/09/2008	17:22	0.016	01/16/2008	17:43	0.026	01/23/2008	17:53	0.019
01/09/2008	17:23	0.015	01/16/2008	17:44	0.023	01/23/2008	17:54	0.018
01/09/2008	17:33	0.013	01/16/2008	17:45	0.017	01/23/2008	17:55	0.025
01/09/2008	17:34	0.015	01/16/2008	17:53	0.025	01/23/2008	17:56	0.018
01/09/2008	17:35	0.02	01/16/2008	17:54	0.032	01/23/2008	17:57	0.024
01/09/2008	17:36	0.023	01/16/2008	17:55	0.028	01/23/2008	17:58	0.021
01/09/2008	17:50	0.021	01/16/2008	17:56	0.026	01/23/2008	17:59	0.021
01/09/2008	17:51	0.022	01/16/2008	18:20	0.031	01/23/2008	18:00	0.018
01/09/2008	17:52	0.023	01/16/2008	18:21	0.034	01/23/2008	18:01	0.02
01/09/2008	17:53	0.026	01/16/2008	18:22	0.035	01/23/2008	18:02	0.025
01/09/2008	18:00	0.013	01/23/2008	16:29	0.027	01/23/2008	18:03	0.031
01/09/2008	18:01	0.013	01/23/2008	16:30	0.024	01/23/2008	18:04	0.026
01/09/2008	18:02	0.014	01/23/2008	16:31	0.021	01/23/2008	18:05	0.021
01/09/2008	18:03	0.013	01/23/2008	16:32	0.018	01/23/2008	18:06	0.021
01/09/2008	18:04	0.015	01/23/2008	16:58	0.043	01/23/2008	18:07	0.022
01/09/2008	18:11	0.013	01/23/2008	16:59	0.039	01/23/2008	18:08	0.024
01/09/2008	18:12	0.015	01/23/2008	17:00	0.045	01/23/2008	18:09	0.021
01/09/2008	18:13	0.015	01/23/2008	17:09	0.024	01/23/2008	18:10	0.026
01/09/2008	18:14	0.016	01/23/2008	17:10	0.023	01/23/2008	18:11	0.024
01/09/2008	18:20	0.017	01/23/2008	17:11	0.026	01/23/2008	18:12	0.04
01/09/2008	18:21	0.015	01/23/2008	17:31	0.023	01/23/2008	18:13	0.034
01/09/2008	18:22	0.014	01/23/2008	17:32	0.023	01/23/2008	18:14	0.027

01/09/2008	18:23	0.014	01/23/2008	17:33	0.024	01/23/2008	18:15	0.022
01/09/2008	18:32	0.018	01/23/2008	18:36	0.083	01/23/2008	18:16	0.032
01/09/2008	18:33	0.021	01/23/2008	18:37	0.126	01/23/2008	18:17	0.02
01/09/2008	18:34	0.02	01/23/2008	18:38	0.033	01/23/2008	18:18	0.024
01/09/2008	18:38	0.017	01/23/2008	18:39	0.034	01/23/2008	18:19	0.027
01/09/2008	18:39	0.017	01/23/2008	18:53	0.02	01/23/2008	18:20	0.044
01/09/2008	18:40	0.015	01/23/2008	18:54	0.021	01/23/2008	18:21	0.021
01/09/2008	18:41	0.014	01/23/2008	18:55	0.022	01/23/2008	18:22	0.026
01/09/2008	18:51	0.016						
01/09/2008	18:52	0.016						
01/09/2008	18:53	0.015						
01/16/2008	16:19	0.021						
01/16/2008	16:20	0.017						
01/16/2008	16:21	0.014						
01/16/2008	16:33	0.016						
01/16/2008	16:34	0.019						
01/16/2008	16:35	0.017						
01/16/2008	18:31	0.019						
01/16/2008	18:32	0.019						
01/16/2008	18:33	0.017						
01/16/2008	18:41	0.032						
01/16/2008	18:42	0.025						
01/16/2008	18:43	0.023						

Appendix C:

Results from NCSS:

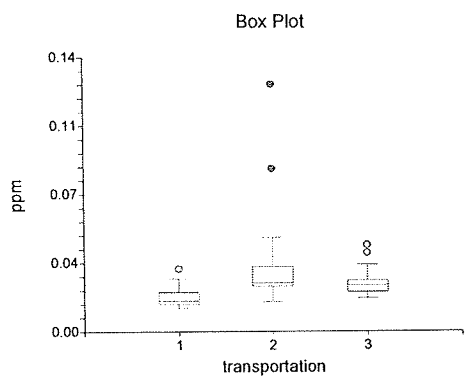
Group 1: Car
Group 2: Bus
Group 3: Bicycle

Analysis of Variance Report
Page/Date/Time 1 2/25/2008 11:40:58 AM
Database
Response ppm

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.05)	
Skewness Normality of Residuals	11.3292	0.000000	Reject	
Kurtosis Normality of Residuals	8.2674	0.000000	Reject	
Omnibus Normality of Residuals	196.7009	0.000000	Reject	
Modified-Levene Equal-Variance Test		4.2250	0.016562	Reject

Box Plot Section



Expected Mean Squares Section

Source Term	DF	Term Fixed?	Denominator Term	Expected Mean Square
A: transportation	2	Yes	S(A)	S+sA
S(A)	138	No		S(A)

Note: Expected Mean Squares are for the balanced cell-frequency case.

Analysis of Variance Table

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: transportation	2	4.276865E-03	2.138433E-03	17.50	0.000000*	0.999794
S(A)	138	1.686769E-02	1.222296E-04			
Total (Adjusted)	140	2.114455E-02				
Total	141					

* Term significant at alpha = 0.05

Analysis of Variance Report

Page/Date/Time 2 2/25/2008 11:40:58 AM
Database
Response ppm

Kruskal-Wallis One-Way ANOVA on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.05)
Not Corrected for Ties	2	59.88111	0.000000	Reject Ho
Corrected for Ties	2	60.0727	0.000000	Reject Ho

Number Sets of Ties	20
Multiplicity Factor	8940

Group Detail

Group	Count	Sum of Ranks	Mean Rank	Z-Value	Median
1	57	2249.00	39.46	-7.5537	0.016
2	42	4195.50	99.89	5.4707	0.025
3	42	3566.50	84.92	2.6350	0.024

Means and Effects Section

Term	Count	Mean	Standard Error	Effect
All	141	0.0233617		2.406475E-02
A: transportation				
1	57	1.745614E-02	1.46437E-03	-6.608605E-03
2	42	3.071429E-02	1.705939E-03	6.649541E-03
3	42	2.402381E-02	1.705939E-03	-4.093567E-05

Scheffe's Multiple-Comparison Test

Response: ppm

Term A: transportation

Alpha=0.050 Error Term=S(A) DF=138 MSE=1.222296E-04 Critical Value=2.4746

Group	**Count**	**Mean**	**Different From Groups**
1	57	0.0175	3, 2
3	42	0.0240	1, 2
2	42	0.0307	1, 3

Notes:
This report provides multiple comparison tests for all possible contrasts among the the means. These contrasts may involve more groups than just each pair, so the method is much stricter than need be. The Tukey-Kramer method provides more accurate results when only pairwise comparisons are needed.

Analysis of Variance Report

Page/Date/Time 3 2/25/2008 11:40:58 AM
Database
Response ppm

Tukey-Kramer Multiple-Comparison Test

Response: ppm
Term A: transportation

Alpha=0.050 Error Term=S(A) DF=138 MSE=1.222296E-04 Critical Value=3.3507

Group	**Count**	**Mean**	**Different From Groups**
1	57	0.0175	3, 2
3	42	0.0240	1, 2
2	42	0.0307	1, 3

Notes:
This report provides multiple comparison tests for all pairwise differences between the means.