A PERSPECTIVE OF AUSTRALIAN TUNNEL VENTILATION

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ABSTRACT

Tunnel ventilation and the resultant impacts on ambient air quality have been the most difficult and controversial aspects of tunnel design in Australia in recent times. There has been a strong push to install filtration equipment in recently developed tunnels for environmental reasons. The resultant pressure on authorities and regulators has led to a conservative design and a considerable cost impost on projects. This paper provides both a retrospective analysis of recent tunnel ventilation design in Australia and a commentary on key areas where these designs may be reviewed in the future.

KEY WORDS

TUNNEL / VENTILATION / AIR QUALITY / FILTRATION / AUSTRALIA

1. INTRODUCTION

Around the world governments have recognised and responded to the need to introduce measures to improve air quality. Whilst the need is universal, emphasis has been placed on different aspects of air quality in individual countries. In Australia, considerable attention has been focussed on the effects of tunnel ventilation on air quality near the tunnel portals and ventilation stacks.

This attention has resulted in an approach to tunnel ventilation design that, by international standards, is conservative and precautionary in many respects. Recent tunnels have been designed to have virtually no affect on air quality around portals, by eliminating portal emissions during normal operation, and high internal air quality with CO levels maintained below WHO 15 minute and 30 minute goals.

Whilst these outcomes are reassuring for local residents and tunnel users, this approach to design comes at a cost. These tunnel ventilation systems consume considerable amounts of energy, are very expensive to operate and result in the creation of large quantities of greenhouse gases at the power source until such time as “green” energy is available in sufficient quantities.

Despite this conservatism, calls for the installation of filtration equipment either in ventilation stacks or in-tunnel have continued to be made.

Whilst Australia is probably unique in its current approach to tunnel air quality, internationally the health effects of poor air quality are recognised. There are indications from other parts of the world that issues such as the health effects of fine particles, particularly the ‘ultra fines’ less than 1.0 micron (PM1.0), on residents in situations of long exposure to high levels, will need to be carefully addressed.

In this environment of increased concern for people’s health, the challenge for tunnel designers will be to design tunnel ventilation systems that provide a balance between these health concerns, energy usage, greenhouse gas emissions, traffic flow, fire life safety, portal and ventilation discharges in a way that is transparent and reassuring to nearby residents.

2. AIR QUALITY IN AUSTRALIA

Air quality in large Australian cities is very good by international standards. Air quality has improved steadily over the last twenty years for almost all key parameters associated with vehicle emissions. This improvement has been achieved despite the significant increase in car usage. The improvement has been particularly significant for carbon monoxide and lead due to a series of measures to reduce emissions from vehicles by design rule changes and other controls such as the introduction of 3-way catalytic converters. Air quality is expected to improve further with the introduction of the Euro 2 standard for light vehicles and Euro 3 for heavy-duty vehicles this year and Euro 4 in 2006/7.

Air quality standards have been reducing progressively and today are generally at the lower end of the range of international standards (see Table 1 below).

Pollutant	Goal	Averaging Period	Agency
Carbon monoxide	87 ppm or 108 mg/m^3 25 ppm or 31 mg/m^3 9 ppm or 10 mg/m^3	15-minute maximum 1-hour maximum 8-hour maximum	WHO WHO NHMRC, NEPM
Nitrogen dioxide	0.12 ppm or 245 μg/m^3 0.11ppm or 200 μg/m^3 0.03 ppm or 60 μg/m^3	1-hour maximum 1-hour maximum annual mean	NEPM, NSW EPA WHO, NSW EPA long term reporting goal NEPM, NSW EPA
Total suspended particulate matter (TSP)	90 μg/m^3	annual mean	NHMRC
Particulate matter < 10 μm (PM_{10})	30 μg/m^3 50 μg/m^3	annual mean 24-hour maximum	NSW EPA NEPM, NSW EPA
Lead	1.5 μg/m^3 0.5 μg/m^3	90-day average annual average	NHMRC NEPM
Ozone	0.10 ppm or 200 μg/m^3 0.08 ppm or 150 μg/m^3 0.08 ppm or 150 μg/m^3 0.06 ppm or 120 μg/m^3	1-hour maximum 4-hour maximum 1-hour maximum 4-hour average	NHMRC, NEPM NSW EPA NSW EPA long term reporting goal NSW EPA long term reporting goal
Sulphur dioxide	0.25 ppm or 700 μg/m^3 0.20 ppm or 570 μg/m^3 0.08 ppm or 225 μg/m^3 0.02 ppm or 60 μg/m^3	10-minute maximum 1-hour maximum 1 day annual mean	NHMRC and NEPM NEPM NHMRC and NEPM
Air toxics and odorous compounds:			
Benzene	5 ppb or 16 μg/m^3	annual average	UK
PAHs (as BaP)	8.7 x 10^{-5} per ng/m^3	unit risk factor	WHO
1,3-Butadiene	0.45 ppm or 1 mg/m^3	3-minute maximum	NSWEPA
Acetaldehyde	0.042 ppm or 0.076 mg/m^3	3-minute maximum	NSWEPA
Formaldehyde	0.033 ppm or 0.05 mg/m^3	3-minute maximum	NSWEPA

μm - micrometre
ppm - part per million
μg/m$_3$ – micrograms per cubic metre
ng/m$_3$ – nanograms per cubic metre
mg/m$_3$ – milligrams per cubic metre
PAH - polycyclic aromatic hydrocarbons
BaP - benzo (a) pyrene, the most widely studied PAH and used as an indicator compound
unit risk factor for BaP refers to the risk of developing cancer from a 70 year exposure to 1 ng/m$_3$ of BaP

Table 1 - NSW Air Quality Goals and other relevant goals

Whilst Australians are sensitive to the environment and the pace of the Government agenda to improve air quality is generally accepted, some local interest groups have been very focussed in pursuing air quality improvements on tunnel projects. This focus developed principally with the Melbourne City Link project in Melbourne and the M5 East project in Sydney.

3. M5 EAST PROJECT

The M5 Motorway was conceived as part of Sydney's motorway network in 1948. It was originally proposed as a surface freeway with the eastern section running along the Wolli Creek corridor. In the early 90s the development of the eastern section of the M5 was strongly opposed by groups seeking to have the Wolli Creek and adjacent bushland areas preserved.

To reduce the environmental impact of the motorway, Roads Traffic Authority, NSW (RTA) turned to a tunnel as a solution to the dilemma. This was a very expensive alternative but was justified by the significant benefits. After considering several alignments, the route running beneath the suburb of Bardwell Park was adopted. Three ventilation stacks were proposed for the ventilation of this 4.0 km tunnel. In response to a strong community reaction to having stacks in residential areas these three stacks were dropped and a single stack adopted and approved in the nearby suburb of Turrella, on the original freeway alignment (See Figure 1).

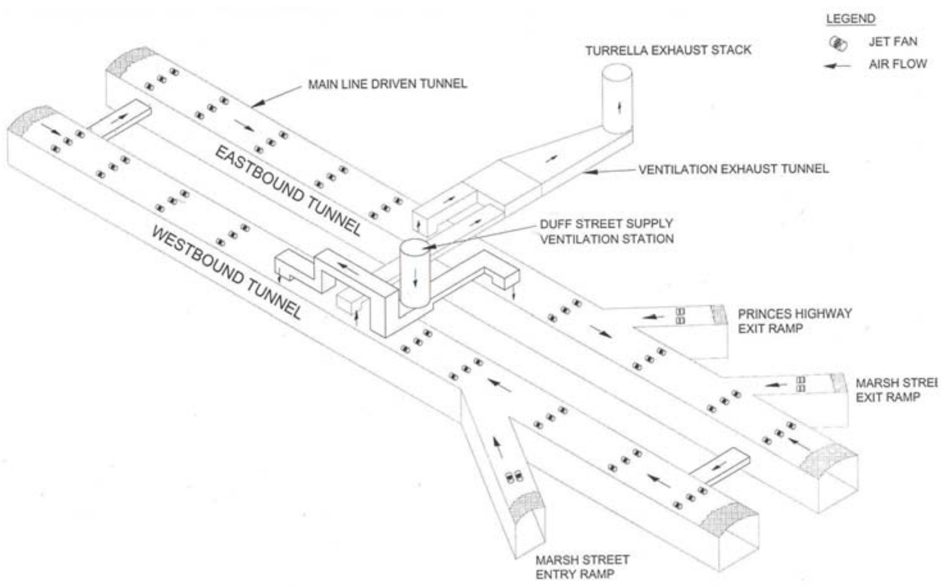

Figure 1 - M5 East Tunnel Ventilation System

Recognising the concerns of nearby residents, the project was approved with conditions that were intended to minimise any air quality impacts of the project.

These conditions imposed the following requirements and restrictions:

a) The ventilation system had to be designed to avoid air emission from the portals as far as practical;
b) Wind tunnel testing of the dispersion of emissions from the stack;
c) Installation of a comprehensive monitoring system;
d) An obligation to provide for future installation of air treatment systems;
e) Funding of subregional air quality improvement measures.

As a result of his change, residents living near the approved stack formed an action group to oppose the construction of the stack at Turrella. This group have been active since that time, continually lobbying the various government agencies to move the stack or to install filtration equipment. Three parliamentary inquiries have been held into the ventilation stack, the air quality standards and outcomes of the project.

The project was opened to traffic on 10 December 2001. Extensive monitoring of ambient air quality has demonstrated that the air discharged from the tunnel ventilation stack has had no discernible affect on ground level receptors (Holmes, 2002). Complaints from local residents of health effects including symptoms such as itchy eyes and respiratory illnesses appear to be inconsistent with the monitored levels of pollutants, but are being investigated by the NSW Department of Health.

4. BALANCING COMPETING OBJECTIVES

It is arguable whether tunnel ventilation in any other country has come under as much scrutiny as in Australia. This scrutiny has probably resulted in tunnel ventilation design and operation that is skewed in favour of local air quality at the expense of energy consumption, pollutant emissions from coal fired power generating plants, and greenhouse gas creation. It would be easy to dismiss the Australian experience as an anomaly that has no applicability to other countries. The international interest in air quality would suggest otherwise. It is timely to review the Australian experience as a barometer of future trends in tunnel ventilation with a view to influencing the direction of tunnel ventilation design development. The design of the Lane Cove Tunnel will be discussed as a case study.

The design of this tunnel has not been finalised but as the most recently developed tunnel it is a good indicator of the current state of ventilation design philosophy in Australia.

The Lane Cove Tunnel in the northern suburbs of Sydney is proposed as a twin tube 3.4km tunnel predicted to carry approximately 104,000 vehicles per day. It will form part of Sydney's Orbital motorway and will be heavily congested in peak hours. It is proposed to have two ventilation stacks, one at either end of the tunnel and an intermediate fresh air intake to allow the air in each tube to be refreshed at an intermediate point. Portal emissions are not permitted except in emergencies.

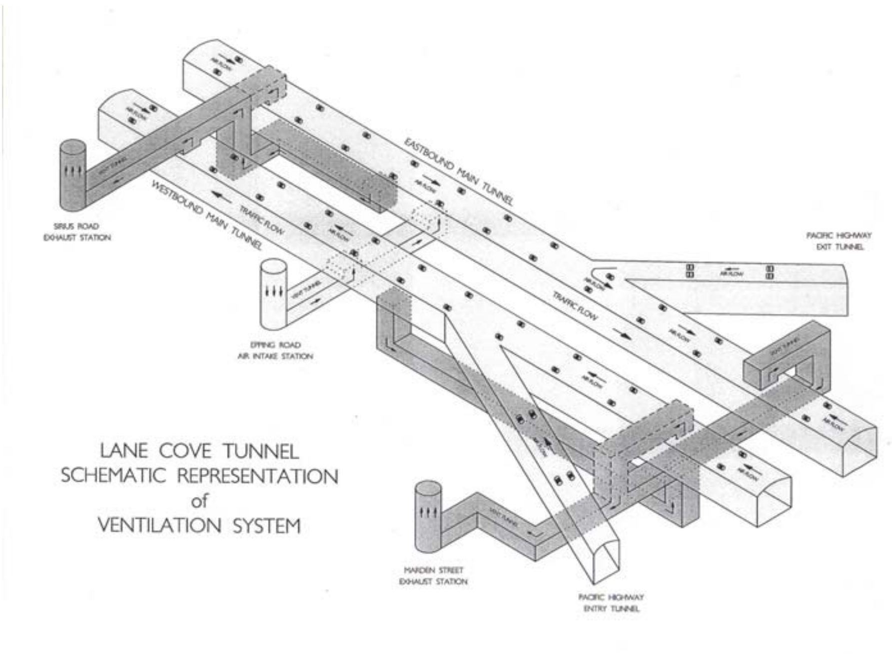

Figure 2 - Lane Cove Tunnel Ventilation System

The design has been heavily influenced by the concerns of local residents and the requirements of the regulating authorities. Specific factors that have been taken into account in the ventilation design include the proximity of the tunnel ventilation stacks to residential areas, the availability of commercial land near to the tunnel on which to locate the stacks, concern for the health of motorists who may remain in the tunnel for extended periods of time during traffic incidents, and the need to make future provision for filtration. These issues have been weighted more heavily than construction cost, operating cost, energy consumption, and greenhouse gases generation.

The original ventilation system for the Lane Cove Tunnel was based on the WHO criterion for CO of 87 ppm over a 15 minute averaging period and on prudent traffic management in the event of exceptional congestion impacting on the tunnel air quality. . Subsequently, requirements were imposed on the project such that the ventilation system was required to accommodate stationary traffic and an in-tunnel WHO CO exposure goal of 50ppm averaged over 30 minutes. As an indication of the impact of these changes, the operating cost of the ventilation was estimated to increase from A$660,000 to A$1,220,000 per annum and the energy consumption from 48,294 to 89,396 MW hours per annum.

The cumulative effect of the changes is obviously very significant. Australian tunnels now under development, when compared to similar tunnels in other countries, will provide probably the highest level of air quality both in and around the tunnels of anywhere in the world. This poses some interesting questions for tunnellers everywhere. Has Australia identified and addressed key air quality issues or has the reaction been unwarranted? For Australia, the huge increase in ventilation costs provides enormous incentive to seek an alternative approach to the management of air quality in tunnels.

What avenues do we have to reduce cost yet still meet health outcomes? The areas that can be looked at include:

Application of Air Quality Goals

The World Health Organisation (WHO) is the international organisation charged with the task of promoting appropriate goals to protect the health of all peoples. WHO has researched and published the WHO *Guidelines for Air Quality* that provide a basis for protecting public health from the adverse effects of environmental pollutants. The purpose of the *Guidelines* is to provide background information and guidance to governments for making risk management based decisions in setting air quality standards.

WHO describes the basis of its goals as being:

"… levels of air pollution below which lifetime exposure, or exposure for a given averaging time, does not constitute a significant health risk. If these limits are exceeded in the short-term it does not mean that adverse effects automatically occur; however the risk of such effects increases. Although the Guidelines for Air Quality values are health- or environment-based levels, they are not standards per se. Air quality standards are air quality guidelines promulgated by governments, for which additional factors may be considered. For example, the prevailing exposure levels, the natural background contamination, environmental conditions such as temperature, humidity and altitude, and socio-economic factors."

When proceeding from the Guidelines for Air Quality to standards, policy options include such questions as how to provide equitable protection, including susceptible groups. Several additional items must also be considered: the legal aspects; a definition of what constitutes adverse effects; a description of the population at risk; the exposure-response relationship; the characterisation of exposure; an assessment of risks and their acceptability; and the financial costs of air pollution controls and their benefits.

In translating air quality goals into standards for tunnel operation it needs to be recognised that the set of in-tunnel air quality occurrences will be normally distributed. This normal distribution will include infrequent outlying air quality readings that will exceed the WHO goal. To design a tunnel such that the WHO goal is *never to be exceeded* is a difficult and costly exercise. Current European regulations utilise peak values that are the 95th or 98th percentiles. This means that the peak value would be exceeded for 5% (438 hours yearly) and 2% (175 hours) of the time each year. (Bettelini, Brandt and Riess 2001).

Designing and Operating Tunnels based on Exposure

The simplest way in which to manage air quality is to set standards and to monitor and control air quality at the most adverse locations in the tunnel. For longitudinally ventilated tunnels this would be near the exit portals. However, the WHO *Guidelines for Air Quality* are based on controlling the *exposure* of people to adverse air quality. Monitoring at fixed locations does not recognise that motorists are moving through the tunnel and are therefore "exposed" to varying pollutant levels throughout the tunnel. A simple approach would be to manage the air quality based on the *average* air quality through the tunnel. Whilst this method would be a better measure of exposure, it would not account for stop start traffic in a tunnel with motorists spending a longer period in the sections of the tunnel where the air quality is poorest.

A more sophisticated approach is to monitor both traffic speed and air quality throughout the tunnel and to calculate motorists' exposure as an aggregate of the time spent and air quality in each section of the tunnel. A simple algorithm can be utilised to provide a continual measure of motorist's exposure, calculated and displayed in real time.

Portal Discharge

Air quality issues also occur at tunnel portals when the air is discharged into areas inhabited by people. The tunnel has the effect of concentrating emissions in the vicinity of the exit portals. Traditionally, this situation has been managed by designing tunnels such that air quality at tunnel portals remains within air quality goals or by incorporating a ventilation stack into the design to reduce portal discharge.

Putting aside the issue of whether the Australian practice of prohibiting tunnel portal discharge is appropriate or not, the indisputable situation is that it has resulted in considerable amounts of energy consumed by the ventilation systems of recent tunnels. Accordingly, there is an opportunity to conserve energy and reduce cost through a change in management of air discharged at portals.

The challenge is to develop a regime of partial portal discharge that ensures that air quality goals are met.

Traffic Control

Given that slow-moving, congested traffic conditions result in the worst in-tunnel air quality, one way to reduce energy consumption and operating costs is to implement a regime of traffic management to avoid these traffic conditions occurring in a tunnel. Such a regime was proposed for the M5 East Tunnel in Sydney. The system was designed such that once traffic speed fell below 60/40/20 km/hr, traffic measures were progressively implemented to reduce the flow of traffic into the tunnel.

As a consequence of the performance of the ventilation system exceeding expectations, it has not been necessary to adhere to this regime. However, traffic is restricted in the event of a breakdown or other incident in the tunnel in order to avoid motorists remaining in the tunnel for prolonged periods and to maintain in-tunnel air quality within approved limits. Early teething problems pointed to the difficulty of timely intervention, although in recent times, tunnel staff, Police and the RTA have become more adept at implementing traffic management measures. Traffic management is a valid tool for reducing operating costs but because of the difficulty of timely implementation and the risk of delay leading to an occasional exceedance of air quality goals, it would be difficult to rely on traffic management alone to maintain suitable air quality.

Personnel Working in the Tunnel

WHO guidelines recognise that the longer people are exposed to polluted air, the lower the pollutant levels must be. Accordingly, if people are stopped or working for a prolonged period in a tunnel, application of the WHO guidelines requires that CO levels drop from 87 ppm for a 15 minute averaging period to 50 ppm for a 30 minute averaging period. What this effectively means is that the tunnel ventilation system must be capable of maintaining CO below this reduced goal under all operating conditions, as a motorist can stop at any time due to a mechanical breakdown and potentially at least remain in the tunnel for thirty minutes or more.

The installation of ventilation systems with a capacity capable of maintaining in-tunnel air quality below 50 ppm for thirty minutes under all conditions, except fire, is a significant financial burden on tunnel projects. This can only be avoided by a more pragmatic risk management approach to traffic management, coupled with a regime of increased portal discharge and greater flexibility in compliance with in-tunnel air quality limits, i.e. occasional minor exceedances.

5. FILTRATION

Studies in Australia have consistently shown that conventional longitudinal systems incorporating ventilation stacks provide the most efficient and economical method of ventilating an urban road tunnel of the lengths recently developed. The Environmental Impact Statement for the Cross City Tunnel (RTA, 2000) reported that:

“ there are no tunnels in the world with comparable traffic numbers, fleet mix, emission rates and atmospheric conditions and social environment where in-tunnel filtration is used as the only form of emissions control and where this has been quantitatively assessed and considered to be environmentally acceptable”.

Australian road authorities have resisted the additional impost of installing filtration systems on tunnels. Investigation of filtration systems installed in other countries has indicated that it is a complex field that is still developing. Insufficient evidence has been found to exist to justify the installation of filtration equipment to supplement or replace conventional fan-driven ventilation systems. This conclusion has been supported by the monitoring of the performance of tunnels such as the Melbourne City Link and the M5 East tunnels.

6. CONCLUSION

Australia's tunnels have become very sophisticated, providing a very high level of reassurance that both external and internal air quality goals will be met. The price paid by this conservatism has been a high construction and operating cost, a high-energy consumption, pollutant emissions from coal fired power generating plants, and greenhouse gas creation.

The question to be answered is whether or not these designs are too conservative, requiring greater consideration of the above environmental and cost factors. The level of acceptable portal discharge and the introduction of more sophisticated traffic management are possible tools for air quality management that warrant further review.

Whilst each country has its own particular circumstances, there are clearly issues arising in Australia that have international implications. Australian representatives have been working with PIARC Working Group 2 to develop guidelines to address the topic of external air quality associated with tunnel design.

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