TECHNICAL PAPER

THE IMPACT OF CHOICE OF TRANSPORT MODE ON PERSONAL POLLUTION EXPOSURE

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ABSTRACT

The climate change debate has resulted in a greater focus on sustainable transport and initiatives are being introduced to encourage more people to use public transport, cycling and walking as their mode of transport. However, in New Zealand we know virtually nothing of the public health implications of doing this. This paper will review the available literature on how pollution exposure varies between transport modes and present the findings of some New Zealand research that assessed the comparative risk associated with exposure to traffic pollution when travelling on different transport modes including car, bike, bus and train. Data for ultrafine particles, PM10, PM2.5, PM1 and carbon monoside were collected in Auckland and Christchruch, New Zealand. In addition time activity data was collected using a combination of GPS data, sounds and photos. Results show that the choice of mode has significant implications for personal pollution exposure. In addition individual events on journeys can result in significantly raised spikes in exposure.

INTRODUCTION

Background

Debates about climate change, air pollution and increasing rates of obesity have resulted in a greater focus on sustainable transport. A range of new initiatives are being introduced to encourage more people to use public transport, cycling and walking as their mode of transport. However, virtually nothing is known of the public health implications of doing this. In New Zealand it has been demonstrated that over 500 people over the age of 30 die prematurely and over 650,000 restricted activity days each year are attributed to traffic emissions (Fisher et al., 2007). What we don't know is how individual choice of transport affects their exposure to traffic emissions. For example the increased health costs associated with additional pollutant exposure on pedestrian and cycle routes may outweigh any health benefits from increased exercise or the savings in burning fossil fuels.

Pollution exposure by transport mode

There has been some work that has measured pollution values while travelling and compared these results to ambient levels (CATF, 2007a, 2007b). From this the contribution of the commuter journey to total pollution exposure can be estimated. Most of this work has looked at exposure to diesel particles and has generally focused on one transport mode (Behrentz et al., 2004; Fruin et al., 2004; Sabin et al., 2005). An extension of this type of research has attempted to compare exposure between different transport modes, which has generally found that car drivers are exposed to higher concentrations of air pollution than public transport users, cyclists or pedestrians (Adams et al., 2001; ETA, 1997; Kaur et al., 2007; Kingham et al., 1998). However "*the extent to which this is generally true remains uncertain, and more research is needed to confirm the effects on exposures of changes in travel mode*". (Briggs et al., 2008, p13). Briggs' own research concluded that "*mean exposures while walking are greatly in excess of those while driving*" (Briggs et al., 2008, p12). They suggest that local factors could be the cause of such differences including such things as "*building configuration, road layout, monitoring methods, averaging periods, season, meteorological conditions, vehicle, driving and walking behaviours, and the strength of in-vehicle sources*" (Briggs et al., 2008, p20). Clearly this is an area where there is uncertainty about such exposure and local factors are a significant influence. To date, no research of this type has been undertaken in New Zealand, and given the importance of local conditions it is not possible to reliably extrapolate results from other climates and countries to the New Zealand case.

Purpose of the proposed research

The purpose of this project was to assess the comparative risk associated with exposure to traffic pollution when travelling on different transport modes and on a range of different routes. This will be achieved by providing an accurate measure of personal pollution exposure by transport mode. The key traffic-related pollutants examined in this study are: particulates (those smaller than 10 microns, PM_{10}; those smaller than 2.5 microns, $PM_{2.5}$; and those smaller than 1 micron, PM_1); ultrafine particles, and carbon monoxide (CO). Airborne concentrations of all of these contaminants in urban air are principally attributable to emissions from motor vehicles; with the particulates and ultrafine particles more representative of diesel vehicle emissions and CO more representative of petrol vehicle emissions. The research objectives were to:

- identify the relative personal pollution exposures to PM_{10}, $PM_{2.5}$, PM_1, ultrafine particles and carbon monoxide pollution associated with travelling by different transport modes.
- assess the contribution to daily personal pollution exposure of travelling by different transport modes.

The research will help answer the questions "*what are the pollution exposure implications of travel choices?*" and "*how can we plan and design bus, cycle and pedestrian routes to minimise pollution exposure?*" In addition it will provide information to inform transport decision making at personal and societal levels; and provide a stronger base for advocating consumer change in behaviour.

This research is explicitly not intended to repeat the study from the CATF US which was designed to asses the contribution of commuting to total daily particulate exposure, but did not attempt to compare exposure on the same routes by transport mode (CATF, 2007b). Instead it was intended to provide a comparative study of pollutant exposure travelling via different transport modes on the same routes. This includes the time spent throughout the entire journey from door to door and includes activities such as waiting at a bus stops or waiting to cross the road. This type of study is sensitive to local factors such as the characteristics of the vehicle fleet, road design and layout and meteorology which are unique to the New Zealand case. For example a recent study by Auckland Regional Council showed that in Auckland's oxidant limited atmosphere concentrations of Nitrogen Dioxide (NO_2) decrease much more slowly with distance from a busy roadway than has been previously shown in North American and European studies (Auckland Regional Council, 2007). From a health perspective the important parameters are exposure to spikes in pollutant concentration and the amount of time spent exposed to concentrations above the National Environmental Standards (NES). These conditions are thought to be a repeatable parameter and it is important to ascertain whether this is the case in the New Zealand context as well as in the US and Europe. The policy implications of differences in pollution exposure are potentially great; and the results of this research will enable better evidence-based transport planning decisions to be made.

METHOD

Pollutants

This project monitored concentrations of key traffic-related pollutants; particulates (PM_{10}, $PM_{2.5}$, PM_1), ultrafine particles, and carbon monoxide (CO). A major strength of this research compared to much previous work is the ability to simultaneously measure all of these contaminants, each of which provides different but complementary information. Particulate mass (e.g. PM_{10}) is globally the best-understood, most widely measured and most comparable measure of particulates, and provides the strongest epidemiological link to excess mortality. However, it is relatively insensitive to traffic emissions (see below) and can be dominated by non-exhaust sources (such as sea spray in Auckland). Ultrafine particles are much more indicative of the impact of exhaust emissions and more strongly associated with toxic effects. NO_2 (especially in the presence of particles) is strongly associated with adverse health effects, especially in the lung development of children, but its chemical reactivity means that concentrations are not easy to interpret. Although the toxic effects of CO are better established than the other pollutants, typically measured levels suggest that it presents a lesser hazard. All these measures of vehicle pollution were simultaneously measured wherever possible. At the start and end, and at other appropriate times, samplers were co-located to ensure consistency. Each of these samplers records real time pollution levels down to a temporal resolution of seconds.

Monitoring equipment

A variety of pollution monitoring equipment were used. All were relatively portable and were carried by an individual for the purposes of personal pollution exposure sampling. The equipment to be used is as follows:

- The GRIMM 1.107 Spectrometer is a portable Environmental Dust Monitor which can simultaneously measure PM_{10}, $PM_{2.5}$ and PM_1 at 6 second resolution using an optical scattering technique.
- Optical instruments such as the GRIMM are limited in that they can only detect particles large enough to scatter a beam of light (> approx. 350 nm in diameter). The vast majority of freshly emitted particles from motor vehicles are smaller than this, mostly by an order of magnitude. This includes elemental and organic carbonaceous particles derived from combustion products, unburnt fuel droplets and lubricating oil. These compounds include carcinogens, but their small size allows them to penetrate deep into the lungs where they can overload natural defences, cross cell membranes and enter the cardiovascular system with ease. These particles are numerically vastly dominant in vehicle exhaust, yet their small size means they contribute little to particle mass and are highly under-represented in traditional measures like PM_{10}.Thus in close proximity (tens of metres or less) to exhaust pipes alternative techniques and measures are demanded. However, Condensation Particle Counters provide an alternative. These devices count ultrafine particles by condensing an alcohol vapour onto its surface until it is large enough to be counted optically. We will use these to provide number concentrations of particles larger than 3 nm. This measure captures, and is most representative of the freshly emitted exhaust ultrafine particles (up to 100 nm in diameter) with which the adverse effects of particles on health are most strongly toxicologically related. Specifically in this project we used the TSI 3007 particle counter, which provides data with 1 second resolution.
- Langan Model T15n CO Measurer is a real time CO analyser. It has an electrochemical sensor optimized to observe carbon monoxide in the 0 to 200 parts per million (ppm) range with a resolution of 0.05 ppm (50 ppb).

Other data

Ambient pollution levels will be collated from Environment Canterbury's monitoring station in St. Albans. Where feasible and appropriate other ambient measurements will be collected.

- GPS data were collected for each mobile sampler.
- Meteorological data were collected and collated.
- Travel data were collected including information on such things as levels of traffic, arrival/departure at traffic lights and junctions, bus and train doors opening/closing by use of photographs taken at 2-3 second intervals and recording sounds observations enabling the traveler to record what was happening during the journey.

Monitoring regime

A programme of monitoring took place under a number of different scenarios:

- During the daily journey to work simultaneously comparing car, bus, bicycle and (in Auckland) train. These were repeated on a number of week days when conditions allowed (anticyclonic conditions, when wind speeds were light and pollution concentrations expected to be at a maximum). Sampling took place at the same time of day (during the morning and evening rush hours) to minimise confounding factors.
- For bicycle and pedestrian exposure on major routes and on paths away from traffic.
- Personal sampling during complete 24 hour periods to enable the calculation of total daily pollution exposure that is the daily commute.
- Mobile sampling was carried out simultaneously on a main road, and on paths 7-9 metres and 17-19 metres away from it.

Inter-modal sampling

Four commuters set out on specified routes that were designed (as closely as possible) to replicate typical commutes to and from sites of work or study. Journeys did not fully reflect the most logical commuting route for the car and main cyclist as it was important they took the same path as the bus commuter. Sampling trips were made during rush hour traffic to reflect when most people travel and to yield higher (more comparable) concentration recordings. The Christchurch study allowed for the replication of two separate journeys per sampling run – one from the northern fringe of the city to the city centre and then another to the University of Canterbury.

A total of 27 Journey 1 and 26 Journey 2 legs were completed in Christchurch with another 26 journeys completed in Auckland. Data was lost for multiple journeys and not all of the collected data was useful.

For Christchurch, the modes consisted of bus (Kit 1), car (Kit 2), cycle off-road (Kit 3) and cycle on-road (Kit 4). One cyclist rode an off-road route via dedicated cycle-ways, through parks and backstreets, while another took exactly the same route as the bus and car. This was to explore the exposure implications of taking a longer off-road route versus a more direct route on-road.

In Auckland, bus became Kit 3, Kit 1 became train and there was no off-road cycle mode due to equipment restrictions and lack of suitable comparative routes. Kits 2 and 4 remained the same as for Christchurch. The cyclist, car and bus again travelled the same route which ran as closely as possible to the train line.

As there were only three 3007s available among four kits, one was switched between kits near the end of each sampling campaign to ensure data was collected across all modes. In Christchurch, a 3007 was placed in Kit 3 for Runs 1-17 and then moved to Kit 1 for the remaining ten runs. In Auckland, a 3007 was switched from the bus to the train for the final journey only. NIWA had already collected substantial UFP data for the train mode and data loss and time constraints meant greater priority was given to the other three modes.

Effect of proximity to traffic

To investigate the impact of proximity to traffic, a number of sampling runs were made using three cyclists riding simultaneously at different distances from the flow of traffic. One cyclist was situated on the road right next to traffic, another on the footpath 4.5 - 7 metres away and the third was on an off-road path approximately 17.5 – 19 metres away on average. Cyclists rode along a specified road/path section and then turned around and went back the other way, repeating the process until at least 20 lengths were completed. This was done three times in each city to account for different weather conditions.

The extent to which pollutant levels decrease at very small distances from traffic has important implications for the positioning of cyclist and pedestrian pathways. While microscale computer modeling may provide clearer answers than monitoring by means of numerous fixed sites, it may not be entirely representative of exposure whilst moving.

Routes

Christchurch inter-modal routes

The Christchurch run was split into two separate journeys to replicate two normal commutes within the rush hour timeframe. The first of these journeys started at 7.40am and ran 8.2 km from 340 Main North Road to the city bus exchange (Figure 1). On arrival, the car driver parked in a parking lot above the bus terminal and met the bus commuter and the cyclists at Cashel Mall (a street closed off to traffic). After a short wait, the second part of the journey ran 7.5 km to the University of Canterbury Geography department arriving at 9am (Figure 2). In the afternoon the journey left the University at 4.45 pm arriving at Redwood at 6.05pm.

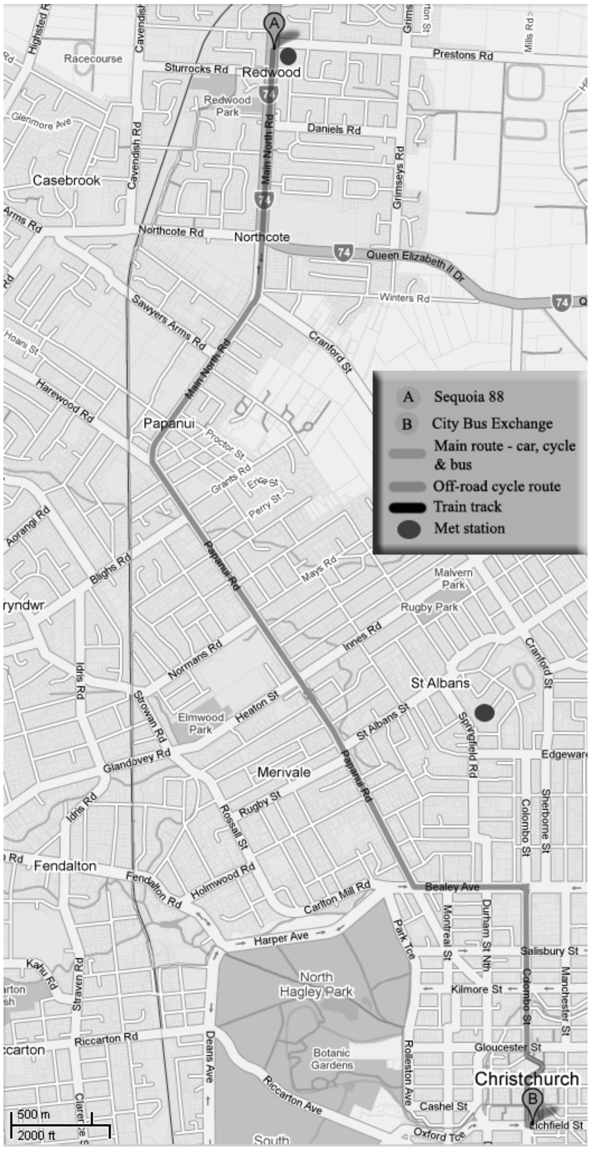

Figure 1: Christchurch sampling route: a. Redwood to city centre

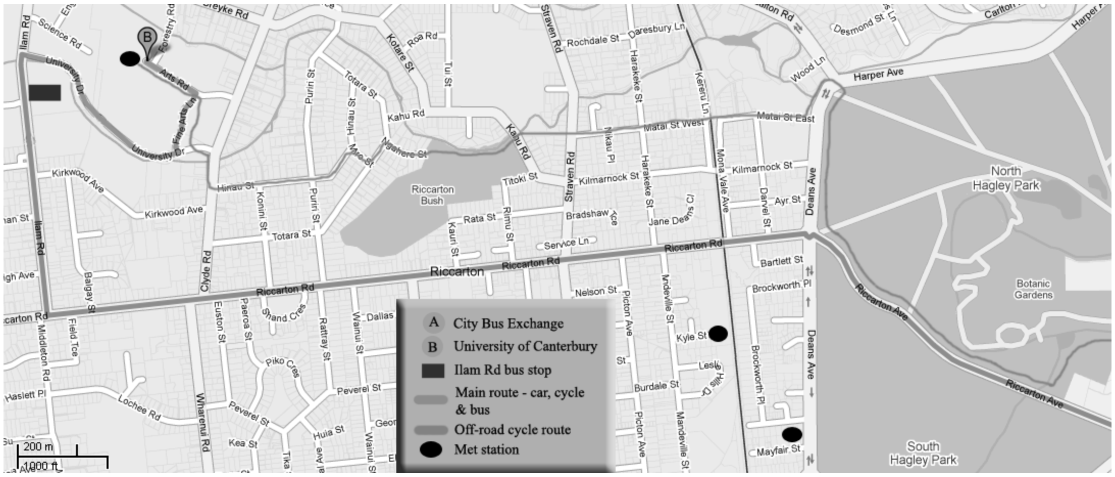

Figure 2: Christchurch sampling route: b. city centre to University

Auckland inter-modal route

The Auckland route ran from 947 New North Road at Mt Albert to NIWA headquarters at Market Lane in the city centre. This route was chosen due to its: proximity to the train track; proximity to volunteers' residences; use as a key commuting route to the city centre; use as a key bus route featuring dedicated rush hour bus lanes. The car, bus and cycle traveled along exactly the same route but the bus commuter walked part of the journey; to and from the Victoria Street bus station. Similarly, the train commuter walked part of the leg, to and from the Britomart Transport Centre along the same route as the car and cycle. The car and cycle route also varied slightly during the afternoon due to 'Bus Only' turning restrictions but this was not considered to significantly alter the results. The total distance of the morning journey was 9 km and the afternoon journey was slightly longer at 9.4 km. In the morning the journey started at 7.40 am and finished at 8.40 am and in the evening ran from 4.25 to 5.30 pm.

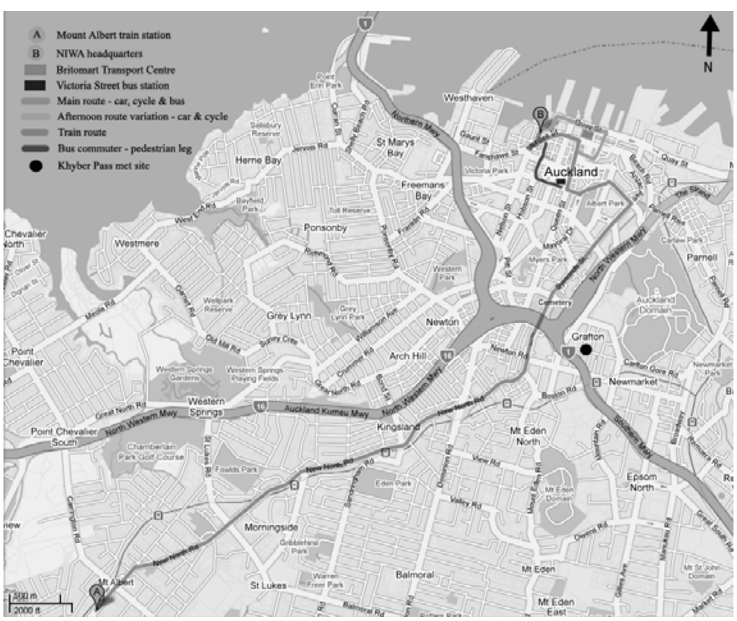

Figure 3: Auckland sampling route

RESULTS

Pollution levels by mode

Car drivers have the highest exposures for carbon monoxide and ultrafine particles (Figures 4 and 5). This is unsurprising as for both CO and UFP traffic emissions will be the main source. This confirms the findings of most other studies.

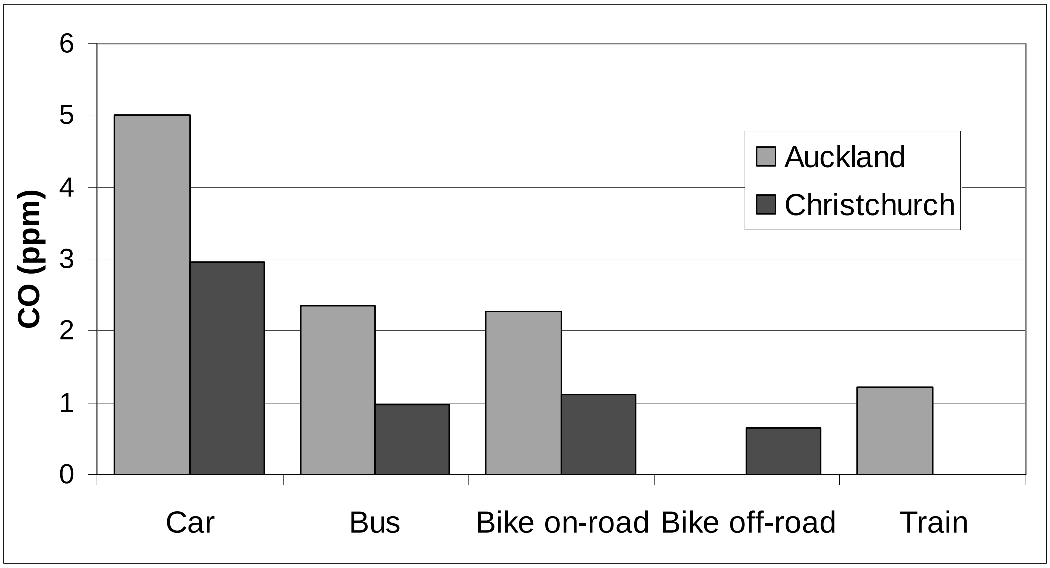

Figure 4: Mean CO results, Christchurch and Auckland

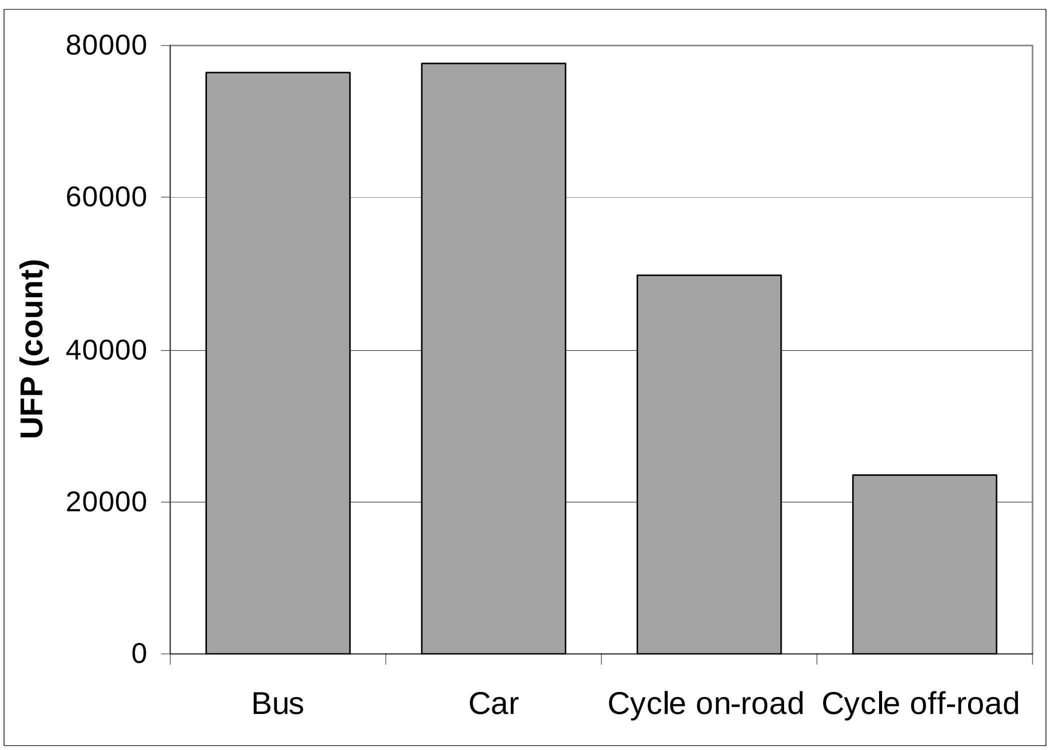

Figure 5: Mean UFP levels, Christchurch

The pattern is less clear for particulates (Figure 6) especially the coarser fraction. There is no consistent pattern across modes for the various size fractions. For the largest size fraction

(PM_{10}) the car passenger seems to be exposed to the lowest levels in both Christchurch and Auckland (although not significantly in the latter). There are two possible reasons for this. Firstly it may be that the filters in the ventilation system are keeping the larger particles out. Secondly, it could be that the cyclists and bus passengers are exposed to resuspended particles. This could especially be the explanation for the high levels for the off-road cyclist as they are away from traffic emissions but may well be exposed to wind blown soil and dust. The main conclusion to draw from this is not that car drivers are protected from pollution but that PM_{10} is a poor indicator of harmful vehicle emissions

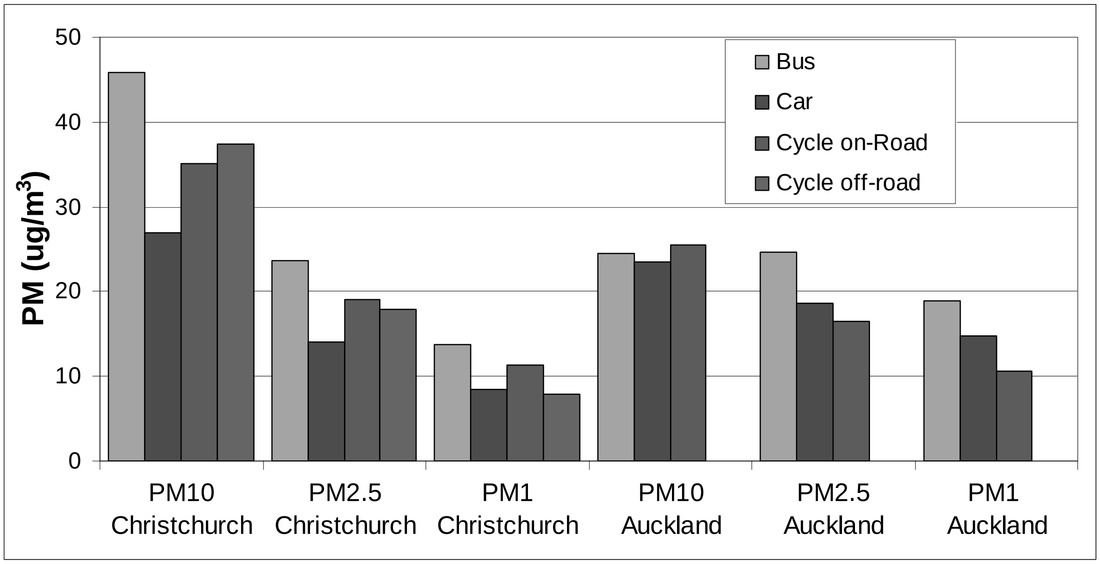

Figure 6: Mean PM levels, Christchurch and Auckland

The off-road cyclist exposures are nearly always exposed to lower levels of pollution than those on the road and the further away from the road the lower the levels (Figure 7).

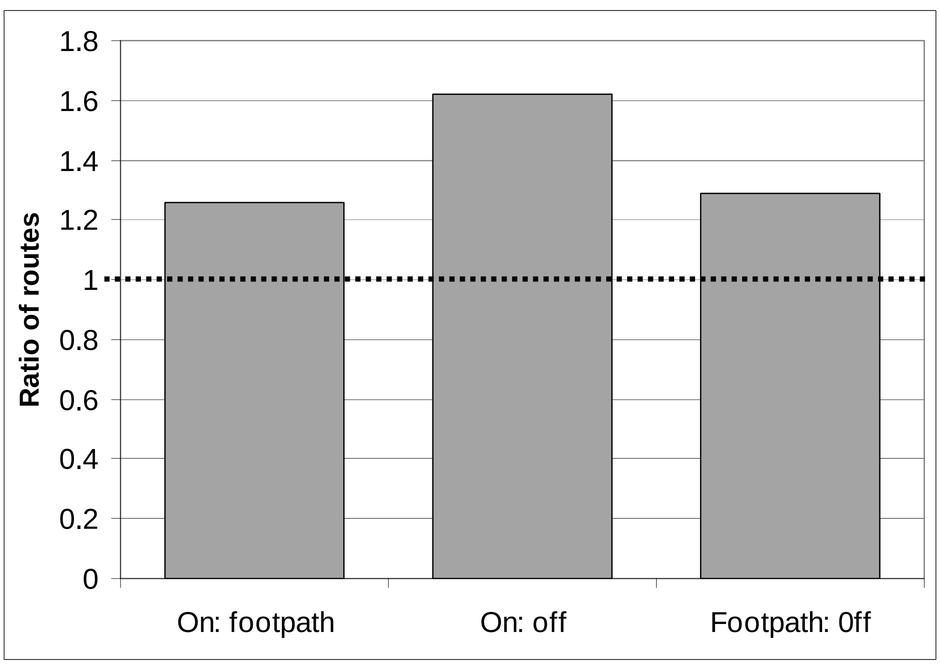

Figure 7: Ratio of cyclist CO levels with proximity to road, Christchurch

In addition by analysing differences between the relative exposure of on-road cyclists to car drivers in Auckland and Christchurch it can be seen that relatively the Christchurch cyclists are exposed to lower pollution levels that those people cycling in Auckland. A possible explanation for this is that in Auckland the cyclists are generally ‘in’ the traffic with no cycle lane, whereas in Christchurch there is at least a painted line enabling cyclists to keep moving even when the traffic stops. This suggests that even this type of facility can reduce a cyclists pollution exposure.

Exposure and place

Pollution, GPS, camera and sound data was incorporated into the GRC Mapper software. An example can be seen in Figure 8. The graphs on the left show (from top to bottom) ultrafine particle counts; PM_{10}, $PM_{2.5}$ and PM_1; and CO levels. The map on the rights shows the route taken with the red dots indicated current location. The image on the bottom right shows what was recorded by the camera at the point in time and place. Preliminary analyses suggest that peaks in pollution levels can be related to route activity and levels of, and proximity to, traffic.

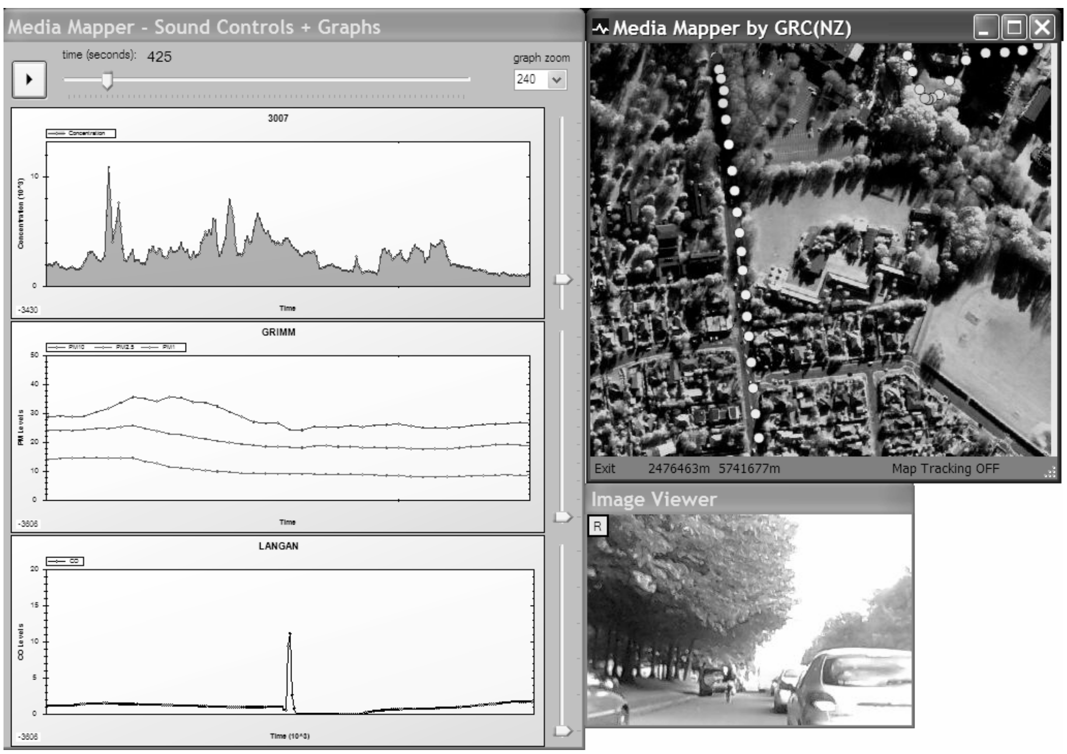

Figure 8: GRC mapper output of pollution, GPS and camera images

CONCLUSIONS

This paper primarily presents some results from an innovative study that assessed pollution exposure while travelling on different modes of transport in Christchurch and Auckland, New Zealand. The results show that mode of transport significantly affects the level of pollution a traveller will be exposed to, with the highest levels of traffic emissions being experienced by those travelling in motor vehicles. This information should be used to help affect desirable changes in travel behaviour. In addition this research has demonstrated that moving cyclists a relatively short distance away from traffic, or even just allowing them move freely and not be ‘stuck’ in traffic’ can significantly reduce pollution exposure. This potentially has significant policy implications. The results should be used in the long term planning of land use plans that include provision for cycle routes. Those responsible for planning, designing and building cycle infrastructure can use these results to achieve more desirable outcomes. The results could be used to develop 'healthier' cycle route design guidelines.

REFERENCES

Adams, H., Nieuwenhuijsen, M. and Colville, R. 2001: Determinants of fine particle (PM2.5) personal exposure levels in transport microenvironments, London, UK. *Atmospheric Environment* 35, 4557-4566.

Auckland Regional Council 2007: Nitrogen dioxide in air in the Auckland Region: Passive sampling results. Auckland: Auckland Regional Council.

Behrentz, E., Fitz, D.R., Pankratz, D.V., Sabin, L.D., Colome, S.D., Fruin, S.A. and Winer, A.M. 2004: Measuring self-pollution in school buses using a tracer gas technique. *Atmospheric Environment* 38, 3735-3746.

Briggs, D.J., de Hoogh, K., Morris, C. and Gulliver, J. 2008: Effects of travel mode on exposures to particulate air pollution. *Environment International* 34, 12-22.

CATF 2007a: A multi-city investigation of exposure to diesel exhaust in multiple commuting modes. Boston: Clean Air Task Force.

CATF 2007b: No escape from diesel exhaust: how to reduce commuter exposure. Boston: Clean Air Task Force.

ETA 1997: Road User Exposure to Air Pollution: Literature Review. Environmental Transport Association.

Fisher, G., Kjellstrom, T., Kingham, S., Hales, S. and Shrestha, R. 2007: Health and Air Pollution in New Zealand. Final Report. Available from www.hapinz.org.nz. Prepared for Health Research Council, Ministry for the Environment and Ministry of Transport.

Fruin, S.A., Winer, A.M. and Rodes, C.E. 2004: Black carbon concentrations in California vehicles and estimation of in-vehicle diesel exhaust particulate matter exposures. *Atmospheric Environment* 38, 4123-4133.

Kaur, S., Nieuwenhuijsen, M.J. and Colvile, R.N. 2007: Fine particulate matter and carbon monoxide exposure concentrations in urban street transport microenvironments. *Atmospheric Environment* 41, 4781-4810.

Kingham, S., Meaton, J., Sheard, A. and Lawrenson, O. 1998: Assessment of exposure to traffic-related fumes during the journey to work. *Transportation Research Part D-Transport and Environment* 3, 271-274.

Sabin, L.D., Kozawa, K., Behrentz, E., Winer, A.M., Fitz, D.R., Pankratz, D.V., Colome, S.D. and Fruin, S.A. 2005: Analysis of real-time variables affecting children's exposure to diesel-related pollutants during school bus commutes in Los Angeles. *Atmospheric Environment* 39, 5243-5254.

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