25th Australasian Transport Research Forum
Incorporating the BTRE Transport Policy Colloquium
Canberra 2-4 October 2002

Estimation and valuation of environmental and social externalities for the transport sector

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Abstract

This paper aims to quantify elements of the Triple Bottom Line (TBL) approach to transport infrastructure investment decision making, in accordance with international best practice. The primary objective is to provide a Table that values social and environmental external impacts relating to transport projects, for project preparation, appraisal and selection. This paper describes the derivation of these values according to an extensive review of Australian and overseas studies. It does not aim to be a definitive listing, acknowledging that the data presented should be used in conjunction with other models and with other real data where possible. It is proposed that this Table provide a starting point to operationalise the TBL, by establishing a common base of default externality values. It is acknowledged that there is a distinct lack of research and studies conducted in Australia of environmental and social externalities on the transport sector. Australia is heavily reliant on overseas studies, which in some cases provide dated values for use in a project appraisal and evaluation. The paper highlights that it is necessary to value externalities as accurately as possible in order to drive policy directions, appraise and evaluate public sector projects, and allocate budgets appropriately.

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Introduction

The Victorian Department of Infrastructure (DOI) is preparing *Investment Appraisal and Evaluation Guidelines*. These Guidelines aim to provide the means to consistently appraise and evaluate the effectiveness and viability of projects of various types across the Department. The *Estimation and Valuation of Environmental and Social Externalities Table* has been developed, as part of the Guidelines, to support a requirement to increase the number of externalities quantified within appraisals.

This paper describes how a series of social and environmental externality values have been derived according to an extensive literature review of both Australian and overseas studies. The Department is in its early stages of implementing this process, with the practical application of these values the next focus. These values are therefore not finalised and further refinement is expected.

Often in a project appraisal, environmental and social impacts are unquantified and valued at zero, creating biased results. This analysis proposes a mechanism to operationalise the Triple Bottom Line (TBL), by establishing a common base of default externality values.

The values exist in an aggregate form and are evolving. The intent at this early stage is to provide broad values for use in project appraisals, where currently little information is available. Where appropriate, the Guidelines encourage the use of project specific data.

To further support the process, DOI is developing a range of models to further develop project appraisals. These include Greenhouse Gas Emission models, Air pollution model and Noise Pollution model. A range of other modelling techniques also exist and VicRoads have developed mechanisms to estimate externalities.

It is noted that numerous other externalities exist as a result of transport activities so this initial list is not exhaustive. It is intended that the Table forms a basis for the discussion of values attributed to certain externalities, and hence obtain more accurate values through this process. The analysis should therefore be considered as a starting point for integrating economic, social and environmental externalities pertaining to transport.

Due to the extensive scope of this analysis of externalities, specific reference to some studies and explanation of Departmental models have been excluded from this paper, however they can be accessed from the Department.

This paper is structured to discuss:

- externalities and the Victorian Government's TBL approach to decision making;
- a background to valuing externalities;
- the Table of externality values;
- how information was used to select externalities;
- methodologies for measuring environmental and social externalities and selection of values; and
- future prospects for quantifying environmental externalities.

Externalities

What are externalities?

Externalities can be defined as *"the effects of economic activities which are experienced by third parties, but which are not reflected in the prices of the activities. Since producers and consumers make their decisions on the basis of prices, the external effects are not taken into account"* (Austroads 2000).

Generally, transport externalities refer to situations in which transport users either do not pay for the full costs of their transport activity or do not receive the full benefits from it. The external costs include environmental and societal impacts, which result from the effects of transport processes. Some examples of externalities are those associated with congestion, accidents, air, noise and water pollution, and greenhouse gas emissions.

Why value externalities?

A key outcome from the Growing Victoria Together Summit in March 2000 was the adoption of a TBL approach to decision making, aimed at integrating sustainable economic growth with social development and environmental stewardship (The Commissioner for Ecologically Sustainable Development Consultation Paper DNRE, November 2000). In accordance with this principle, the TBL should be used as a framework for measuring public/private organisational performance, and should minimise negative externalities and create economic, social and environmental value (Investment Appraisal and Evaluation Guideline DOI 2002).

External social and environmental impacts have traditionally been omitted from the pricing of transport projects, hence pricing is incomplete and does not reflect all costs. In an economic sense, it is necessary to correct for externalities, as in a market economy, the existence of external costs and benefits creates a divergence between marginal social and marginal private costs. Market decisions of individual consumers and producers no longer add up to an outcome that provides maximum benefits to society (Stanley 2001). Failure to price resources at their marginal social costs results in a deadweight loss to society compared with optimal resource allocation. This situation can lead to systematic bias and distortions in the allocation of scarce resources. The valuation of these externalities therefore provides an essential tool for correcting this bias, and is the main purpose of this paper.

While it is conceptually obvious why externalities should be valued, a range of opinions exist as to the practical utility of such efforts. Significant debate exists over the monetisation of environmental externalities. Many environmentalists are strongly opposed to quantifying externalities and consider that the reduction of the environment to cash equivalence is morally deplorable (The Economist 2002). These advocates argue that policy should be applied without a need to value the environmental damage it is intended to avoid.

However, even if environmental goods were not valued, at some point in time priorities and choices would still have to be made and measured. In reality, it is a monetary value which is necessary to bring external costs and benefits to account through government and private intervention. This can only occur by placing values on externalities, in order to drive policy directions, appraise and evaluate public sector projects, and allocate budgets appropriately.

It is acknowledged that assessment of these externality costs and estimating their value in monetary terms is an emerging area of expertise. Values are difficult to estimate given the absence of quality data pertaining to Australian conditions and scientific uncertainty regarding effects on human health, social well-being and environmental ecosystems. Research is highly dependent on the conditions set, measurement techniques used, and where the studies were undertaken (primarily overseas). The overlapping and compounding nature of these impacts in the short and long-term (e.g. the precautionary principle and irreversible species loss), controversy surrounding valuation, and lack of methodologies to determine externalities are also barriers to estimating values.

In project appraisal and evaluation, it is acknowledged that some effects can only be qualitatively assessed, or can only be quantified on a project-by-project basis. In some instances, it may be more appropriate to analyse impacts qualitatively or consider quantification for individual projects, where information is available.

Nonetheless, the existence of transport externalities is an empirical fact. The question is whether or not project appraisal is advanced more by attempting to value externalities, or by not including them.

Current practice in Victoria is to value social and environmental externalities given the amount of sufficient information available to date. This Table provides a significant step in compiling external social and environmental externality values. It is also considered that through valuing these externalities and incorporating values into a Cost Benefit Analysis, the economic, social and environmental impacts can be determined appropriately, allowing individual projects and policy options to be more fully assessed and considered.

The Table of externality values

The values ascribed to externalities have been presented in the form of a table shown in Appendix A.

The objective of the Table is to estimate and value the impacts of the transport task by calculating overall default dollar values per vehicle kilometre travelled (cents/vkm) for a range of externalities, with exception given to accidents.

The Guidelines recognise the following externalities that can be generated by the operation of motorised vehicles:

Social:
- congestion;
- accidents;
- loss of amenity value;*
- loss of land; *
- change in land value; *

Environmental:
- air pollution;
- greenhouse gas emissions;
- water runoff from roads;
- noise pollution;
- vibration; *
- barrier effects for humans and animals; and *
- animal deaths. *[1]

Overall cents/vkm were selected directly from other studies, or calculated according to extensive research of information sources. For emissions, values for dollar per tonne costs, and grams per vehicle kilometre (emission factors) were separated into low and high rates. For the purpose of this paper, the range of other sources considered in the analysis are not included, however they appear in the full Guidelines. A single point/rate value was selected for the $/tonne and emission factors. These were chosen on the basis of the most relevant and robust data available.

The inclusion of a range of values provides the reader with a number of options. For example, the high value could give a figure for "worst case scenario", or urban regions. The Table also avoids averaging values and figures obtained from other studies as this would create under or overstated results, due to the different conditions and assumptions made for each study (e.g. some studies may have high $ cost per tonne for emissions, whilst others may have lower values).

[1] * Represents externalities that have not been valued due to insufficient data or application on a project specific basis.

Overall cents/vkm values were calculated for emissions by multiplying single point/rates for $/tonne and emission factors, and have been provided in Appendix A.
When undertaking project appraisal, specific TBL variables will need to be selected and modified to suit the specific application.

Information sources - what was and what wasn't used

This section provides a process which identifies how externalities were selected. It discusses which externalities have been excluded from the Table, and the externalities that have been applied and why. Significant focus has been placed on emissions, specifically air pollutants. This is because of a fundamental concern about treatment and use of air pollutant data. The next section provides a description of the values in the Table.

It discusses:

- Selection of air pollutants for the Table
- Concerns with air pollution data
- Selection of greenhouse gases
- Life-Cycle analysis
- Emission factors
- Selection of other externalities

Selection of air pollutants

Whilst debate continues over the valuation and application of externalities, the science of these effects associated with transport has progressed over recent times. Scientific analyses pertaining to the transport sector and externality categories were reviewed according to their relevance in Victoria. Sources of data were then analysed, and the figures traced back to original sources for verification. Final values were selected according to the most robust and relevant data available.

A decision was made to exclude some components within the broad air pollution externality categories. These included sulphur oxides (SOx), sulphur dioxide (SO_2), and lead (Pb). With the introduction and tightening of regulatory measures such as the Australian Design Rules, and Fuel Quality Standards Act 2000, a fall in airborne pollutants is expected. Additionally, whilst sulphur oxide is a significant contributor to acid rain, it was not considered to be a major issue in Australia.

Non-Methane Volatile Organic Compounds (NMVOCs) comprise of a range of substances. These include hydrocarbons, halocarbons, oxygenates and aldehydes (ie formaldehyde) (Encyclopaedia of Atmospheric Environment 2000). Emissions of these arise primarily from vehicle exhausts and via atmospheric chemical reactions, and include a number of potentially harmful substances such as non-methane hydrocarbons (NMHCs) eg. benzene, polycyclic aromatic hydrocarbons (PAHs), and 1, 3 butadiene (petrol driven vehicles) (Encyclopaedia of Atmospheric Environment 2000). A total for NMVOCs has been included in the absence of sufficient data to separate the impacts of these air toxins from the transport sector.

Additionally, other chemicals emitted from fuel combustion processes and fugitive releases (fuel evaporation and air-conditioner refrigerant leakage) include, chlorofluorocarbons (CFC's) and fluorocarbons (FC) (Cosgrove 1994). Victorian legislation to address vehicle emissions is however yet to be established, and owing to insufficient data, values have not been prepared.

Ozone has an additional environmental effect of reacting to form photochemical smog in the troposphere (lower atmosphere), and is interrelated with the above compounds. It has been identified as an area requiring further research. For the near term, values from Cosgrove (1994) have been used, where the rate of formation of ozone is proportional to the level of NOx emissions. These estimates are however only approximate, as the formation of ozone depends non-linearly on ambient concentrations of NOx, CO and NMVOCs. Due to these factors, a separate ozone total has therefore been omitted from the Table.

Uncertainty and inconsistencies in the use of air pollution data

Significant uncertainty exists in the determination of air pollution data. Inconsistencies are driven largely from the lack of research and data developed in Australia, primarily for valuing air pollutants. As a result, Australia is reliant on overseas studies with different local conditions, which are difficult to compare and transfer; due to different concentrations of pollutants at local and regional levels, population number and density, and the transfer of health impacts. Often conversion of overseas data to Australia does not take into account these different conditions, which in turn causes:

- inconsistencies in the classification of chemical compounds, and hence valuing; and
- inaccurate conversion of values obtained from overseas data.

Selection of values in the Table were dependent on analysis of these factors. A complete discussion of specific studies has been prepared for the *Guidelines*. In summary, inconsistencies in the classification of dollar ($) per tonne values for NMVOCs and Hydrocarbons (HC) were identified. These terms were used interchangeably in some studies, hence difficulties occurred in comparing values. A difference exists between NMVOCs and Hydrocarbons. NMVOCs, include hydrocarbons, halocarbons, oxygenates and aldehydes. Hence there was uncertainty as to whether the HC cost per tonne of emissions should be considered as a NMVOC equivalent, or a component of NMVOC. As a result, reference to HC in the attached Table was removed and only included a NMVOC total.

It is understood that there are no Australian studies that have been conducted without translating overseas costs per tonne of emissions. Recent Australian values were traced back from a number of studies and were found to be dated and purely based on European and US conditions. Values have only been converted via an exchange rate, and no adjustment has been made for local conditions that are Australia-specific (e.g. concentration of air pollutants, population and density, specific local pollution chemistry and differences in health impacts, mortality rates, asthma levels etc). Conditions are also dissimilar due to differences in demographics, topography, tax structures, and fuel standards.

Some studies obtained a median of dollar estimates per tonne of emissions based on European and US conditions, stemming back to the 1980s. It was found that the initial methodologies of these overseas studies were different for each country, and based on different conditions and assumptions. For example in the valuation of studies for oxides of nitrogen, estimates have been determined for electricity generation, damage costs, avoidance costs or from summary studies, and have different local conditions in each country. Taking the median of these studies is inappropriate as these studies are incomparable when placed together.

Additionally, as these studies are dated, the initial exchange rate at which these values were converted has changed significantly. Values have also been measured according to conditions that have changed, in some cases got worse, and we now have new knowledge about the impact of chemicals on human health.

It is of great concern that these dated (European and US) studies that have only been translated to Australian values on the basis of an exchange rate conversion alone, are being continually extrapolated over the years and used within Australia.

The lack of research and data developed in Australia, reflects an imperative to continue research to assist in policy making decisions, and project appraisal and evaluation.

Selection of greenhouse gas emissions

In addressing greenhouse gas emissions (GHG), resulting from the transport sector, CO_2-equivalent is a measure used for the emissions of CO_2, CH_4 and N_2O. In the attached Table, CO_2-e represents the abovementioned gases, and is calculated according to Global Warming Potential (GWP). The transport sector generates *direct* and *indirect* GHG's, which are also derived from the air pollutants as previously outlined. *Direct* gases include, carbon dioxide, methane, nitrous oxide, and CFC's, whereas *indirect* greenhouse gases include carbon monoxide, other oxides of nitrogen and NMVOCs, and influence atmospheric concentrations of GHG's.

For the purpose of the *Guidelines*, GHG emissions and air pollutants have been separated. Due to the primary and secondary reactions occurring between these externalities, difficulties arise in measuring and separating each compound, its effects, and hence estimating values (refer to methods of measuring externalities section for discussion of values). Caution must therefore be taken in using the results in the Table to solely determine results for a project appraisal.

Life-cycle analysis

In selecting emission externalities and values, consideration was given to environmental impacts of a transport activity (primarily road and rail) by assessing the entire life-cycle associated, where relevant, and as data permitted[2]. For example, emissions associated with electric trains incorporate the generation and distribution of electricity, such as emissions from power stations. This is a significant issue for CO_2 emissions in the delivery of electricity from black and brown coal fired power stations. Life-cycle emission analysis is important when evaluating emissions from different fuels, and consideration should be given to the location of emissions. Stanley (2001) recognises that emissions from end-use sources are released at the ground level, often in highly populated urban areas, whilst upstream emissions have different local air quality effects for more remote/offshore areas.

Emission Factors

Emission factors or conversion rates have been used for deriving dollars/per vehicle kilometre values for air pollutants, as shown in Appendix A, and are depicted as emission rates in g/vkm. The rate of emission depends on a number of factors such as the type of vehicle, type of control equipment fitted, type and quantity of fuel consumed, vehicle speed, condition of the vehicle, and operating conditions (driver behaviour, weather, season, traffic conditions and road type) (Cosgrove 1994). It has been assumed that these conditions are constant, and no adjustment is made for these factors. The emission factor does however include the units of grams of gas emitted per megajoule of energy use, grams of gas emitted per kilometre travelled, and acknowledges that different vehicle categories will emit different amounts, e.g. a heavy diesel vehicle will emit more particulate emissions than a light vehicle (Cosgrove 1994). The Table therefore divides externalities by mode category and fuel

[2] Full fuel cycle (life-cycle analysis) accounting framework incorporates emissions arising from direct propulsion from upstream impacts in the use of transport facilities (fuel extraction, processing and distribution, vehicle manufacture and disposal, vehicle use, provision of infrastructure (road maintenance), feed stock transport refinery fuel use and product transportation) (Apelbaum Consulting Group pers comm, Stanley 2001). This incorporates both direct and indirect effects.

type. Further calculation of emission factors to account for these effects, and different road environments requires additional research and incorporation into the Table, or can alternatively be obtained through modelling.

Selection of other externalities

Environmental externalities also include visual impacts, erosion and indirect effects from transport such as vibration. These can contribute to the deterioration of infrastructure, or loss of biodiversity. Many of these externalities have been included in the Table; however they are noted as being "future developments" requiring further investigation. These externalities should also be considered on a case-by-case basis for each project appraisal, and may be qualitative in nature.

Methods of measuring externalities and limitations

Although there are concerns with estimating, measuring and monetising environmental and social costs and benefits that have been well documented in previous studies, a number of distinct benefits are associated with including externality values into the appraisal of projects.

A range of techniques exist to derive estimated values, and their application varies for each externality. These methods include:

- Hedonic prices
- Contingency valuation (stated preference)
- Dose response relationship
- Willingness to Pay
- Control costs (mitigation costs)

This section discusses the use of these methodologies in valuing social and environmental externalities, and the analysis of information sources to obtain appropriate values.

Social Measurement Techniques

Aspects of some effects attributed to transport comprise of both internal and external costs, and it is unclear what proportion of costs are internalised or considered an externality. Hence, social externalities are perhaps more difficult to measure than environmental externalities.

The *Investment Appraisal and Evaluation Guidelines DOI (2002)* provide a way of classifying TBL impacts for transport infrastructure investment as;

- transport system effects - changes in how well the transport assets and service deliver systems serve (will serve) their users; and

- how a transport project effects (will affect) individuals in the community, other than those actually using transport facilities or services generated (3rd party effects).

Congestion

This externality has both environmental and social implications. Environmental effects resulting from the transport sector include increases in greenhouse gas emissions and air pollutants resulting from idling and vehicles stopping and starting. According to a recent Bureau of Transport Economics (BTE) report 'Urban Congestion - the implications for greenhouse gas emissions' (2000), congestion has the potential to double the output of these gases under highly congested conditions, and fuel consumption per vehicle (litres/100km) is approximately twice that under free-flow conditions.

The BTE defines the cost of congestion as being "the estimated value of the excess travel time and other resource costs (such as extra fuel used) incurred by the actual traffic over those that would have been incurred had that traffic volume operated under completely free-flow conditions"(p.2). It is a measure of the scale of the problem, rather than the actual savings incurred (BTE 2000). If the road user is aware of traffic conditions, the private costs of congestion will be internalised. That is the increased travel time resulting from the benefit of travelling by car. However, users are not likely to consider the marginal external costs of congestion imposed on others (additional delays and public costs on other road users) as a result of their decision to travel.

Figures on congestion have been sourced from an analysis of Stanley and Ogden (1993), VicRoads traffic data, and New Zealand data (Internal DOI report by Ashley 2001).

The congestion reduction value in the attached Table applies only when road traffic is removed as a result of a public transport improvement project. It is therefore a benefit to remaining road users resulting from a reduction of road traffic, for example a diversion of road passengers to rail. These values include time, vehicle operating costs and accidents, and are corridor based. The values are most likely to be of use for relatively small projects where transport planning models are not used to estimate changes in demand.

For relatively large projects, impacts on the road system should be assessed through specific road network modelling, with the outputs of the model also giving the changes in travel time and distance travelled on the road system, which can be valued using the standard values of time and vehicle operating costs[3]. For assessment of a road improvement, the congestion reduction value is therefore not relevant.

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[3] As this paper refers only to externalities, standard values of time and vehicle operating costs have not been included.

This area would greatly benefit from further research to provide more accurate estimates for trips occurring in more than one area, speed of traffic, diverse traffic conditions (ie peak period/busy road), location of traffic, or time of day. It is also necessary to correctly assess the disaggregation of congested, moderately, and lightly congested roads and time frames between peak and non-peak.

Accidents

Extensive debate exists over the inclusion and estimation of accidents as an externality, as some accident costs are both internalised and considered as an externality.

According to Stanley (2001) accident costs to society can be internalised through accident prevention/reduction mechanisms, such as traffic safety programs or payments directly/indirectly by those responsible for accidents ie insurance[4]. Alternatively, costs can be internalised by the costs of dealing with accidents after they have occurred.

Accident costs include:

- deaths, injuries, disabilities, pain or grief;
- hospital and medical costs;
- material damage;
- lost production;
- prevention expenses (community education, road design and maintenance, vehicle safety equipment); and
- costs for legal, police or fire services.

Some accident costs are also external at an individual or sector level, such as incremental crash risk associated with increased traffic volumes, expenses not paid by drivers or costs imposed on pedestrians (Litman 2002). For example, an individual is unlikely to consider the full effects of travel on other users, and by choosing to travel, an individual may be increasing the crash probability of other road users (Austroads 2000).

Accident costs can be determined by evaluating and measuring the above categories. For example; measuring accident costs include estimation of deaths and injuries according to direct costs (medical care[5], transportation costs, vehicle repair bills); and indirect costs (production losses). The Table divides accidents according to average costs per crash type and average costs per casualty outcome, and gives the numbers of crashes and persons associated with each series. These values have been obtained from *Austroads - Economic Evaluation of Road Investment Proposals at September 2000*; and have been extrapolated to 2002.

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[4] The reference to insurance assumes an absence of moral hazard e.g. insurance of a vehicle may lead to more reckless driving behaviour.

[5] Allowance must be made for misclassification of injuries and unreported crashes.

Other methods for valuing accidents include willingness to pay. However, in practice, few evaluations are based on this method, as values may not reflect the way people value the worth of life to the community. Alternatively, in project appraisal, benefits derived from safety improvements can be identified and estimated by assessing the pre-existing and anticipated road/travel conditions. These benefits involve reductions in the rate of accidents and property damage-only accidents; however estimation of how many accidents will be avoided is difficult to determine (Investment Appraisal and Evaluation Guidelines DOI 2002).

Loss of amenity value, loss of land, changed land value

The construction of road infrastructure removes land from other potential productive uses, and competing land developments may have future long-term impacts[6]. It can be valued directly according to the most productive use forgone or opportunity cost (e.g. potential agricultural land, residential land, native forest), and can also have associated negative impacts (externalities).

Land take in the context of lower-density urban expansion (sprawl) is associated with positive and negative economic, environmental and social impacts. Benefits are largely internal and can not be assumed to offset external costs of sprawl. There are increased costs for building infrastructure such as paving of roads and stormwater drains that should be considered in a project appraisal (Litman 2002). Negative impacts of community severance and other social costs therefore may not be completely captured by commercial land values.

As variable costs and indirect negative externalities arise from land take, and differ for each circumstance, it is not appropriate to quantify land take as an overall value and attribute all effects to land take alone without double counting other externalities. Attributing the direct association of these externalities to the transport sector alone also requires further research.

Notwithstanding the associated loss of amenity value resulting from the loss of potential future land, positive effects may also arise through the construction of a road (increased land value, internal benefits to road users), which offset the cost of land take. For example, implementation of a road or highway may increase land value and access to amenities. From an economic perspective, these positive effects largely reflect savings in road user costs through travel time savings. These increases in land values should not be incorporated in a project, as it would result in double counting these benefits.

It is recommended that in a project appraisal, the value of the land use required should be included on a project-by-project basis. The economic value of land can be obtained from the sum of the market value of output produced and the

[6] It is also recognised that roadside reserves represent a significant proportion of native vegetation. A decision to double the carriage way of a road (say) has implications for loss of amenity value (Apelbaum Consulting Group pers. comm.).

non-market value of its amenity, ecological and recreational activities (Austroads 2001).

Environmental Measurement Techniques

Air Pollution

Recent studies identify a strong link between air pollution and increases in adverse health effects imposed on society as a result of transport, particularly in urban areas. It is however noted that transport does not solely influence these effects. Pollutants of greatest concern include PM_{10}, $PM_{2.5}$ and ozone, and are increasingly being associated with health effects such as the exacerbation of asthma, other existing respiratory disorders, cardiovascular disease, reduced defence mechanisms, increased risk of cancer, and increased hospital visits (CSIRO 2000, Stanley 2001). Sensitive groups of the population include the elderly, children and people with existing respiratory and cardiovascular disease. Air pollution can also contribute to degraded visibility, and damage to infrastructure such as discolouration of stone, erosion and building soiling (Stanley 2001).

Often emission costs ($/tonne) are approximate costs (ie health costs) imposed on society per tonne of gas emitted. Values ($/tonne) in the Table have been derived by identifying groups in society who are at risk, estimating the responses of these groups to certain levels of air pollution (ie dose response relationships on health, or willingness-to-pay), and estimating the values of these responses using data such as medical expenses. For example, externality values for particulate matter can be estimated from hospital admissions or the annual number of deaths attributed to particulate matter. The indicator of the external risk often differs, and values may be derived according to asthma or cancer. In either case, the dollars per tonne values are very different[7]. Consideration of these discrepancies must be given when using these values.

Costs per tonne of emissions estimated by Cosgrove (1994) have been used in addition to the ranges provided by Stanley (2001), due to the transfer of overseas data to Australian local conditions. Stanley (2001) derives these results from the ExternE project, which takes into account health impacts in the form of asthma levels, in addition to other local factors. Cosgrove values have also been extrapolated by Sinclair Knight Merz consultants to 2001 values. The cost of each pollutant is based on reported willingness to pay to avoid the negative consequences (health effects, degraded environment etc). They are calculated via a dose-response model where human mortality is a function of air pollution. Although these values appear to be Australia's best at this stage, these values should be used with caution as they are only approximate costs with further research required.

[7] Recent European studies value diminished quality of life and lost work time whereas other studies value mortality only, hence recent values are higher (Apelbaum Consulting Group pers. comm.).

It is again stressed that in the attached Table, the values exist on an aggregate level to allow general use in a range of project appraisals. It is acknowledged that they can be calculated according to speeds, type of fuel consumed, road type, traffic conditions and road type, and these factors will be considered in future development of default values. It is intended that where it is necessary to further appraise these aspects of a project, that modelling be used.

Climate Change

Costs per tonne of GHG emissions in the Table have been determined from a range of Australian and international sources. Considerable debate exists in assigning an appropriate value of $/tonne, as an international carbon-credit trading mechanism (designed to equalise the costs and benefits of emitting or sequestering a tonne of CO_2-e) is yet to emerge, and is largely dependent on the implementation of the Kyoto Protocol (Sinclair Knight Merz 2001). As such, values to date have only been determined according to informal and voluntary trading mechanisms, however costs are anticipated to increase dramatically in future years. Bearing in mind that the Kyoto Protocol is yet to be ratified by Australia (and the US) and an international carbon-credit trading mechanism is yet to be finalised, markets are expected to change accordingly.

Significant debate also exists in the use of generic carbon-trading based price for application to transport. A range of opinion exists that valuation using this scheme only reflects the marginal price of reducing CO_2 emissions to the Kyoto Protocol agreed levels. It is considered that avoidance costs should be based on sector specific technologies that recognise the magnitude of the emission output (Apelbaum Consulting Group pers. comm.).

The Infras/IWW 2000 study used the average cost of *reducing transport emissions by 50%* in accordance with an IPCC scientific determination of sustainable CO_2 emissions, and arrived at a value of approximately $200 per tonne. ExternE (1998) estimated *damage* costs (based on sea level rise, climate change, desertification, loss of habitat, species, coral reefs, arable land etc[8]) at between $33 and $92 per tonne of CO_2-e (lower and upper estimates) (Apelbaum Consulting Group pers. comm.). In consideration of both approaches, a damage cost value of $40/tonne has been selected in the Table, however it is likely to change according to future developments.

Estimated values measured vary amongst studies according to the types of controls and conditions set. For example, values may incorporate a business-as-usual approach, or use proxies, control costs or baseline parameters. In

8 The Extern E (1998) report has been converted to June 2001 Australian dollars. Values represent an 'equity weighting' and makes allowance for greater effects on some countries than on others. Selection of a discount rate considers whether there are viable alternatives (relocation of human populations, shift of habitat of flora and fauna), and if effects are irreversible, to what extent is it appropriate to discount costs in the light of the principle of inter-generational equity. It is considered to be not appropriate to value CO_2 from transport by the cost of planting forests to sequester carbon (Apelbaum Consulting Group pers. comm.).

order to set a baseline and understand the severity of impacts, emission models need to be developed and refined to provide satisfactory estimates. DOI is developing models to quantify GHG emissions for application in policy and strategy decisions. It is however important to note that limitations in these models exist, and are dependent on the accuracy of input data, and ensuring the parameters are updated and based on real data. Additionally, there are limitations that climate change is a global problem, and the results provided in the model are only Victoria based. The DOI Greenhouse models are currently being further calibrated to assist in providing additional data to fully develop project appraisals.

Water Pollution

The valuation of water pollution resulting from transport (run-off from roads from vehicles: engine oil leakage and disposal, road surface, particulate matter and other air pollutants from exhaust, tyre degradation) is problematic (Austroads 2000).

Determining transport's contribution to water pollution is difficult as there are often great distances between the pollution source and the waterway it pollutes, and water flow paths are often complex and unpredictable. There is difficulty in separating and attributing the effects of water pollution to the transport sector alone, and estimating the contribution of transport sector pollutants to water quality in one area compared to another. Once the pollutant reaches a natural body of water, the ecological or health damages are also dependent on the type of pollutant, density and size of insoluble pollutants, nature of the soluble pollutants, pre-existing water quality, and type of associated habitats.

Methods to value water pollution impacts resulting from road transport include dose-response, contingent valuation and willingness to pay. These methods are however inaccurate as the degree of data and information provided through research is currently insufficient in determining the environmental impacts of water pollution, and will subsequently render insufficient values. Additionally, use of revealed or stated preference is not pursued because, public perception of run-off from road sources may be small to non-existent, and hence values obtained from willingness-to-pay or willingness-to-accept will not reflect the true cost associated with water quality.

Although there is a lack of scientific study attributing ecological damages or effects on human health to road run-off, evidence suggests that the effects of water pollution can be quantified on a case-by-case basis, where road-runoff is a significant contributor to water pollution. Control costs/mitigation costs provide a practicable mechanism of valuing transport related impacts by estimating social costs of installing mitigation devices (ie vegetation, sedimentation tanks, combined catchment and treatment of stormwater run-off) over entire road networks or on a per vehicle-kilometre basis.

In the Table, values associated with water pollution resulting from road-runoff are obtained (using mitigation costs) from the New Zealand, *Ministry of Transport, Te Manatu Waka, Land Transport Pricing Study - Environmental Externalities (1996).* Evidence assembled from overseas and New Zealand experience gives an overall cost of installing mitigation devices (similar to Australia) for both urban and rural highways in the range of NZ 0.1 to 0.5 cents/vkm (best estimate 0.3 cents/vkm). This best estimate has been converted to Australian dollars in the attached Table to obtain 0.27 cents/vkm. Currently, this offers the most effective way to estimate this environmental externality by representing the cost according to the 'best practicable options' for pollution mitigation.

Shortcomings in values in the Table are of two types:

- use of mitigation methods; and
- transfer of overseas data to Australian conditions.

Shortcomings in the methodology of using control cost estimates are that costs are unlikely to equal actual damage costs for the transport sector alone, and costs are dependent on the type of drainage system, drainage path length, rainfall intensity and area of road drained.

No adjustment for local conditions is made in the attached Table, as the mitigation devices in NZ and overseas are similar to those used in Australia, however there are shortcomings in this transfer due to differences in road type, traffic flow etc.

Project appraisal for particularly sensitive water bodies, where road run-off is considered to be significant, may require analysis of higher unit costs per vkm estimates. With regard to water pollution, disruption to stream morphology and flood cycles in addition to water quality should also be considered. It is suggested that these projects be based on calculating case-by-case mitigation costs, and careful assessment should be made as to whether a project should be continued based on environmental costs, or whether benefits arise.

Future expansion of the Table for water pollution could include other modes of transport such as valuing the impacts of ballast water and anti-fouling systems from maritime transport activities on the aquatic environment, pending the extent of research and data available.

Noise Pollution

Analysis of noise pollution requires the use of a logarithmic scale of decibels (dB), reflecting the human ear's response to sound pressure. The frequency sensitivity is included by applying an "A-weighting" scale (dB(A)). The impact of transport related noise can be assessed using Equivalent Continuous sound Level (L_{eq}), which averages a fluctuating noise level (acoustic energy) over a defined period (Stanley 2001). Another standardised method for predicting transport noise with distance from roads is $L_{10}(18)$ which is the mean noise level (of the hourly L_{10} levels) over an 18 hour period (6am till 12pm). L_{10}dB(A) represents the noise level in dB(A) that is exceeded for 10% of the time over a one hour period.

A Noise Depreciation Index (NDI) is a widely used parameter to link road traffic noise to a monetary value using hedonic pricing (Austroads 2000). NDI gives an estimate of the depreciation (%) in house value for a unit (1 dB) increase in noise level above the threshold level selected (measured as daily equivalent noise levels (L_{eq}))(Austroads 2000). In the attached Table, an NDI is selected as 0.5-1%, with a threshold of 50 or 55 dB(A), L_{eq}(24).

Limitations in valuation include inconsistencies in selecting an appropriate threshold level and NDI value for performing Cost Benefit Analysis related to the measurement of noise reduction. Conclusions derived are therefore sensitive to the choice of threshold. The OECD recommends the use of an NDI of 0.5% of property value per dB(A) L_{10}(18), whereas for Australia, Austroads recommends use of a property depreciation of 0.9% of dB(A) above 50dB(A) (Austroads 2001). Limitations of hedonic pricing are that it does not capture the impacts on public property and non-residents and occupiers of commercial buildings. People are also unlikely to know the full effects of noise when purchasing a property (Austroads 2000).

Methods to measure noise include Mitigation costs and Willingness to Pay. These may include planning, design and construction of road and adjacent land use developments, retrofitting noise insulation to buildings, noise barriers, reducing source noise levels and traffic management. The limitations include a lack of information between studies in determining the timing of noise control measures, the degree of noise reduction to be achieved, and use of mitigation measures to achieve the noise reduction. Control costs are unlikely to equal true damage cost as it takes limited account of noise effects outside buildings and ignores other effects of mitigation measures such as heating savings.

The Willingness to Pay method of noise measurement is limited because the noise burden is determined by the perception of individuals and responses to certain noise levels and noise sources. Contingent valuation methods are also subjective (not based on market transactions), with respondents unlikely to reveal their true willingness to pay preferences in survey questions. This results from the application of "imbedded" responses, where respondents have never thought about the issue or have a bias against noise pollution and may therefore place a high intrinsic cost on it when the noise pollution levels are in fact not significant.

Currently, insufficient information is available to calculate a detailed value for Australian Noise amenity effects. Stanley (1991) has reported that values can be calculated using the marginal cost estimates from Delucchi and Hsu (1998). The study notes that due to the uncertainty of key parameters, the values only estimate the order of magnitude of the cost (Delucchi et al. 1998). These include uncertainty of the interest rate, amount of noise attenuation due to ground cover and intervening structures, gradient of the road, density of housing alongside roads, average traffic speeds, the cost of noise away from the home, and uncertainty in the cost of noise per decibel above or below the threshold.

In the attached Table, indicative values calculated from this study have been included for each mode of road transport, however they should be used with caution. This section highlights the importance of further research required for noise in Australia. An example is where the Table provides an overall value (cents/vkm) for rural areas, noting that the values for urban regions should be used for towns. Determining more accurate values for rural areas is required.

Other limitations acknowledged in the Table are that accurate noise measurements are dependent on the time of the day (ie night-time), intermittent noise, vibration from heavy vehicles or rail (also has implications of double counting with noise values), or region (urban or rural), and whether the marginal noise of an additional vehicle on a road is associated with the transport sector alone.

Where further development of a project appraisal is required, modelling is encouraged (contact DOI Strategic Planning Division for details). It is also noted that VicRoads administers a traffic noise reduction policy and has conducted significant work in noise modelling and valuation for road projects.

Although limitations with current data exist and further research for Australian studies is required, the Table provides a way of considering, through Cost Benefit Analysis, the significance of a noise externality in a project appraisal.

Vibration, animal deaths and barrier effects

In the Table, vibration, animal deaths and barrier effect values are denoted "future developments", with significant research required.

Vibration from transport is associated with damage to buildings (including heritage sites), infrastructure, pipes, drains, or erosion to shorelines (Austroads 2000). Separate valuation of vibration may lead to double counting as it is closely aligned, and often incorporated in the value for noise pollution. It is difficult to separate the effects of vibration and noise, and to trace vibration damage to only the transport sector. Direct costing is commonly used to apportion vibration to the transport sector by evaluating the cost to repair the damage. This method may however slightly underestimate the true social costs of vibration as it does not include overall structural damage to an area such as burst water pipes, or electricity shutdowns (Austroads 2000). Project appraisal to assess the impact of transport vibration on historic buildings may require separate valuation of vibration. Contingent valuation techniques can be used under these circumstances (Austroads 2000).

Determining the value of *animal deaths* is very subjective. Although a market exists for the valuation of road kill through stated preference mechanisms (contingent valuation), it is dependent on whether the animal is a pet, wild animal, a pest, or food item. For example, equivalence between the value of a wild or domestic animal may not be accepted (Department of Transport 1995). Although domestic animals (including farm animals) can be valued at market price, wild animals do not have a cost of production, which may suggest that price would be lower. But in reality, it may be considered a higher value through society's willingness to pay, particularly if the species is endangered. It is noted that some wild animal species are valued more highly than others, ie a rare species compared to an insect, and some species can be valued according to its best alternative use, such as hunting.

Notwithstanding the weighting society may place on animal deaths through stated preference, the loss of wildlife resulting from road traffic significantly affects abundance, diversity, and ultimately may contribute to a population's extinction. Reductions in the frequency of animal deaths can be achieved through mitigation strategies, such as fencing, underpasses and reflectors.

A recent study was undertaken by the Ministry of Transportation and Highways Planning, British Columbia - *A method for estimating the dollar values of lost wildlife diversity and abundance resulting from wildlife-road vehicle collisions* (Johnson 1995). Dollar estimates on external costs of wildlife-vehicle collisions were obtained through Cost Benefit Analysis and collision impact studies on the viability of mitigation strategies for each of the province's eight Environmental Management Regions. The study also states that dollar values established by Reid (1996) provided species-specific estimates for consumptive, non-consumptive use and aggregate preservation through willingness to pay species weighting and avoided cost.

It is recommended that costs be calculated using these methods on a case-by-case basis, as wildlife mortality is directly related to the road location, road design, local abundance and type of wildlife species. It would be inappropriate to use an overall generic per km value for an entire region. Overall values have therefore not been included in the Table due to these factors.

Barrier effects are closely associated with mitigation costing methods to measure animal deaths, or the preservation of waterways and ecosystems. The value of a biological ecosystem may be measured according to its estimated resource use or existence of buffers, that prevent animal deaths or flooding of environments. However, even if values for the implementation of barriers or resource use were available, obtaining overall values for the fragmentation or loss of an entire ecosystem is unobtainable at present (Austroads 2000).

Barrier effects are also associated with creating barriers to movement in society. For example, the existence of infrastructure or use of infrastructure may create delays or danger to pedestrians crossing roads. Traffic barrier effects such as roads cutting off shopping areas from residential or recreational zones have been measured overseas using contingent valuation (Department of Transport 1995). When conducting a project appraisal, these impacts should be considered, however further research is required before incorporation into the attached Table.

Other major issues involved in estimation

Notwithstanding the valuable contribution of recent science in placing appropriate monetary values on major externalities associated with transport; as identified in the previous sections, significant difficulties still exist in estimation. Major problems with estimating the resource costs of transport-induced externalities are that impacts may be wide ranging and externalities are largely interrelated.

As outlined in the *Investment Appraisal and Evaluation Guidelines DOI 2002*, these relationships include:

- *Local effects* - noise or local air pollutants contribute to adverse affects on human health, damage of emissions and vibration to infrastructure, reduced safety, loss of amenity, reduced land values, and traffic congestion.
- *Regional or trans-boundary* effects - medium term in nature, and include low-level ozone spreading throughout urban areas. These effects can adversely impact on adjacent areas.
- *Global effects* - long term related issues such as the depletion of the ozone layer, greenhouse gas emissions and subsequent induced global warming, increased vector-born disease and increased risks of cancer, rising sea levels, reduced biodiversity and productivity.

These effects overlap and compound to a large degree, which makes estimation complex.

Although short-term impacts may be able to be estimated, long-term impacts are difficult to forecast and hence quantify. This results from scientific uncertainty surrounding the interrelationship between the type of externalities and their eventual long-term impacts. This is a fundamental concern for separating short and long-term effects and placing values on these externalities. For example, run-off from roads may pollute water bodies, but also result in long-term adverse impacts on biodiversity, and economic loss associated with the depletion of fish stocks for industry. A second example is that the long-term impacts of CO_2 are difficult to determine due to difficulties in forecasting future ambient levels, and because of the lack of complete knowledge of exact linkages between the original emission and eventual global warming (Investment Appraisal and Evaluation Guideline 2002).

One of the more contentious issues associated with externalities is the valuation of permanent ecological damage (for example, loss of bio-diversity, open space and various outcomes of global warming including sea level change and the destruction of habitat). This should be addressed to the extent that data allows (Apelbaum Consulting Group pers. comm.).

Non-linear relationships exist in many externalities and other transport effects. For example, additional cars on the road not only contribute to increased congestion, but exponentially increases atmospheric pollution and associated health risks imposed on society. Correlation therefore exists between the external costs borne by the transport sector (e.g. congestion) and costs imposed on third parties (e.g. vibration, noise, air pollution). There are difficulties in separating the impacts of each externality and accurately costing these externalities (Investment Appraisal and Evaluation Guideline 2002).

Difficulties in measurement are also inherent with the extent of social and environmental impacts, or where physical external effects and their monetary estimation involve more than one link. For example, air pollution includes aspects of human health, structure, vegetation and forests, soil pollution and climate, and noise pollution includes consideration of comfort, production and public health (Apelbaum Consulting Group pers. comm.). Project appraisals should therefore consider the widest range of externalities, and where possible separate environmental, social and economic effects (Investment Appraisal and Evaluation Guideline 2002).

Additional limitations in the valuation of transport externalities include consideration of:

- wind speed, ambient temperature, season;
- class of the vehicle;
- type of pollution control equipment fitted into vehicles;
- type of fuel consumed and average rate of fuel consumption;
- travelling speed of vehicles and distance travelled;
- age and condition of the vehicle;
- level of maintenance of the vehicle;
- driver behaviour; and
- road type and traffic levels.

As indicated, there is no one technique for quantifying environmental transport externalities, as service delivery, transport infrastructure and environmental implications (direct or indirect) are diverse. It is noted that some techniques are more appropriate than others for each environmental externality. For example hedonic prices for short term noise externalities are appropriate, whereas contingent valuations may be more applicable to assessing the environmental impacts of an intermodal shift from road to rail (Investment Appraisal and Evaluation Guidelines DOI 2002).

Conclusion

This paper describes how a series of externality values has been derived according to a literature review of Australian and overseas studies. It proposes a way to operationalise the TBL, by establishing a common base of default externality values. Rather than applying zero to environmental and social external impacts in a project, these values can be applied, through Cost Benefit Analysis, to assist in policy making decisions, allocate budgets appropriately and assist in project appraisal.

These values in the Table are not a definitive listing and are intended as a basis for discussion on the derivation of more accurate values. It is also noted that the practical utilisation of these values requires ongoing discussions within the Department.

As these values exist as aggregates to enable use in a range of projects, the potential exists to extend the Table to:

- incorporate analysis of other transport sector modes, such as maritime, pipelines, aviation;
- divide data for freight and non-freight transport;
- include of Victoria specific data based on international best practice, and where possible Australian studies (ie air pollution);
- adjust air pollution $cents/vkm to changes in vehicle technology, speed of vehicle, division of costings between urban and regional areas, and adjustments of the Table for fuel consumption rates;
- further consider the area of operation (for example capital city versus non urban);
- continue research into valuing the externalities marked "future developments";
- consider double counting and methods to avoid this from occurring in separate valuations; and
- provide more accurate congestion estimates for trips occurring in more than one area, speed of traffic, diverse traffic conditions (ie peak period/busy road), location of traffic, or time of day. And correctly assess the disaggregation of congested, moderately, and lightly congested roads and time frames between peak and non-peak.

This paper highlights that there is a heavy reliance on overseas data, which in some cases is dated or has been incorrectly transferred to Australian studies. Ongoing research and analysis is therefore needed for this area, not only to address the above factors, but because this issue is of increasing significance within Australia and internationally for implementation in project appraisal and evaluation.

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Table 1

Estimation and Valuation of Social and Environmental Externalities Table

		Overall Unit Prices ($/tonne costs)				Overall Emission Rates (grams per vehicle km)				Overall Value cents/vkm	References
Type of Externality	Particles/Components	Low	High	DOI Single Point/Rate	Unit	Low	High	DOI Single Point/Rate	Unit	Rate	
Congestion	Heavily Congested Roads: Peak									90	Internal review by Ashley, Sinclair Knight Merz (2001)
	Heavily Congested Roads: Off Peak									16	Internal review by Ashley, Sinclair Knight Merz (2001)
	Moderately Congested Roads: Peak									60	Internal review by Ashley, Sinclair Knight Merz (2001)
	Moderately Congested Roads: Off Peak									16	Internal review by Ashley, Sinclair Knight Merz (2001)
	Lightly Congested Roads									16	Internal review by Ashley, Sinclair Knight Merz (2001)
Accidents Crash	Deaths			$1,387,000	$m per death						Economic Evaluation of Road Investment Proposals, Austroads (2002)
	serious injury			$401,000	$m per injury						Economic Evaluation of Road Investment Proposals, Austroads (2002)
	minor injury			$16,000	$m per injury						Economic Evaluation of Road Investment Proposals, Austroads (2002)
	property damage only			$6,600	$m per accident						Economic Evaluation of Road Investment Proposals, Austroads (2002)
Person	Deaths			$1,263,000	$m per death						Economic Evaluation of Road Investment Proposals, Austroads (2002)
	serious injury			$320,000	$m per injury						Economic Evaluation of Road Investment Proposals, Austroads (2002)
	minor injury			$13,400	$m per injury						Economic Evaluation of Road Investment Proposals, Austroads (2002)
Loss of amenity value										Future developments/project specific analysis	
Loss of Land										Future developments/project specific analysis	
Change in Land Value										Future developments/project specific analysis	
Air pollution - Specific Components	Carbon Monoxide (CO)	$0	$12	$12	$/tonne						John Stanley (2001)
	Cars (petrol)					7.81	12.66	12.66	grams per km	0.015192	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998)
	Light Trucks (diesel)					1.08	1.11	1.08	grams per km	0.001296	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Medium Trucks (diesel)					1.82	6.62	6.62	grams per km	0.007944	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Heavy Trucks (diesel)					6.62	7.86	6.62	grams per km	0.007944	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Buses (diesel)					2.88	2.88	2.88	grams per km	0.003456	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Rail Freight (diesel)									Future developments	
	Oxides of Nitrogen (NOx)	$700	$15,000	$1,807	$/tonne						(June 2001 quoted by Sinclair Knight Merz) Cosgrove et al. (1994), John Stanley (2001)
	Cars (petrol)					1.02	1.23	1.21	grams per km	0.218647	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998)

		Overall Unit Prices ($/tonne costs)				Overall Emission Rates (grams per vehicle km)				Overall Value cents/vkm	References
Type of Externality	Particles/Components	Low	High	DOI Single Point/Rate	Unit	Low	High	DOI Single Point/Rate	Unit	Rate	
	Light Trucks (petrol)					1.18	1.18	1.18	grams per km	0.213226	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Medium Trucks (diesel)					3.1	8.52	8.52	grams per km	1.539564	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Heavy Trucks (diesel)					8.52	15.29	8.52	grams per km	1.539564	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Buses (diesel)					4.9	4.9	4.9	grams per km	0.88543	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Rail Freight (diesel)									Future developments	
	Particulate matter (PM_{10})	$7,000	$1,200,000	$14,362	$/tonne						(June 2001 quoted by Sinclair Knight Merz) Cosgrove et al. (1994), John Stanley (2001)
	Cars (petrol)					0.05	0.05	0.05	grams per km	0.07181	Cosgrove (1994), VicEPA (1999)
	Light Trucks (diesel)					0.22	0.22	0.22	grams per km	0.315964	Cosgrove (1994)
	Medium Trucks (diesel)					0.5	0.5	0.5	grams per km	0.7181	Cosgrove (1994)
	Heavy Trucks (diesel)					2.09	2.09	2.09	grams per km	3.001658	Cosgrove (1994)
	Buses (diesel)					0.5	0.5	0.5	grams per km	0.7181	Cosgrove (1994)
	Rail Freight (diesel)									Future developments	
	Non Methane Volatile Organic Compounds (NMVOC)	$460	$460	$460	$/tonne						(June 2001 quoted by Sinclair Knight Merz) Cosgrove et al. (1994), John Stanley (2001)
	Cars (petrol)					0.5	0.96	0.96	grams per km	0.04416	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998)
	Light Trucks (diesel)					0.53	0.53	0.53	grams per km	0.02438	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Medium Trucks (diesel)					0.99	1.18	1.18	grams per km	0.05428	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Heavy Trucks (diesel)					1.04	3.78	1.04	grams per km	0.04784	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Buses (diesel)					1.56	1.56	1.56	grams per km	0.07176	Cosgrove (1994), AGO Inventory (1999), NGGIC Workbook for Transport (1998), National Greenhouse Gas Inventory Committee (1996), CSIRO Stage 1 Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (2000)
	Rail Freight (diesel)									Future developments	
Climate change (damage costs)	Greenhouse gas emissions - Carbon dioxide (CO2), nitrous oxide (N20), methane (CH4)	$10	$90	$40	per tonne CO_2-e						$10-$100, with an average of $50-$60 (Sinclair Knight Merz, 2001). $10-$50, mid range $30 (Australian Greenhouse Office, 1999) $20-$90 per tonne based on ExternE with a central value of $40/tonne (John Stanley, 2001). Short run $US5 to $US15 central range, long run range $US60 to $US200 (Delucchi MA (2000)), $US10 to $US20 per tonne Forkenbrock (1999), $US13.50 to $US30 Miller and Moffet (1993), $200 per tonne Infra/IWW study (2000), $33-$92 ExternE (1998).
	Cars (petrol)					276.23	276.23	276.23	grams per km	1.10492	AGO Inventory (1999)
	Cars Total (petrol, diesel, LPG, Natural gas)					278.76	278.76	278.76	grams per km	1.11504	AGO Inventory (1999)
	Light Trucks (petrol)					324.09	324.09	324.09	grams per km	1.29636	AGO Inventory (1999)
	Medium Trucks (diesel)					741.75	741.75	741.75	grams per km	2.967	AGO Inventory (1999)
	Heavy Trucks (diesel)					1363.91	1363.91	1363.91	grams per km	5.45564	AGO Inventory (1999)
	Buses (diesel)					779.31	779.31	779.31	grams per km	3.11724	AGO Inventory (1999)

		Overall Unit Prices ($/tonne costs)				Overall Emission Rates (grams per vehicle km)				Overall Value cents/vkm	References
Type of Externality	Particles/Components	Low	High	DOI Single Point/Rate	Unit	Low	High	DOI Single Point/Rate	Unit	Rate	
Energy usage for rail	Trams							8.9	MJ per km	9.65	Victorian Transport Externalities Study EPA (1994), NGGIC Workbook for Transport (1998)
	Trains							61.8	MJ per km	66.99	Victorian Transport Externalities Study EPA (1994), NGGIC Workbook for Transport (1998)
Water Pollution (run-off from roads from vehicles: engine oil leakage and disposal, road surface, particulate matter and other air pollutants from exhaust, tyre degradation)	Organic Waste/Persistent toxicants									0.27	Land Transport Pricing Study: Environmental Externalities Discussion Paper, Ministry of Transport Te Manatu Waka (March 1996). 0.3c/vkm converted to $AUD = $1.13 NZ, 1995 average.
						Noise Depreciation Sensitivity Index (NDSI) Low	Noise Depreciation Sensitivity Index (NDSI) High	Threshold values	Unit: 1 dB change in noise level		
Noise Pollution	Road					0.50%	1%	50dB(A) or 55dB(A)	1 dB change in noise level		John Stanley (2001), Austroads (2001)
	Cars (Urban)									0.3	John Stanley (2001); Delucchi and Hsu (1998)
	Cars (Rural) NB: Use urban $ for towns									0	John Stanley (2001); Delucchi and Hsu (1998)
	Medium Trucks (Urban)									1.8	John Stanley (2001); Delucchi and Hsu (1998)
	Medium Trucks (Rural) NB: Use urban $ for towns									0	John Stanley (2001); Delucchi and Hsu (1998)
	Heavy Trucks (Urban)									5	John Stanley (2001); Delucchi and Hsu (1998)
	Heavy Trucks (Rural) NB: Use urban $ for towns									0	John Stanley (2001); Delucchi and Hsu (1998)
	Buses									1.8	John Stanley (2001); Delucchi and Hsu (1998)
	Rail Freight (diesel)									Future developments	
Vibration										Future developments	
Barrier effects for humans and animals										Future developments	
Animal Deaths										Future developments	