Traffic Related Air Pollution: Health Consequences and Mitigation Strategies

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1. Introduction

Motor vehicles are ubiquitous to any urban area. In Toronto, the largest source of air pollution results from on-road motorized vehicles. This form of pollution is commonly referred to as traffic-related air pollution (TRAP). It has been estimated that TRAP is responsible for an estimated 1090 hospitalizations and 280 premature deaths in the city of Toronto. These represent 55% and 42% of all hospitalizations and premature deaths caused by some form of air pollution. The high level of impact seen in Toronto results from the many major roads and highways in the region. In Canada about 32% of the population live within 100m of a major road or 500m of a highway. In Toronto this number jumps drastically: 82% of those in Toronto live within 100m of a major road, or 500m from a highway [1]. This high level of exposure consequently results in a large array of health consequences – some very serious. Exposure to TRAP, however, can be mitigated through the proper use of public policy. Approaches involving land-use planning, building modifications, transportation management, tailpipe emission reduction and citizen education all show promise at reducing exposure to TRAP and limiting potential health effects.

2. An Overview of TRAP

What is TRAP?

TRAP consists of many different chemical components. In general, however, TRAP is defined as any of the following [2], which is produced or liberated by a motorized vehicle:

- carbon monoxide (CO), carbon dioxide (CO_2) and black carbon
- hydrocarbons
- nitrogen oxides (NO_x)
- particulate matter ($PM_{10}, PM_{2.5}$) and ultrafine particles ($PM_{1.0}$)
- mobile air toxins such as acetaldehyde, formaldehyde and metals

This list can be broken down into two categories: (a) primary pollutants that are formed via combustion processes and (b) secondary pollutants that that result from chemical reactions involving the primary pollutants. For example, primary pollutants include NO and black carbon while secondary pollutants include NO_2 and ozone (O_3).

TRAP does not only include tailpipe emissions. Emissions from tire wear (i.e. metals such as iron, sodium, aluminum, etc.), break wear as well as suspended road dust each contribute to TRAP. These can be important sources of mobile air toxins that do not result specifically from engine combustion [2].

TRAP Gradients near Highways

As stated previously, living close to a highway can cause one to be exposed to high concentrations of various components of TRAP. Figure 1 displays the concentration of various TRAP components with increasing distance from road edge, splitting them into three categories based on their rate of decay. The figure consists of data from a total of 41 road side air quality monitoring stations. Most pollutants reach background levels between 115 and 300m, however require a much greater spatial extent to return to background levels, such as benzene, NO_2 and $PM_{2.5}$, which remain elevated as much as 500m from the roadway edge. The fastest decline in concentration occurs with CO and UFP1 [3]. Here UFP1 represents particulate matter with diameters between 3 and 15nm, UFP2 represents particulate matter with diameters between 15 and 300nm and fine particulate matter represents particulates with diameters greater than 300nm.

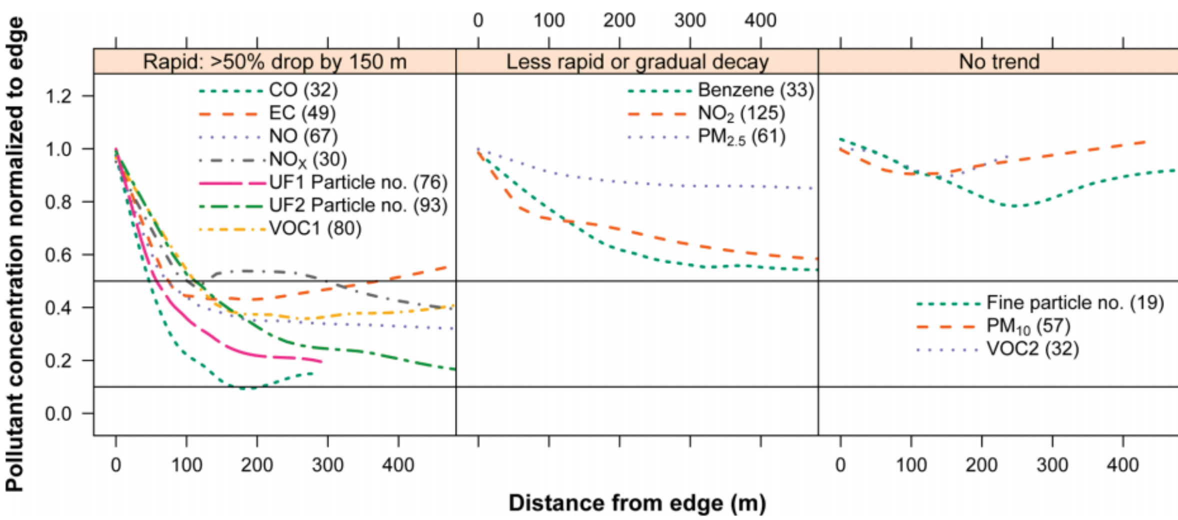

Figure 1 - Gradients of various pollutants with distance away from a highway. The data is presented in three categories depending on the rate of decay: rapid, gradual, or no trend. From [3].

The concentration of TRAP in a particular area depends mainly on (a) factors affecting the rate of emission and (b) factors affecting the dispersion and mixing of the emitted pollution. The rate of tailpipe emission of a vehicle depends on several factors: its age, fuel type, level of technology, level of maintenance and movement patterns. Older vehicles generally emit more since they have older technologies and tend to require more maintenance. In addition, the type and quality of fuel is directly proportional to the type of pollutants that are emitted. Diesel fuel results in much higher levels of TRAP than gasoline. Finally, how the actual vehicle is moving affects its emission, with periods of acceleration and deceleration yielding much greater emission than moving at a constant speed [2].

Once the actual pollution is in the atmosphere its dispersion depends on meteorological factors but also on the surrounding infrastructure. For example, a phenomena known as a street canyon occurs when tall buildings located on both sides of a road (an example of poor urban planning). In general, vertical mixing of air above roof level is required in order for ground level pollution to be dispersed. In street canyons, however, this does not occur, leading to stagnation and enhanced TRAP concentrations. If an atmospheric inversion layer is present, this effect is further enhanced. A street canyon is generally defined using an aspect ratio, a:

$$a = \frac{H}{W}$$

Where H is the height of the street canyon and W is its width. Generally a street canyon is defined as $a > 1$, however some looser definitions have $a > 0.5$ being defined as a street canyon. Therefore the surrounding infrastructure is another important determination factor of TRAP gradients in an urban area [4].

TRAP Exposure: Who and Where

As displayed in Figure 1, TRAP concentrations decay with distance from the highway. Depending on various factors, the rate of decay at a particular time may vary (for example, TRAP gradients decay faster upwind than downwind). In general however, exposure to TRAP is generally defined using proximity to the road, with those within 150m from a major road or highway with annual average daily traffic (AADT) greater than 15,000 being defined as inside the exposure zone. Evidence is emerging that strongly suggests TRAP gradients are significant even 300 to 500m from a major road [5], in line with results in Figure 1 from [3]. Some improvement can be made in estimating exposure zones by employing land use regression models. These models can be based on several methodologies, such as spatial interpolation, proximity models and dispersion models. They base their concentration levels on known levels from air quality monitoring stations and set these measurements as the dependent variables. The model then work backwards (i.e. regression) to extract the best fit to the concentration gradients based on a set of independent variables. These independent variables include traffic source strength (which is proportional to AADT), fleet characteristics (such as amount of heavy-duty trucks), topography and meteorological conditions. By utilizing these types of models small scale temporal and spatial variability in TRAP can be assessed more accurately – which is a much better than identifying an exposure zone solely based on TRAP parametrizations (i.e. distance from the road edge). [6]

In general, individuals who spend the majority of their time within these exposure zones are most impacted by TRAP. These include outdoor workers (such as road-work crews), pedestrians using sidewalks or bike lanes, those with a residence within the exposure zone (up to 500m from the roadway edge in some cases) and anyone who is inside a motorized vehicle driving on the road [7].

3. Health Consequences

To make an effective policy decision regarding TRAP, it is prudent to understand its health effects and which population groups are at greatest risk of adverse effects. Table 1 displays health effects of various pollutants, clearly demonstrating their toxicity [8]. Each of the four outlined pollutants are also present in TRAP, therefore similar effects could be hypothesized to occur when exposed to high TRAP concentrations. Table 2 displays known TRAP effects based on their likely causality: sufficient evidence exists, suggestive but insufficient evidence exists and inadequate and insufficient evidence exists [7]. There is indeed a high degree of similarity between known health consequences of various pollutants displayed in Table 1 and TRAP health consequences displayed in Table 2. For example, long term exposure to ozone and sulphur dioxide can lead to the development and exacerbation of asthma, especially in children. Likewise there is sufficient evidence to suggest exposure to TRAP can cause the development and exacerbation of asthma in children. However direct evidence linking TRAP induced asthma to the presence of a particular pollutant, such as ozone or sulphur dioxide, is lacking.

As summarized in Table 2, the main health consequences of TRAP exposure are respiratory and cardiovascular effects. Evidence is also emerging to suggest a possible link between TRAP exposure and cancer, as well as birth defects, but more research is still needed.

The main effects from TRAP are felt on individuals who are more susceptible to respiratory and cardiovascular consequences. These include those with underlying health conditions, such as the elderly, children and infants whose respiratory system is still developing and active commuters who through increased respiration are exposed to a higher dose of TRAP.

Pollutant	**Health Outcome**	
	Short-Term Effects	**Long-Term Effects**
Ozone, O_3	• Cardiovascular and respiratory mortality	• Asthma development and exacerbation • Mortality among those with preexisting conditions (i.e. COPE, diabetes, heart attack) • Cardiovascular and respiratory mortality • Preterm births
Particulate Matter, $PM_{2.5}$	• Mortality and morbidity	• Adverse birth outcomes • Atherosclerosis • Cardiovascular mortality and morbidity • Childhood respiratory disease • Chronic disease (i.e. diabetes) • Neurodevelopment and cognitive impairment
Nitrogen Dioxide, NO_2	• Respiratory morbidity and mortality	
Sulphur Dioxide, SO_2	• Adverse birth outcomes • Asthma symptoms in children • Cardiovascular and respiratory morbidity and mortality	

Table 1 – Health effects of various pollutants. From [8].

Strength of Evidence	Health Outcome		
Sufficient	**Respiratory** • Asthma onset in children • Exacerbation of asthma		
Suggestive, but insufficient	**Cancer** • Lung Cancer	**Cardiovascular** • Atherosclerosis • Cardiovascular mortality • Heart attack	**Respiratory** • Asthma onset in adults • Lung function impairment • Respiratory symptoms (non-asthma related)
Inadequate and insufficient	**All-Cause Mortality and Other (non-lung) Cancers**	**Respiratory** • Allergies • COPD	**Pregnancy and Birth Outcomes**

Table 2 – The health consequences of TRAP. Shown are three categories, sufficient, suggestive, and inadequate. Health outcomes are placed in these categories based on their strength for a causal relationship with TRAP. From [7].

4. Mitigation Strategies

Several approaches can lead to a reduction in TRAP concentrations, but not all are possible from a public policy perspective. It is important to take into account the stakeholders – anyone who is potentially affected by TRAP (either directly or indirectly). The main stakeholders involved in TRAP are community members, building owners/managers, government policy makers, industry (i.e. vehicle manufacturers) and urban planners/transportation engineers. An ideal solution will incorporate all of these groups to obtain the most acceptable solution to the problem. This section will detail five different approaches that can be used to reduce the negative impacts of TRAP and how each stakeholder can affect change. The five mitigation strategies discussed include urban planning, transportation management, tailpipe emission reduction, building modifications and behavioral change.

a. Urban (Land-Use) Planning

A reduction in TRAP concentrations can be accomplished through proper urban planning. Land-use planning involves all aspects of infrastructure development – their position, shape and materials. Practical solutions involve the development of urban plans that minimize the stagnation and overall concentration of TRAP.

Mitigation Strategies

Several aspects of land-use planning will lead to a reduction in TRAP. Street canyons, as discussed earlier, can be avoided by varying building heights or restricting the development of high-rise buildings to one specific side of the road [9]. In addition, mandating a setback distance for new developments will ensure populations are not constantly exposed to dangerous levels or TRAP in their residences or their places of employment [7, 9]. These mitigation approaches primarily need to be tackled by government policy makers and urban planners since policy makers are responsible for setting guidelines for urban designs, and urban planners are responsible for their development and execution.

It is also important to ensure that public transportation is not developed such that active commuters are disproportionally affected by TRAP. Like buildings, bike lanes and sidewalks should ideally be placed away from the roadway. For many areas moving sidewalks and bike lanes is not practical, however bus shelters can still be placed in locations that limit TRAP exposure. For example, bus shelters can be located on the far side of the intersection (i.e. after crossing). This reduces the exposure that active commuters would have to vehicle exhaust plumes resulting from acceleration through the intersection. The addition of transportation systems means that a new stakeholder must be consulted – the transportation engineer. Their transportation plans should be developed alongside urban planners to maximize on the potential to limit TRAP exposure.

What has been done?

Some areas have begun to adapt or recommend land use policies aimed at minimizing TRAP exposure. In Canada, the Province of British Columbia [2] and the Halton Region [10] in Ontario have both recommended that all new buildings have a minimum setback distance of at least 150m. California, unlike Canada has mandated setback distances of 150m for all urban schools (and other susceptible populations) located near a traffic corridor with AADT exceeding 100,000 (Senate Bill No. 352) [11]. California, also includes a large list of recommendations aimed at transit oriented designs that maximize pollution dispersion and limit TRAP exposure. Clearly more can be done using urban planning to help limit the burden that TRAP has on Canadians.

Strengths and Weaknesses

Land-use planning, particularly mandating setback distances, will decrease the dose of TRAP that populations are exposed to (dose = concentration x time). This is especially important for susceptible populations (i.e. public schools, hospitals) who are predisposed to experience the negative effects of TRAP. Increasing the separation between roadways and bike lanes (and perhaps sidewalks) also limits exposure, but it likewise increases the safety of these active commuting zones. This may make these forms of alternative transportation more appealing, thus limiting on-road vehicles and hence TRAP concentrations.

Despite setback distances being an ideal solution in most cases, buildings in urban areas are already erected and cannot easily be moved to satisfy a setback criteria. This limits the usefulness of this approach to new developments. Therefore this mitigation strategy is a short-term solution for newly developed areas, but will require several years or decades (perhaps even longer) in areas that are already developed.

b. Transportation Management

The control and structure of traffic is an important factor when attempting to decrease TRAP. The main stakeholder for mitigation strategies in this category is the transportation engineers, since they are often responsible for the development of transport systems. However, since the transportation systems run through urban areas, urban planners should work in conjunction with transportation engineers for an ideal TRAP exposure reduction solution.

Mitigation Strategies

There are many ways to approach limiting TRAP concentrations through transportation management. Since diesel vehicles produce a disproportionate amount of TRAP, dedicated routes for this class of vehicles should be placed away from populated areas. Diesel vehicles are generally heavy-duty trucks used for shipping, such as transport trucks and dump trucks. Another solution would be to limit these heavy-duty trucks from entering particular areas all together. If they must enter the area then they would incur a fine – providing an incentive to stay away.

Other large sources of TRAP production are vehicle idling, periods of high speeds (greater than $80\ \mathrm{km/h}$ for example) and periods of vehicle acceleration and deceleration. A study in Rotterdam and Amsterdam in the Netherlands demonstrated that limiting highway speeds to $80\ \mathrm{km/h}$ reduces the emission of $\mathrm{NO_x}$ by $5-30\%$ and $\mathrm{PM_{2.5}}$ by $5-25\%$. They employed method of strict enforcement over a 4km length of highway: copious automated cameras coupled with licence plate recognition software to allow the automatic generation of traffic tickets. They also noted that the effect was most pronounced for larger volumes of heavy-duty vehicles [13].

What has been done?

Canada has not implemented much transportation management aimed at limiting pollution, however some has been done. The City of Toronto in 2010 restricted vehicle idling to one minute (Toronto Municipal Code, Chapter 517, 2010) [14]. Several other jurisdictions in Canada have also enacted some form of anti-idling law.

London, UK been done much more than any Canadian city to combat TRAP from a transportation management perspective. In 2006 London set a daily limit on the amount of vehicles that could enter central London. The result of this was a $20-30\%$ reduction in traffic volume in the area. Transport for London also estimates that the congestions charging scheme has reduced traffic-related emissions of $\mathrm{NO_x}$ by 8%, $\mathrm{PM_{10}}$ by 7% and $\mathrm{CO_2}$ by 19%. [15] Furthermore, in 2008 all of London was designated as a low emission zone (LEZ). The LEZ targets and charges all heavy polluters (i.e. diesel vehicles) that fall outside of an allowed emission standard. They enforce the LEZ through automated camera which determine the vehicle type via the licence plant number. Road works and public health and safety vehicles are exempt from these regulations [16]. In 2020 London is implementing a new "ultra-low" emission zone that toughens regulations and increases the fine if a heavy-polluter enters the LEZ. [17]

Strengths and Weaknesses

Transportation management is effective at reducing TRAP in high density areas that otherwise seem uncontrollable. Limiting the use of vehicles also forces citizens to find other modes of transportation, such as public transportation or car-pooling. This may inevitably lead to a change in behavior of the population overtime. In addition, transportation management is generally a short term solution which can show almost immediate results.

The main difficultly with these restrictions is enforcement. Enforcement can be difficult and expensive and ultimately may rely largely on automated means. Congestion may also increase outside of regions that have some restriction placed on vehicles entering the area. The limited ability of heavy-duty trucks to enter into a region may cause economic repercussions – since shipping costs will be increased. In addition, restricting only heavy polluters may disproportionally affect lower income classes who cannot afford to upgrade their vehicle to cleaner technology.

c. Tailpipe Emission Reduction

If it is not possible to eliminate vehicles, then it may be possible to limit the amount of pollutants that are actually emitted from the tailpipes of these vehicles. If it is not possible to decrease tailpipe emissions then perhaps another approach is warranted, such as government programs to recycle old, heavy polluting vehicles. The main stakeholders include government policy makers who set emission standards and industry who must conform to these standards.

Reduction Strategies

Reducing tailpipe emissions can be done through the adoption of new technologies, such as three-way catalytic converter and diesel particulate filters. A three-way catalytic converter, for example, can reduce CO, hydrocarbons and NO_x by more than 90% [7]. Government incentives to encourage the adoption of these technologies may be beneficial to ensure all population groups have the same level of access. Vehicle buyback programs may also benefit those whose vehicles are unable to adopt to these new clean technologies. Once the technologies are adopted, inspection programs should be put in place to ensure that on-road vehicles meet emission standards and that the vehicle is being maintained.

Finally, the actual composition of the fuel being used affects the pollutants emitted during combustion. Setting limits on sulphur for example limits the emission of SO_2 and affects the emission of particulate matter, CO, hydrocarbons and NO_x. SO_2 generated during combustion can be oxidized to form SO_3 and then dissolved in water vapor, thus forming sulphuric acid vapor – an acid rain precursor. The fuel composition also affects the ability of some clean technologies to operate efficiently. Limiting sulphur below 15 ppm allows NO_x absorption technology to operate successfully, above this limit the technology can be damaged and become ineffective [18]. Thus it is important that government policy makers set fuel standards to match the current level of technology and limits the amount of pollutants generated during combustion. These regulations are what set the standards for industry when they develop new vehicle models – therefore it is important they are stringent and kept up-to-date. It would also be beneficial if we began a search for an alternative fuel (i.e. electricity) that does require combustion. This would involve academic institutions and industry to help advance knowledge to meet our changing needs.

A Canadian Perspective: What has been done?

Canada has steadily improved their vehicle emission and fuel composition standards over the past decade. On January 1, 2003 the On-Road Vehicle and Engine Emission Regulation (SOR/2003-2) [19] came into force, a regulation in the Canadian Environmental Protection Act (CEPA). This new regulation set emission standards for several different pollutants (CO, formaldehyde, NO_x, particulate matter) for various vehicle classes, such as light- vs heavy-weight, that were entering the Canadian market from abroad after the 2004 model year. Table 3 displays the regulation as it pertains to NO_x. Shown is the maximum allowed fleet average NO_x concentration for all fleets entering Canada for model years between 2004 and 2008. The maximum allowed fleet average NO_x concentration is almost four times less in 2008 than 2004. Beyond model years 2008 and 2016, there is no longer a decrease in allowed fleet average NO_x concentration

Model Year	NO_x Fleet Average (g/mi)
2004	0.25
2005	0.19
2006	0.13
2007	0.07
2008	0.07
2009 – 2016	0.07

Table 3 – The allowed NO_X fleet average concentration, presented in g/mi for light and medium weight vehicle classes. The fleet average is defined as $F = c^{-1}\sum_{i=1}^{i=n} A_i B_i$, where A is the NO_x emission standard for each full useful life, B is the number of vehicles in the fleet that conform to that NO_x emission standard and C Is the total number of vehicles in the fleet. From SOR/2003-2

On January 16, 2015 an amendment to the On-Road Vehicle and Engine Emission Regulations was brought into force to update the outdated regulations (SOR/2015-186, s.22) [19]. This represents the most comprehensive attempt to reduce TRAP Canada wide. The amendment places even more stringent emission standards for light-weight vehicles entering the Canadian market. The amendments are for model years 2017-2025. For light- and mid-weight vehicles the maximum allowed fleet average $NO_x + NGOM$ emission should reach $0.03\ g/mi$ by model year 2025. The amendment also targeted fuel composition standards. This amendment particularly targets sulphur content (for reasons discussed earlier) and sets the allowable annual average sulphur content in gasoline to 10 ppm by 2017 (down from 30 ppm).

Strengths and Weaknesses

Emission standards are efficient at targeting the most heavily polluting vehicles. In this process however, equity among different population groups becomes a concern, since heavily polluting vehicles tend to be of older age. Lower income groups who own these older vehicles may not be able to retrofit them or exchange them for newer, cleaner vehicles. However, retrofitting and maintenance alone may sufficient to lower the emissions of some vehicles.

d. Building Modifications

Many different approaches can be taken directly by building managers to help limit TRAP exposure of its occupants. Generally however, such modifications are monetarily expensive and thus are neglected. Thus it is up to government policy makers to mandate these mitigation approaches be installed in all existing residential and commercial buildings located in exposure zones. This section will discuss these possible modifications and their associated strengths and weaknesses.

Mitigation Strategies

The most effective way to reduce exposure of non-gaseous TRAP, such as particulate matter, is to install high efficiency HVAC (heating – ventilation – air conditioning). These systems have minimum efficiency reporting values (MERV) for particulate matter for two size windows: between 300 to 1000nm and between 1000 to 3000nm. Some high MERV filters can also be effective at removing ultra-fine particles, however this efficiency is generally not reported. A study in Sweden placed HVAC systems inside 40 randomly selected schools. They demonstrated that the presence of these filter systems reduced the incidence of asthma by increasing the air exchange and lowering exposure to harmful pollutants [20]. The air intake for such systems should be placed away from major traffic or on the building's rooftop. Additionally, soundproofing the building will help reduce air exchange with outdoor, unfiltered air.

Other mitigation approaches include surface treatments (i.e. barriers, ground) to increase the absorption, deposition and decay of pollutants. One such treatment is titanium dioxide, which decomposes environmental pollutants by photocatalysis [21]. These treatments are often placed on physical barriers called sound walls. Sound walls can limit the amount of air exchange and can decrease TRAP concentrations downwind of the wall by as much as 35% in high wind situations. Evidence on their effectiveness in low wind situations is insufficient. The effectiveness of these barriers depends on factors several factors such as their height, weight and the presence of surface treatments [7]. Introducing vegetation inside and outside the building will also help reduce the effects of many pollutants [22].

Strengths and Weaknesses

Filtration is an immediate source of exposure reduction. However the monetary cost of installation can be high and only provide protection against non-gaseous TRAP. Therefore HVAC systems are not sufficient alone at reducing TRAP exposure. Furthermore, improper filter replacement and poor long term maintenance of these systems can render them ineffective for their intended purpose.

e. Behavioral Change and Education

To help combat the habitual use of motorized vehicles, incentives can be given to increase the use of alternative modes of transportation (i.e. carpooling or public transportation). This can be accomplished by providing free access to public transportation. For example, as of December 2016 all public transportation is free Paris, France to combat the worst air pollution in 10 years. [23]

Another method to help change the behavior surrounding transportation is to provide information and education on TRAP, its risks and ways it can be reduced at an individual level. To inform the public on air quality levels, air quality monitoring stations should be placed in areas where high population density coincides with elevated concentrations of TRAP. By providing the public with accurate data they can better make informed decisions regarding their personal safety and perhaps even the safety of others.

5. Recommendations and Conclusion

Many options to mitigate the effects of TRAP have been discussed, with several different stakeholders potentially involved in the process. In general however, some mitigation strategies are likely to be more effective than others. To conclude the discussion, the main recommendations for each stakeholder group is summarized below.

Community Members

- Complement your home with indoor plants
- Use public transportation and/or car-pooling when possible

Government Policy Makers

- Mandate setback distances of 150m on roads with AADT exceeding 15000
  - for already existing structures that house susceptible populations (i.e. hospitals, schools)
  - for any new developments
- Mandate the installation of HVAC systems in residential and commercial buildings that are located within exposure zones
- Install air quality monitoring systems in areas where high population densities coincides with high traffic densities
- Educate the public about TRAP related dangers

Urban Planners and Transportation Engineers

- Separate active commuting from traffic corridors (i.e. bike lanes and sidewalks)
- Focus on transit-oriented designs that aim at limiting TRAP exposure and increasing safety

There is much that can be done to help tackle the growing effects that TRAP has on our daily lives. It begins with us as individuals to make the correct choices -- which will shift our behavior as a population, hopefully paving the way for clearer, fresher urban atmosphere.

References

[1] Gower et al. (2014, April). *Path to Healthier Air: Toronto Air Pollution Burden of Illness Update* (Tech.). Retrieved from http://www1.toronto.ca/City Of Toronto/Toronto Public Health/Healthy Public Policy/Report Library/PDF Reports Repository/2014 Air Pollution Burden of Illness Tech RPT final.pdf

[2] Brauer, M. (2012, March 28). *Develop with Care 2012: Environmental Guidelines for Urban and Rural Land Development in British Columbia* (Tech.). Retrieved from http://www.env.gov.bc.ca/wld/documents/bmp/devwithcare2012/index.html

[3] Karner, A. A., Eisinger, D. S., & Niemeier, D. A. (2010). Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data. *Environmental Science & Technology, 44*(14), 5334-5344. doi:10.1021/es100008x

[4] Vardoulakis, S., Fisher, B. E., Pericleous, K., & Gonzalez-Flesca, N. (2003). Modelling air quality in street canyons: A review. *Atmospheric Environment, 37*(2), 155-182. doi:10.1016/s1352-2310(02)00857-9

[5] Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects. (2016). Retrieved from https://www.healtheffects.org/publication/traffic-related-air-pollution-critical-review-literature-emissions-exposure-and-health

[6] Ryan, P. H., & Lemasters, G. K. (2007). A Review of Land-use Regression Models for Characterizing Intraurban Air Pollution Exposure. *Inhalation Toxicology, 19*(Sup1), 127-133. doi:10.1080/08958370701495998

[7] Traffic-related air pollution and health : A Canadian perspective on scientific evidence and potential exposure-mitigation strategies. (2012, March 1). Retrieved from https://open.library.ubc.ca/cIRcle/collections/facultyresearchandpublications/52383/items/1.0132

[8] *Review of evidence on health aspects of air pollution – REVIHAAP Project* (Tech.). (2013). Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report-final-version.pdf

[9] Wu, L. (2014). *Reducing Traffic-Related Air Pollution Exposure in the Built Environment: Recommendations for Urban Planners, Policymakers, and Transportation Engineers* (Rep.). Retrieved from http://lasustainability.org/wp-content/uploads/2012/07/LASC_Report_LisaWu.pdf

[10] McAdam, K. (2010, March). *Air Quality in Halton: Traffic Corridor Report* (Rep.). Retrieved from http://www.env.gov.bc.ca/wld/documents/bmp/devwithcare/DWC-Air-Quality.pdf

[11] Board, C. A. (n.d.). Sustainable Communities. Retrieved from https://www.arb.ca.gov/cc/sb375/sb375.htm

[13] Keuken, M., Jonkers, S., Wilmink, I., & Wesseling, J. (2010). Reduced NOx and PM10 emissions on urban motorways in The Netherlands by 80km/h speed management. *Science of The Total Environment, 408*(12), 2517-2526. doi:10.1016/j.scitotenv.2010.03.008

[14] TORONTO MUNICIPAL CODE CHAPTER 517, IDLING OF VEHICLES AND BOATS. (n.d.). Retrieved from TORONTO MUNICIPAL CODE CHAPTER 517, IDLING OF VEHICLES AND BOATS

[15] *Central London Congestion Charging*. (2008, July). Retrieved from http://content.tfl.gov.uk/central-london-congestion-charging-impacts-monitoring-sixth-annual-report.pdf

[16] Kingdon, H. (2010, October). *Greater London Low Emission Zone* (Rep.). Retrieved from http://www.fta.co.uk/_galleries/downloads/email_news/london_low_emission_zone_guide.pdf

[17] Fleet News Fleet News. (2015). Mayor of London confirms ultra-low emission zone will launch in 2020. Retrieved from http://www.fleetnews.co.uk/news/2015/3/26/mayor-of-london-confirms-ultra-low-emission-zone-will-launch-in-2020/55274/

[18] Blumberg et. al (n.d.). LOW-SULFUR GASOLINE & DIESEL: THE KEY TO LOWER VEHICLE EMISSIONS. Retrieved from http://www.unep.org/transport/pcfv/pdf/publowsulfurpaper.pdf

[19] On-Road Vehicle and Engine Emission Regulations (SOR/2003-2). (n.d.). Retrieved from http://laws-lois.justice.gc.ca/eng/regulations/sor-2003-2/page-5.html

[20] Smedje, G., & Norbäck, D. (2000). New Ventilation Systems at Select Schools in Sweden—Effects on Asthma and Exposure. *Archives of Environmental Health: An International Journal, 55*(1), 18-25. doi:10.1080/00039890009603380

[21] Burton, A. (2012). Titanium Dioxide Photocleans Polluted Air. *Environmental Health Perspectives, 120*(6). doi:10.1289/ehp.120-a229

[22] *Interior Landscape Plants for Indoor Air Pollution Abatement* (Rep.). (1989, September 15). Retrieved from https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930073077.pdf

[23] (n.d.). Retrieved from http://www.independent.co.uk/news/world/europe/paris-public-transport-free-air-pollution-spike-a7460191.html