nzier
authoritative analysis

Externalities

Methods for attributing costs between internal and external components

Report to Ministry of Transport

June 2009

Preface

NZIER is a specialist consulting firm that uses applied economic research and analysis to provide a wide range of strategic advice to clients in the public and private sectors, throughout New Zealand and Australia, and further afield.

NZIER is also known for its long-established Quarterly Survey of Business Opinion and Quarterly Predictions.

Our aim is to be the premier centre of applied economic research in New Zealand. We pride ourselves on our reputation for independence and delivering quality analysis in the right form, and at the right time, for our clients. We ensure quality through teamwork on individual projects, critical review at internal seminars, and by peer review at various stages through a project by a senior staff member otherwise not involved in the project.

NZIER was established in 1958.

Authorship

This report has been prepared at NZIER by Jagadish Guria and reviewed by John Yeabsley. The assistance of Joanne Leung and Michael Bealing is gratefully acknowledged.

8 Halswell St, Thorndon
P O Box 3479, Wellington
Tel: +64 4 472 1880
Fax: +64 4 472 1211
econ@nzier.org.nz
www.nzier.org.nz

Key points

This report discusses methodologies for identifying costs internalised by users of the transport system and external costs they impose on other users and the rest of society, in three areas: congestion, accident and pollution, for three modes road, rail and maritime.

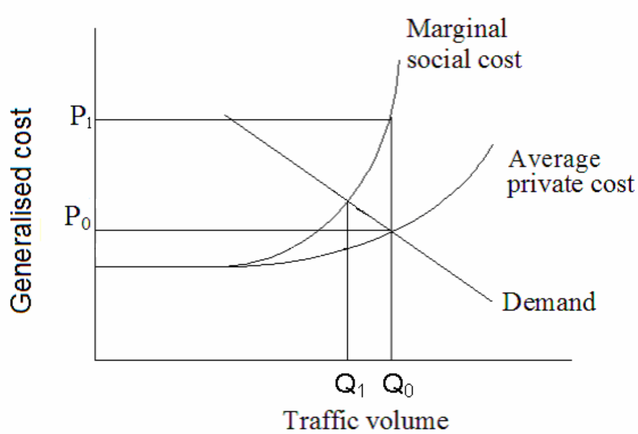
Cost of pollution incurred by an user is negligible in comparison with the total. So almost all of it is external cost. In case of congestion, part of the total cost is internalised by the user. External cost can be substantial, particularly when the congestion level is high. It is much less straightforward for accident costs, in particular for private passenger road transport.

Private passenger road transport is a familiar issue. We start with this and then discuss the differences for other situations and other modes.

Congestion

Congestion occurs when traffic density increases to such a level that the average speed is reduced. This not only costs more to the new entrant in terms of travel time and vehicle operating costs but all others also face additional costs (Figure 1).

Figure 1 Cost volume relationship



Source: Based on Walters (1961) and Stubbs, et al (1980).

Marginal social cost in this diagram includes only the additional cost of travel time and vehicle operation imposed by the last entrant. If we included pollution cost with it, then the marginal social cost would shift upward and would also be steeper. The marginal social cost should also include cost of additional accident risk to other users. The relationship is not straightforward as discussed later. The total social cost of accidents initially increases with traffic but as speed reduces further the rate of accident reduces along with average severity and the total social cost may also decline.

The congestion costs of road freight transport can be determined in the same manner as it will be part of the traffic stream. In fact the same logic holds for other modes, viz., rail and maritime. Since peak period traffic in rail is dominated by scheduled services, there may be scope for reducing the travel time through revision of the time table. For maritime, congestion may occur at ports. The basic consideration for estimating the costs of externalities remains the same in all cases.

Accident

Risk is internalised if the user bears the cost of the consequences of accidents due to his/her actions. For road passenger transport, it is not obvious what proportion of the risk faced by passengers is considered by the driver.

Part of the total social cost is always borne by the society. The Value of Statistical Life in New Zealand is the value society is willing to pay to reduce the risk of death so that one premature death is avoided. Part of this value is the amount the concerned person and his/her close ones are willing to pay (WTP). The other part is the WTP value of the rest of society. This last part is always an external cost. In addition certain costs are borne by society, in NZ case, through ACC. That is also part of the external cost.

For estimation we suggest the following:

Accidents due to natural causes: Costs incurred by the society as a whole are the external cost. Here we assume that the drivers take into consideration the risks to themselves and to their passengers but not damages to others.

Accidents due to risk taking behaviour or vehicle problem: For public transport, including rail and maritime modes, external cost includes all costs to passengers, other road users and society's share of the social costs of injuries to the driver.

For private transport we considered two scenarios: (a) passengers are aware of the risk and they accept it and (b) only driver's risk is internalised (i.e., driver has not taken into account the additional risk on passengers). In the first case, external cost include all costs to other road users and society's share of the social costs of injuries to the driver and passengers.

In the second case the external costs includes the costs suffered by passengers in addition to the external cost in (a).

The actual situation is likely to be in between these two scenarios. There is no clear indication of this in the literature. Also, it is likely to vary between societies. One way to determine the situation in New Zealand would be to conduct a survey or include this as part of some other survey or surveys.

Pollution

Only a small fraction of the total cost of pollution caused by a transport user is suffered by the user. The rest of pollution costs are external costs.

The effect may occur many years from the time of travel or pollution exposure. Also the effect can be a reduction in life span and loss in quality of life instead of premature death which would be valued at the Value of Statistical Life (VOSL) used in social cost estimation of accidents. Investigating this will require the establishment of values of quality adjusted life years lost and also the discount rate to be used to estimate the present value of costs.

Next step

In this report we have discussed methodologies for identifying and estimating external costs. To what extent the external costs should be disaggregated will depend on the purpose of determining the externalities.

While marginal social cost of congestion, for example, is an important factor for determining the optimal congestion price, there are other factors that should be considered to determine the impact of a congestion tax. It would depend on the distribution of value of time of vehicle users at that time and the availability of alternative routes or systems such as public transport. It is necessary to study the inter-linkage between these factors.

As far as pollution is concerned, it is the total pollution cost and its valuation, that should be of interest as most of these are external costs. The internalisation policy needs to find out the impact of that policy on the total pollution level as the health effect of pollution depends on the total pollution level, not just the amount emitted by transport. The social cost of pollution considering loss of life and life quality is an important factor for any intervention evaluation and systematic estimates are necessary for this. An important information, currently lacking in this context, is the value of loss of life years or quality adjusted life years.

Accidents, particularly road accidents, occur mostly due to driver behaviour, i.e., risk taking behaviour of drivers and other road users for a given network. The variation in risk taken by road users is an important factor in the development of a policy to internalise the external costs. Also it is necessary to find out the level of passengers' risk taken into consideration in drivers' risk taking behaviour.

Studies should also be carried out to determine the level of risk internalised by passengers, particularly in public transport.

Contents

Appendices

Figures

Tables

1. Introduction

All instances of travel are associated with risks of accidents resulting in injuries, deaths, property damage and sometimes crowding causing time delays for travellers or goods. In addition, motorised trips contribute to environmental pollution.

These various effects result in substantial social costs (explained more fully later). Policies and programmes are developed to reduce these social costs. Better identification of the proportions of the total cost of travel borne by the trip–maker, and those imposed on society would help develop appropriate mitigation policies and programmes.

A study (Surface Transport Costs and Charges (STCC)) carried out by Booz Allen Hamilton and associated consultants in 2005 for the Ministry of Transport estimated the average and marginal costs of road and rail transport operations. The Ministry is now interested in developing appropriate methodologies/approaches for attributing costs between internal and external components, considering data, time and resource constraints for three modes, road, rail and maritime, and also for passenger and freight transport systems. For convenience here we focus our discussion on road transport and, once a picture has been developed, discuss the differences with other modes.

The aims of this research are to:

- Review and confirm the importance of being able to separate internal costs from externalities, in the context of estimating total, average and marginal costs of transport use. We shall also discuss and define the concept of internalisation.

- Review relevant international literature, existing research, published practical guidance, published case studies, and other appropriate materials to determine the state of the art methods in achieving the above.

- Recommend appropriate methodologies/approaches for attributing costs between internal and external components, considering data, time and resource constraints.

The findings of this report are expected to be incorporated into the Social and Environmental Cost work stream of the Understanding Transport Costs and Charges study.

Negative externalities in transport operations are the non-market costs and risks imposed on other users and the rest of society by users of the transport system. There are also positive externalities from transport use (e.g. agglomeration benefits). However, positive externalities are not the subject of this report. Therefore, throughout this report, we refer externalities mainly to the negative externalities related to social and environmental costs of transport.

In terms of road safety, externalities caused by a road user are the risks of crashes and injuries faced by others (mainly other road users), and the associated costs imposed on society as a whole, as a result of that road user's travel.

It is easy to see in a simplified approach what happens in the latter. A free flow of traffic occurs up to a certain level of vehicle density. Beyond that critical value, traffic slows down – due to the interactive effect between the sheer volume of traffic - and everybody on the road at that time suffers as a result. The 'costs' imposed by an extra road user on other road users (due to the additional time and other disbenefits they incur because of the congestion) are classified as externalities.

Similarly, motorised travel usually contributes to environmental pollution through the by-products of its motive power system. This affects not only the road user and other road users, but also all members of society.

As discussed later, cost of pollution incurred by an user is negligible in comparison with the total. Almost all of it is external cost. In case of congestion, part of the total cost is internalised by the user. External cost can be substantial, particularly when the congestion level is high. It is much less straightforward for accident costs, in particular for private passenger road transport. So we discuss congestion and accident externalities in more details.

While the estimation of the costs of externalities sounds like a straightforward concept, in practice it is a difficult notion to apply; in particular it is rather complex to estimate the costs of externalities.

This report discusses the likely internalisation by specific users of the transport system and that way externalities seem to fall on others, under the current system of administration and regulation. It does not discuss measures for internalisation.

We first discuss briefly the rationale of this work, followed by a discussion on the concepts of social cost, cost internalisation and external costs. We will also discuss our initial thoughts on the internalisation process. We then review literature on methods for attributing internal and external costs in the third chapter. In the fourth chapter we discuss and recommend the methodology for estimating costs internalised and hence external costs for road transport, separately for congestion, accident and environmental effects. We then discuss the differences from this for rail and maritime transport systems.

2. Rationale and initial thoughts

2.1 Rationale

A crucial rationale for pursuing this research is that it facilitates policy developments for controlling externalities by identifying the size of the social and environmental impacts. Most studies of externalities relate to the process of determining an optimal pricing system. While price is an important possible policy mechanism, there are other measures which could be employed, and which would 'internalise the externalities.[1]

The background to this investigation is fundamental to the analysis we develop here. Examining more closely the way the total social costs of transport partition into internalised and external costs, is a stage on the route to the consideration of possible new policy mechanisms. A critical part of that partition is the exercise of 'control' over choices by the different agents – this is the point of considering internal and external costs. This information will help to look robustly at the incentives operating, and thus determine an appropriate mix of policies.

2.2 Definitions

2.2.1 Social cost

Social cost of transport use is the total cost to society including costs of accidents, congestion and environmental effects. This includes all direct and indirect costs and both tangible and intangible costs. The broad social cost of accidents include value of loss of life and life quality, value of time lost, loss of output, medical and rehabilitation costs, legal and investigation costs, and property damage. The costs of congestion include value of time lost, vehicle operating cost and cost of emissions. For environmental effects, the social cost items include climate change impacts, loss of environmental quality, health effects, including loss of life and life quality (e.g. due to stress, respiratory diseases, cancer, sleep disorder, fatigue, hearing loss etc.)

2.2.2 External costs and internalisation

Externality is the cost or benefit part of the total cost or benefit that is not internalised. In most cases, by externality we mean technological externality. Another form of externality commonly discussed in the economics literature is the pecuniary externality which occurs only through effects on prices (Greenwald and Stiglitz 1986, Baumol and Oats 1988). As Greenwald and Stiglitz (1986) note, technological externalities occur when the action of one individual or firm affects the utility or profit

[1] The idea of 'internalising the externality' as a solution to the problem is based on the view that all decisions are reasonably rational so if individuals bear the full consequences of their actions (which is the meaning of 'internalisation'), they will make the right choice.

of another individual or firm. This paper focuses on technological externalities and does not cover pecuniary externalities.

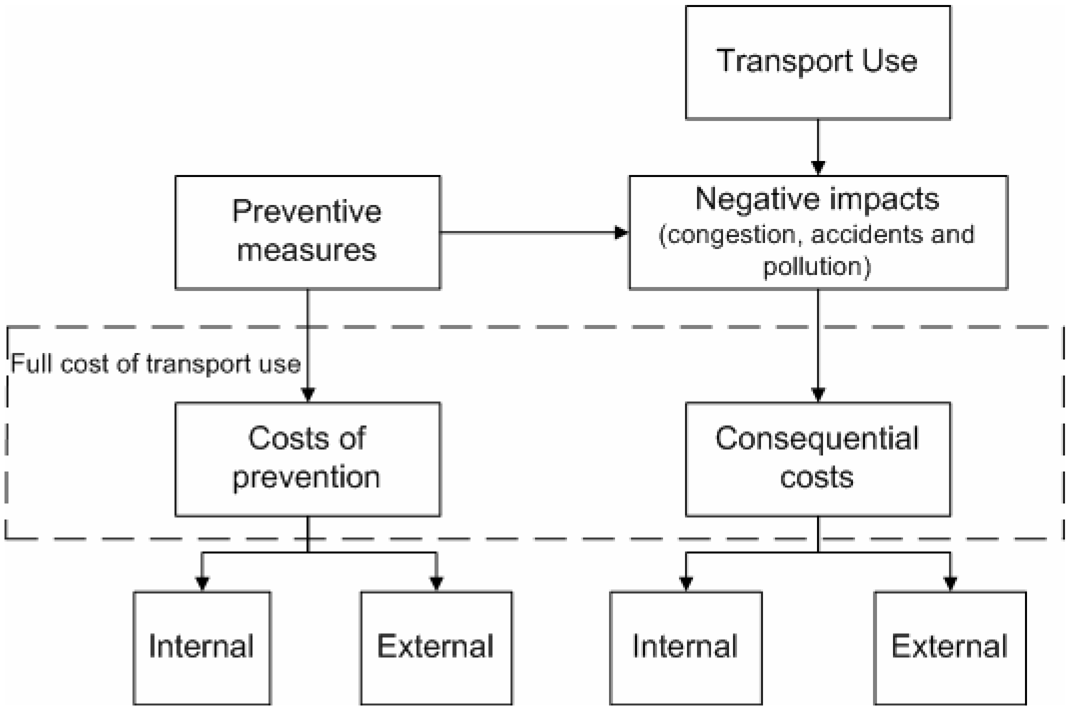
The externality, or more specifically the external cost, is the cost imposed on other members of society as a result of the action of an individual or a group. It is the part of the total cost that is not internalised. The cost internalised can be defined as the cost borne by the party who causes the effect.

The external cost estimation can be at a particular point in time or for a system in the short run or at the optimal flow level as in the case of road congestion.

2.2.3 Preventive and consequential costs

Preventive measures are taken to reduce the negative impacts of transport use (e.g. risk of crashes). The costs of preventive measures are part of the total cost as shown in Figure 2. It also shows that the preventive measures are prompted by the risks of crashes and injuries.

Figure 2 The Full Costs of Transport Use



Source: NZIER, MOT

The total social cost of a given system is the net effect after incorporating the impact of the preventative measures that have already been taken. Therefore, we do not include the costs of preventive measures in determining the costs of externalities. This separation of social costs and costs of preventive measures is also necessary to evaluate the effects of any policy changes on externalities.

If the objective is to determine the full cost of transport, then of course, both the costs of preventive measures and the social costs should be added together.

In this report we are discussing specific cost categories, which produce externalities, viz., congestions, accidents and environmental effects. Here, even for total and average costs we include only the consequential costs or the social costs as we have defined here.

2.2.4 Total, average and marginal costs

Broadly we can categorise costs into total, average and marginal cos. Each of these has a role in the policy development process. For pricing, for example, marginal cost is an important factor for improving efficiency. However, it is difficult to estimate, primarily due to data limitations.

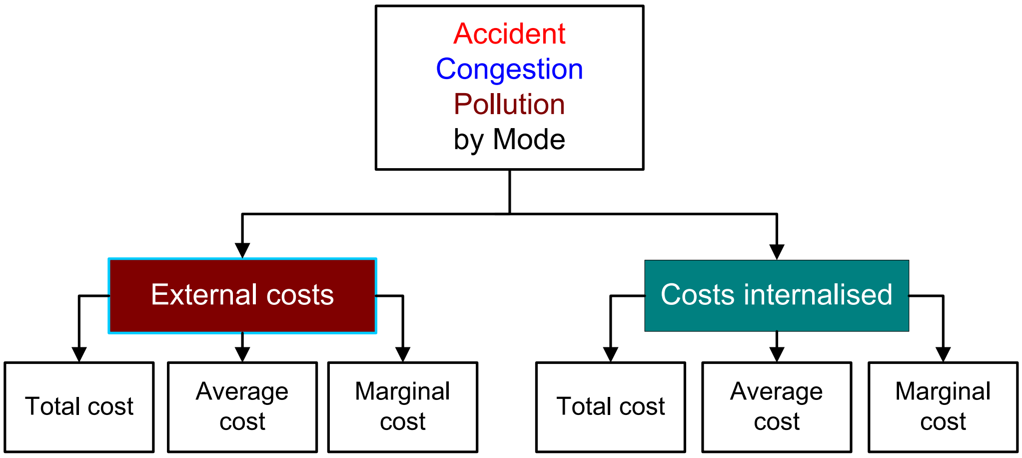
Once the total cost is estimated, it is straightforward to estimate the average cost, as total cost per unit of travel (number of drivers, road users, vehicle km, tonne km etc.). Marginal cost, which can be defined as the additional cost per unit of travel, is more complex to determine, particularly when dealing with economies or diseconomies of scale. It is important from an economic analysis view point as the decisions about optimality typically hinge on marginal values.

If during the period when vehicle-kilometre travelled (VKT) is increasing over time, there is a downward trend in number (or the social cost) of crashes, it does not necessarily mean the marginal cost of risk is decreasing due to increase in traffic volume. The result could be due to improvements on the road network, traffic behaviour, quality of vehicles etc. The total social cost could still be lower if there was one less VKT.

The methodology to be developed must take such complexities into consideration, particularly the short and long run effects.

In summary, we need to determine the methodology for identifying costs internalised and estimating external costs as shown in Figure 3.

Figure 3 Externality



Source: NZIER

Studies formulating and estimating externalities usually aim at determining an efficient pricing system. Since theoretically price equalling the marginal cost is efficient, these studies usually focus on estimating the marginal costs of travel.

If C(Q) is the total cost of travel Q, then average cost is $\frac{C(Q)}{Q}$ and marginal cost is $\frac{dC}{dQ}$.

Marginal externality is then defined as $\frac{dC}{dQ}$ - marginal cost internalised.

Even though it is not straightforward to estimate $\frac{dC}{dQ}$, it is much more complex to determine the extent of the costs internalised.

2.3 Valuation methodologies

An Austroads report (Tsolakis et al 2003) refers to three possible approaches to valuing externalities:

- damage costs,
- avoidance cost; and
- willingness to pay (WTP) value for avoiding externalities.

What we have described as 'preventive costs' above is the 'avoidance costs' in the Austroads report. Here we take the WTP approach for valuing costs of non-fatal injuries and fatalities, which are used to estimate the social costs of accidents. For environmental impacts, emphasis is usually given to avoidance or preventive costs due to the difficulty in determining the consequential costs. However, this paper is about the methodology for separating internal and external components. Therefore, we have not investigated further the appropriateness of using avoidance or preventive costs to measure environmental effects[2].

2.4 Initial thoughts

2.4.1 Looking toward analysis

To consider the general case we start with the examination of a vehicle moving on a road. This is a common example and it also provides a convenient starting point from which other examples can be developed.

We start our discussion with the presumption that information on all cost components is available.

[2] We note though the logic that, if the measures are efficient, then it follows that the value of the harm avoidance must exceed the cost of the measure taken to prevent it, but the intriguing question is the amount of the 'gap.'

The total cost (C) is the total of all tangible and intangible costs irrespective of the level of internalisation.

This includes

- vehicle operating costs
- value of travel time
- expected cost of a crash to driver, passengers, other members of society and to those interested in the goods carried
- costs of environmental pollution.

Most of the total cost to society (or the social cost) is the total of *private* costs to all road users and to other members of society. This includes costs to pedestrians and cyclists and also to the rest of society, including those costs which are borne by all. For freight transport, any damage to goods will be most probably borne by the shippers, who are not necessarily the road users during the freight trips.

2.4.2 More than just the easy bits - partitioning is complex

Most studies define costs internalised as the market or private costs borne by the transport operator. This appears to be a common definition used for estimating externalities (for example, Newbery 1990, Banfi et al 2000, Mayeres et al 2001, Ozbay, Bartin and Berechman 2001, Piecyk and McKinnon 2007, Lemp and Kockelman 2008). They treat all other costs as external costs.

It is not appropriate in our view, to equate private costs with costs internalised in all cases. As noted by Maddison et al (1996, p115) "*accident costs are external to the extent that an additional vehicle kilometre driven increases the probability of any other motorist having an accident"t*. **A cost is internalised only if the producer of the cost bears the cost**. On the other hand, the private cost is the total cost borne by an individual or a group.

In terms of external safety cost, as rightly pointed out by Edlin and Mandic (2006), some drivers are more dangerous than others and hence the cost imposed on other road users vary with risk-taking (or more accurately, risk-making) behaviour of drivers and other road users.

The risk of a crash occurring when there is drunk driving in the system, (which might involve other road users) is considerably higher than if all drivers were sober. The prevalence of drunk drivers increases at certain periods of time. The risk of a crash and consequent injuries increases during these periods for all road users. If an individual decides to change the time of travel because of this high risk, then the cost of inconvenience of that change should be treated as an externality. In fact, any special action taken by other road users due to the risk taking behaviour of a particular road user is an externality of that risk taking behaviour.

Another common assumption in the literature on estimating external safety costs is that all costs suffered by pedestrians and cyclists are classified as external costs to them because they are the most vulnerable road users. This is not strictly true.

An accident can occur due to the inappropriate behaviour of a pedestrian or a cyclist. In such a situation, often the pedestrian or cyclist may be killed or severely injured, while the injury suffered by the vehicle driver involved is minor or nonexistent. (Even so the driver and other passengers in the vehicle may suffer mental trauma, which is an external cost to them.) Standing on pure theory, as articulated above, the high cost outcome for the risk taken by the pedestrian (or cyclist) here should be treated as a cost internalised by them. Recognising and carrying through this logic is an important factor in the development of policies for reducing externalities.

2.4.3 Passengers – no single obvious partition

Another important factor in allocating the degree of accident or safety externality is the *responsibility* of the driver, when there are other passengers in the vehicle. The level of internalisation depends on the risk to the passengers taken into account by the driver in commencing the trip and his/her driving behaviour. So the mechanical condition of the vehicle may be known more to the driver than the passengers. In such cases, the level of risk internalised is not necessarily the total risk to all occupants.

The implicit contract between the passengers and the driver is an important factor too. If there has been a degree of agreement that each of the passengers accept the risk exposure represented by the driver's likely behaviour then there is a different amount of internalisation than if the passengers are expecting higher safety standards than the driver actually exhibits.

This quick discussion illustrates an important feature of the logic of internalisation/ externalisation, which relates to the expectation of the individuals involved. This ties up with the way decisions are made by these agents; when they have looked ahead and foreseen consequences of their decisions and acted accordingly there is internalisation – though possibly not complete. This aspect is developed further later in this paper.

Here we have concentrated our discussion on road transport externalities for two reasons: (a) most externalities occur in road transport and so the international research also is dominated by road transport; and (b) it is convenient to discuss road transport as most people are familiar with this than with other modes. For other modes, we relate to our findings in road transport and identify the areas of differences. We have not separately discussed walking and cycling. We have treated these as part of road transport and discussed externalities in that context.

3. Literature review

3.1 Congestion

Traffic congestion is one of the scourges of modern life. It costs the economy not only in terms of traffic delays and hence cost of time and related economic impacts, but also associated costs of fatigue, fuel consumption and environmental effects in consequence. It may also have an impact on the risk of a crash.

Congestion occurs when demand for a good or service (e.g., the road network) exceeds its supply capacity. Economic theory tells us that the amount of good or service demanded by people depends on the price charged for that good or service. Congestion usually occurs during specific time periods and at specific parts of the road network. During the rest of the day, there is free flow of traffic. However, the price paid by the users is almost the same during both the peak and off peak times. Thus any change in price or capacity of the network is likely to change the level of congestion and hence the level of congestion externality.

The scarcity value of the network during peak hours is considerably higher than the value during other times. The total social cost in terms of costs to all in society per unit of travel can be considerably higher during peak hours.

3.1.1 Causes of congestion

Congestion is usually defined as a condition of traffic delay that occurs because the number of vehicles on the road exceeds the capacity at which traffic can flow freely. Thus over time there is a tendency to increase congestion due to traffic volume increasing faster than the improvement in network capacity.

As noted by Weisbrod et al (2001), congestion has three dimensions of variation:

- Spatial pattern – congestion can be area or location specific,
- Temporal pattern – it may occur during specific time periods of day – e.g., morning and afternoon peaks,
- Stochastic element – it can occur systematically at specific times or sporadically as a consequence of a traffic crash or some other incident.

Kinzel (2007) finds sporadic or non-recurring congestion accounts for about a fourth of all delays in the USA. Whether systematic or sporadic, the frequency and severity of congestion increases with increase in volume of traffic.

Our discussion here is mainly for spatial and temporal patterns. Congestion (traffic delay) due to a specific incident like a traffic accident should be considered part of the cost of that accident.

3.1.2 The economics of congestion

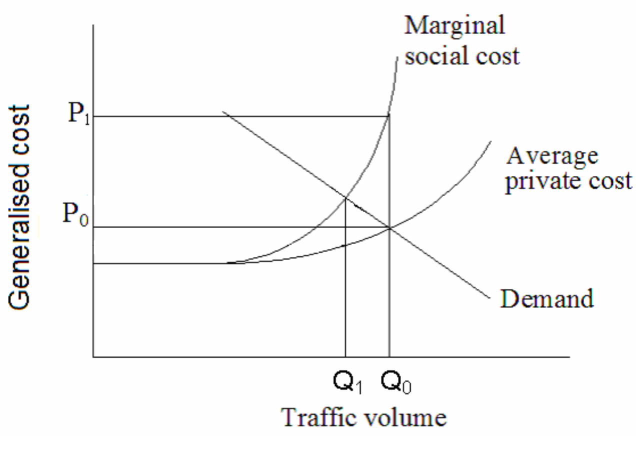
In economic terms congestion occurs due to an excess demand for (relative to the supply of) network space. During peak hours, the high traffic volume that result in congestion indicates that the demand for network space at that time exceeds its design capacity, which is relatively inelastic in the short term. As noted by Walters (1961), the high demand for road space increases the traffic density and that results in reduced traffic flow.

However, as discussed earlier, traffic volume and travel are affected by the price paid by users. Figure 4 shows the demand for network space as a function of generalised cost, which should be the total costs including value of time.

For simplicity we include here only the costs of vehicle operation and travel time in the generalised cost and then we discuss the effects of accidents and pollution later. In this case, the marginal private cost and average private cost are the same (for congested traffic) at each level of traffic since everybody incurs the same generalised cost. Since the costs of congestion are suffered by vehicle users only, the total private and social costs are the same and is equal to $\frac{C(Q)}{Q}$. The marginal social cost, $\frac{dC}{dQ}$ differs from the marginal private cost $\frac{C(Q)}{Q}$. As shown in Figure 4, marginal cost is higher than marginal private cost beyond a certain level of traffic.

The private cost curve indicates how the cost borne by any individual user increases with volume of traffic. Average cost increases as the volume of traffic increases beyond a certain level (the horizontal part of the private cost curve). From this point onward an additional unit of traffic increases the delay for everybody on that part of the road network at that time. This increase in the marginal cost to all users is shown by the marginal social cost curve.

Figure 4 Cost volume relationship



Source: Based on Walters (1961) and Stubbs, et al (1980).

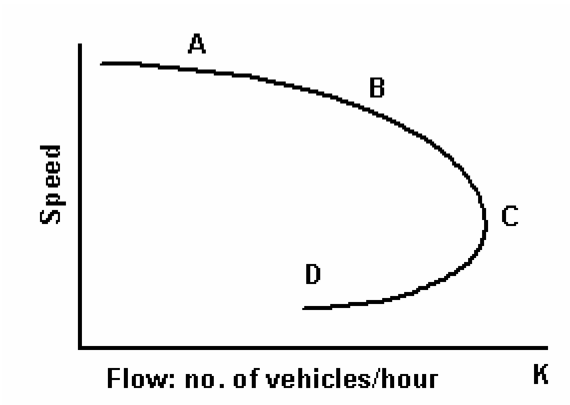
At price P_0 (Figure 4) the level of traffic is Q_0. The difference between the marginal private and marginal social costs indicates the marginal cost of externality – the cost each unit of traffic is imposing on the rest of the traffic. The marginal social cost is indicated by P_1 at Q_0. The difference between P_0 and P_1 is the marginal external cost at Q_0.

This relationship gained importance for determining the optimal congestion tax or a Pigouvian tax. In the diagram this is equal to the difference between the average private cost and the marginal social cost at Q_1 where the demand curve intersects the marginal social cost curve.

As noted by Parry et al (2007), this is based on the assumption that motorists care only about the average private cost. There is also an implicit assumption that all of average private costs are internalised. As we will discuss later, it is not necessarily so, if the generalised cost includes the costs of crashes and pollution effects as well.

There can be situations where the flow-congestion relationship becomes unstable. Parry et al (2007) note that the flow-congestion relationship is not a very good description of peak hour traffic, which is characterised by "*very high density, stop and go traffic, and "hypercongestion", where travel speeds are so low that total traffic flow actually declines – often to considerably less than half of road capacity" (p 380)*.

Figure 5 Speed flow relationship for a link



Source: Newbery (1990), NZIER

As traffic increases, the average speed reduces, from A to B (Figure 5) and then to C at which the inflow of traffic reaches the capacity of the link K. At this point the flow changes to stop and go condition and traffic flow reduces through the bottleneck. With respect to out-flow of traffic, the relationship between cost and flow would also be backward bending (Guria 1986). Small and Chu (2003) note that "*hypercongestion is a real phenomenon, potentially creating inefficiencies and imposing considerable costs"* (p 342). The speed flow relationship, at this point, becomes unstable (Newbery 1990, Small and Chu 2003, Parry et al 2007). Small and Chu (2003) further note that "*severe congestion short of gridlock ultimately dissipates once the demand surge abates"* (p 342). Therefore, for estimation purposes we should concentrate on flow-congestion relationship as shown in Figure 4.

3.1.3 Traffic crash costs

The crash rate (number of crashes per vehicle kilometre travelled or VKT) is usually high at low levels of congestion. It decreases as the level of congestion increases but it starts increasing again at a certain level of congestion, reported by AAA Foundation for Traffic Safety (1999) based on a USA study by Zhou and Sisiopiku (1997). Noland and Quddus (2004) also support this relationship from their study in the UK.

Traffic speed decreases as congestion level increases reducing the crash rate. However as congestion increases further, the number of crashes tends to increase, possibly due to frustration and also a tendency to overtake. The average severity of crashes decreases with increase in the level of congestion – related to speeds which are falling.

The effects on risks of accidents cause a difference between total (and average) private and social costs. Unless the level of congestion is such that it substantially reduces the severity of accidents, there is a likelihood of the social cost increasing with the level of traffic.

The methodology for attributing traffic crash costs between internal and external components will be discussed in details in Section 3.2.

3.1.4 Time and vehicle operation costs

As far as value of time and cost of vehicle operation are concerned, the total (and average) private and social costs are the same, but marginal private and social costs are different.

The cost imposed on others is the external cost, which is shown by the difference between marginal social cost and average private cost curves in Figure 4.

3.1.5 Pollution costs

Congestion increases fuel consumption and hence adds to pollution costs. Another factor here is that the level of pollution affects the whole society. The share of pollution effect suffered by the generator of the cost is negligible. Therefore, most of the total pollution effect is external (also see Section 3.3). With congestion the level of pollution per unit of travel increases and therefore the marginal external pollution costs increases with traffic volume.

3.1.6 Total effects

We have discussed three effects of congestion:

- Time and vehicle operation costs
- Accident costs
- Pollution costs

These effects can be expressed mathematically (see Appendix A).

The difference between marginal private and social costs shown in Figure 4 covers mainly the first cost category. The early congestion cost analysis work considered only this aspect.

Combining the first and the third cost categories would not have much effect on the shape of the private cost curve. However, the marginal social cost curve would be steeper as most of the additional pollution cost due to congestion would be external costs. In fact, there would be a difference between the marginal private and social costs even on the horizontal section of the cost curve and the marginal social cost would be higher than the marginal private cost from the beginning, assuming any amount of travel would cause environmental effects. If we included the cost of fatigue associated with congestion, there would be no change in the broad shapes of these curves.

However, if we included accident cost as well there might not be a monotonic increase in private costs with traffic volume. The marginal social cost would differ from the private cost curve right from the beginning. In addition, at a certain level, the marginal accident cost could be negative due to very slow traffic at that point.

The external cost will be the difference between the marginal social cost and the average private cost.

We have not considered any external cost due to a system failure, e.g., a signal system failure for rail or a traffic light problem in road transport. We consider these to be part of the operational cost of the system and not related to traffic volume[3].

3.1.7 Road freight transport

As far as congestion is concerned road freight transport will have similar effects. Some distinct features of road freight transport are that

- freight transport vehicles have a higher unit congestion effect due to their larger sizes
- while the number of vehicle occupants is expected to be lower per vehicle, the value of time per driver may be higher than average per driver, as it would all be work time
- also the cost should include value of time delay for the goods carried.

Since road freight transport shares the same road with buses, cars and other vehicles, the difference between private and social costs for freight should be estimated in the same manner. The internal costs are those borne directly by the road freight transport operators, as noted in Piecyk and McKinnon (2007). All other costs are external costs.

[3] This is obviously a first order approximation; in practice, the traffic volumes present around the area of the failure will affect the impact it has on the way traffic flows.

3.1.8 Rail

Unlike road transport, rail transport, particularly passenger rail transport is a scheduled service – it runs literally on its own tracks in New Zealand. Congestion effects or delays in rail transport occur when the system fails. It is more likely to be sporadic than systematic as in road congestions. The associated costs can be treated as an operational cost instead of an external social cost. The effects include the costs of waiting time and missing connections in the next leg of the journey (Banfi et al 2000, Maibach et al 2008)

In other cases, including freight transport, congestion occurs when the service level exceeds the track capacity.

Some costs can be eliminated through better management of the system; for example, Maibach et al (2008) note in the context of UK rail transport that congestion cost in rail is often eliminated by revising the timetable.

For rail safety, costs internalised and external costs are similar to those laid out for public transport (to be discussed in Section 3.2). In terms of rail pollution effects, the majority of the costs are external (see Section 3.3).

3.1.9 Maritime

Congestion in maritime transport occurs mainly at sea ports especially in cargo and storage handling facilities. In this case the external cost is estimated by additional crew costs for vessels waiting at a port (Maibach et al 2008). Maibach et al (2008) , however, also note in the European context that ports hardly ever keep records of vessel waiting times and hence it is difficult to estimate the congestion costs.

3.2 Accidents

In this section we start our discussion by neglecting the legal side of the issues. Only once we have developed our thinking do we take account of the effect of the law.

As discussed by Parry (2004), the estimates of total cost or the social cost of accidents include the following cost items

- costs of loss of life and life quality;
- loss of production;
- costs of emergency services, medical treatment and rehabilitation;
- travel delay costs;
- property damage; and
- legal and insurance administration costs.

The cost components used in New Zealand are very similar (Ministry of Transport 2008).

The values of loss of life and life quality is normally based on the official value of statistical life or VOSL[4].

Once these costs are estimated, the total and average cost estimation would be straightforward. However, as we have discussed earlier, there are complexities in estimating marginal costs and also the proportion of the costs internalised.

Parry (2004) identifies the following as external portion of accident costs.

- All costs to pedestrian/cyclist injuries;
- Single vehicle crashes –no external costs, i.e., all costs are internalised;
- Multi-vehicle crashes – depends on how an extra vehicle changes the risk faced by other vehicles and their occupants;
  - Low cost scenario: no external cost;
  - High cost scenario: one driver's externality cost is $\frac{1}{n-1}$ times the cost of all injuries in an accident involving n vehicles.
- Property damage costs – not clear to what extent drivers internalise the costs given that most vehicles are insured. He uses 0, 25% and 50% as low, medium and high costs scenarios;
- Travel delay costs – all are external;
- Medical, emergency services, and legal/court costs – depends on the insurance system. Parry uses 85% of all these costs as external costs.
- Lost wages – drivers take into account the risk of wage loss to themselves.
  - All loss to pedestrians and cyclists are external costs;
  - The wage loss to other vehicle occupants are considered as 0% and 100% for low and high cost scenarios respectively.

We now discuss these individually.

3.2.1 Pedestrians and cyclists

It is often argued in the literature that vulnerable road users, such as pedestrians and cyclists, suffer all external costs when in a collision with protected road users (Jansson 1994, Parry 2004). An implicit assumption is that either such an accident does not cause any harm to the vehicle or its occupants, or that such costs are internalised by them.

The literature recognises that external costs vary between drivers because some drivers are more dangerous than others (Edlin and Mandic 2006). This should also apply to pedestrians and cyclists. Some pedestrians and cyclists impose considerable risks to motorised traffic through their risk taking behaviour, which is beyond the expectations of other road users. Even though in an accident involving a

4 In New Zealand the VOSL is $3.35 million at June 2008 prices, the value of loss of life quality is 10% of VOSL per serious injury and it is 0.4% of VOSL per minor injury (Ministry of Transport 2008). These are based on household surveys estimating the amount people would be willing to pay to reduce their risk by a certain proportion.

pedestrian and a vehicle, the pedestrian suffers physical harm in most circumstances, with little or no physical harm to the vehicle driver or other occupants, the cost of such a crash is not expected to be internalised by the driver if the risk has been taken by the pedestrian unexpectedly. It is undoubtedly complex to identify and estimate the costs internalised by each party. However, it is also inappropriate to automatically assign all external costs to motorised vehicles and none to pedestrians and cyclists, just because most of the impact falls on them.

On the issue of who is responsible for the cost of an injury, Vickrey (1968) notes that *"jurisprudence tends in principle, though less in practice, to draw a sharp line between licit and culpable behavior. Action that fails to transgress this line may be held to involve damnum absque injuria ("a loss or damage without injury") and to carry no penalty, however great be the damage done to others and however small the potential benefit to the actor. The economist tends rather to take natura non facit saltum ("nature does not make a leap") as his motto, and to insist that the degree of culpability and accountability is measured by the damage done and not by any arbitrary line defining limits of acceptable behavior"* (p 464).

In response to Vickrey's view, it can be argued that risk taking-behaviours of some road users cause considerable social costs and the marginal social costs vary substantially between road users. Rational behaviour is expected from all using the road network. A strong deviation from that norm, which is responsible for increasing the risk of a crash, should be treated differently from those following the norm. It is often argued that the accident would not have happened if the vehicle was not there. True, but that does not make the vehicle responsible for the accident and the associated costs. In other words, it does not automatically make the cost an externality of driving and not the externality of risk taking behaviour of the vulnerable road user, when in practice it is so.

Though due to the creation of the ACC system, a tort law does not cover most personal injury accident cases in New Zealand, the observation by Mattiacci and Parisi (2006) that a tort law should be designed to "*induce parties to internalize the external costs of their activities and to adopt optimal levels of precaution"* (p 3), is relevant in the present discussion. This leads to identification of externalities and development of policies to internalise them.

3.2.2 Single vehicle accidents

Many consider the costs of single vehicles crashes are internalised by the driver of the vehicle (Parry 2004, Parry et al 2007). However, as noted by Jansson (1994), part of the cost is borne by society as a whole. The value of loss of life and life quality to society is measured by the amounts of money the person, the person's close relatives and the rest of society are willing to pay (WTP) to reduce the risk faced by the person. Even if the first two components (his/her and close relatives' WTP) are taken into account in the decision making by the driver, the rest of society's share in VOSL can be considered an external cost as suggested by Jansson (1994). In addition, part of the costs of medical treatment and rehabilitation for non-fatal injuries are borne in New Zealand by ACC, which can be considered an external cost, since levy rate is based on the claim costs ACC has to bear and not on the claims by an individual.

Property costs on the other hand is mostly internalised through the insurance system. Premium rates are likely to increase with claims and also there is an 'excess' payment that the vehicle owner usually has to bear.

3.2.3 Multiple vehicle accidents

In multiple vehicle crashes, smaller vehicles suffer more than larger vehicles. For a homogeneous set of car traffic, obviously this would not be a factor. Jansson (1994) develops a simple model to derive the marginal external cost imposed by a car on other cars. In a two car accident, Jansson shows mathematically that the marginal external cost of a car is equal to the cost of additional crashes to others plus the cost imposed on rest of society for injuries to the car occupants. The cost imposed on the rest of society is the cost per car involved in an accident borne by the rest of society.

As noted by Jansson, there is uncertainty on the risk and its consequences taken into account by the car driver. It is perhaps a reasonable assumption for most cases that drivers take into account the risk consequences to them and their passengers. However, there are situations where it is doubtful if the driver took into account the risk and its consequence even to himself/herself. An example would be the risk evaluation by a drunk driver. That question did not arise in Jansson's analysis as he considered homogeneous traffic in all respects. As shown in Figure 6, any cost that is not taken into account by the driver and passengers is the external cost to society.

In a mixed traffic situation, Jansson (1994) derives the marginal external costs for cars and bikes in car-bike accidents. Only one car and one bike are assumed to be involved in these accidents. Assuming that car occupants do not suffer in such an accident, i.e., no part of the cost is internalised by car drivers, Jansson's model shows that the external cost imposed by bikes is small and can even be negative depending on risk elasticity with respect to bike kilometre.

Starting with this formulation, McInnes Group (1994) developed an extension to determine marginal external costs in accidents involving a heavy vehicle (truck) and a light vehicle (car). Persson and Ödegaard (1995) think this formulation could underestimate the external cost, because of a concave relationship between willingness to pay and risk reduction, instead of a linear relationship. This is likely to be a relatively minor point in the estimation of external costs.

In all these cases, it is assumed that all car traffic and all truck traffic are identical and there is no variation between risks imposed by individual car drivers or individual truck drivers. In practice there are differences.

3.2.4 Relative risks

While it is convenient to assume homogeneous traffic for modelling purposes, in practice, as we have stressed before, risk-taking behaviour varies between road users and that should be taken into account while estimating externalities.

3.2.5 Property damage costs

All property damage costs in a single vehicle accident can be assumed to be internalised. If the vehicle is insured, then the vehicle owner suffers the excess amount prescribed in the insurance contract and also loses the no claim bonus. Thus the premium rate, in effect increases as a result of a crash. If the vehicle is not insured, the owner suffers the full cost.

In a multiple vehicle accident, the vehicle responsible for the accident is legally required to bear the cost, through insurance or otherwise. When that happens the costs are internalised. However, the owner of the other vehicle has to suffer the inconvenience of not having the vehicle for a certain period of time when it gets repaired. Also, if the vehicle at fault is not insured, the cost may not be borne by the owner of that vehicle. In this case, the level of external cost depends on the level of insurance coverage. In all cases, there are some external costs.

3.2.6 Travel delays, medical and lost wage costs

The cost of travel delays due to an accident affects all those who are on the road at that time and the cost is unlikely to be internalised by a driver. Besides, for an accident, the cost of delay experienced by the driver involved in the accident is small in comparison with the total cost of the accident.

As mentioned earlier, part of the medial cost is borne by ACC. However, part of the cost may have to be borne by the injured. That part is an external cost.

In New Zealand, the loss of output is assumed to be part of the VOSL. Thus it is part of the external costs suffered by other road users. However, part of the wage loss to the driver under consideration is compensated by ACC. That part should be treated as external cost of the accident.

3.2.7 Rail

Accidents may cause not only injuries and property loss to passengers and loss of freight but also considerable delay for trains using the same track. The cost of delay can be substantial in the case of a rail accident. Externality in this case is the total cost including damage to infrastructure, freight, other property and injuries to passengers and crew and costs of delay to other train passengers and freight, that is not covered by the rail operator.

Freight transported by rail is likely to be insured against damage due to handling or accidents. If the insurance is paid for by the rail operator then the cost is internalised. However, it is most likely to be paid for by shippers. In that case, the cost of damage borne by shipper's insurance company is also an external cost to rail. Any cost that is not borne by the rail operator should be considered an external cost.

Accidents at rail level crossings that involve a train and a road vehicle normally have severe consequences for the road vehicle and its occupants. In their analysis, McInnes Group (1994) classified road vehicle and rail as unprotected and protected users of the system and consider the same mathematical derivation of marginal external costs as for a truck and car accident.

While an accident may cause substantial costs on the vehicle and relatively lower cost for the train, it does not necessarily mean train has caused the external cost on the car in such an accident. The McInnes Group (1994) derivation is appropriate if accident occurred without any party taking additional risk. In real life, such accidents are rare. In most case, accidents occur because one party took additional risk. A train being a heavy vehicle, and going at a certain speed on its own track is unlikely to cause additional risk than what is expected on crossing the track by a sensible vehicle driver. If the road vehicle driver has not been careful and looked around to see likelihood of a train coming, he/she is taking an additional risk and that risk should be considered as internalised by the vehicle driver.

On the other hand, if the rail authority has not maintained the clear vision around the crossing or the train did not make any warning sound or the level crossing barrier or lights or bells are not working, the additional risk and the consequent cost is imposed by rail (assuming these are expected from the rail operator). In that case, the consequential cost other than the damage to the rail property is an external cost.

3.2.8 Maritime

Unlike congestion, accidents can occur at any facility – vessels and ports. Most of the injury costs of maritime accidents are external costs. However, passengers expect certain risk of accidents and injuries which they accept as part of their generalised (internalised) cost.

There is no straightforward way of determining the degree of costs internalised – it is in general going to vary by operator. One way would be to estimate people's willingness to pay to reduce the risk of an accident due to natural causes. Alternatively, if passengers are fully aware of the risk, social cost of injuries except the part borne by society as a whole, along with any damage to the vessel and its properties can be taken as costs internalised. However, if the accident or injury is due to non-availability of facilities expected to be provided by the shipping company, then the cost of that accident or injury should be treated as external cost to society.

The level of external accident costs in maritime transport may be small. In their estimates of external costs in Western Europe, Banfi et al (2000) consider water transport does not cause any external cost. This is not necessarily true, accidents can occur due to excessive speed or some other manoeuvring of the vessel[5]. In that case, only the costs of damage to the vessel and its properties are internalised. All other costs of the accident are external costs.

3.3 Pollution

Very little, if any, of pollution effect is internalised, except in the case of noise. Only a small fraction of the total social cost of noise pollution is borne by road users; the rest is external cost. The main external costs are those suffered by people choosing to live close to the transport system. In case of rail, a large part of noise pollution is borne by those living close to rail lines. Except for this, all pollution costs can be considered external costs.

As noted by Delucchi (2000), the total environmental damage of a trip suffered by the trip maker is negligibly small. However, with improved awareness of pollution effects such as climate change or global warming some people consciously opt for more fuel efficient vehicles or use other modes of transport. Such actions are cost internalisations.

Another important aspect of pollution effect is that vehicles are becoming more fuel efficient over time. Provided there is a normal distribution of the benefits this brings, it should reduce the marginal external pollution costs over time.

As noted by Piecyk and McKinnon (2007, p 9), "*combustion of fossil fuels leads to two types of emissions from vehicle engines: noxious gases and greenhouse gas emissions*". They also describe the likely health effects of these emissions. McCubbin and Delucchi (1999) and Small and Kazimi (1995) provide a good account of some vehicle emission pollutants and how that should be treated in social costs. They discuss mainly the primary pollutants of which substantial fractions are from transport emissions, viz., volatile organic compounds (VOC), Carbon monoxide (CO) and nitrogen oxides (NO_X). Then they discuss their secondary effects such as ozone formation. For damage estimation, they use direct estimation method, in which the link between air emissions and adverse consequences is traced and economic values are put on those consequences.

Parry et al (2007) note that light duty vehicles account for about a fifth of the total carbon dioxide (leading greenhouse gas) in the USA. In this particular case, the harm occurs in the future. The present value of the social cost of that harm depends on the discount rate. Thus, the selection of a discount rate to be used can be a crucial factor in the evaluation of a strategy to reduce the effect of pollution. *The Stern Review of the Economics of Climate Change* (Stern 2006), for example, used a 1.4% discount rate for future benefits and costs. Weitzman (2007) shows that the same strategy which indicates a benefit/cost (B/C) of 4.5:1, would have a B/C ratio of 1:10 at a

[5] Large vessels in New Zealand waters have ploughed straight over smaller ones because the larger ships failed to keep an appropriate look out.

discount rate of 6%. Dasgupta (2007), on the other hand, argues that the discount rate may not be constant over a long period of time and there are considerable uncertainties on how should it change over time.

There is another factor to be considered for estimating the costs of pollution. The effect of pollution can be a reduction in life span and also in quality of life instead of premature death which refers to the Value of Statistical Life (VOSL) used in social cost estimation of accidents. This will require establishment of values of quality adjusted life years lost and also the discount rate or rates to be used to estimate the present value of costs.

One important point noted by Small and Kazimi (1995) is that "*a pollutant emitted into the atmosphere changes the spatial and temporal patterns of ambient concentrations of that pollutant and perhaps others. …. The resulting ambient concentrations then interact with people, plants and animals in a way that depends on their locations and activity levels. The results may be physical or psychological effects"* (p 13-14).

To evaluate the consequences they suggest the willingness to pay approach, in which individuals are surveyed to determine the amount of money they would be willing to pay to reduce the risk of health effects, e.g., the risk of dying from lung disease.

Because the health consequences of air pollution depend on the concentration of these pollutants and also the secondary effects, the relationship between health consequence and the level of air pollution may not be linear, as pointed out by Small and Kazimi. However, they observe that ambient concentration of a primary pollutant is proportional to emission. They also note that even for secondary effect such as ozone formation, a linear approximation is reasonable.

McCubbin and Delucchi (1999) provide a systematic approach of estimating health effects and economic costs through the following four steps:

- estimate emissions related to motor-vehicle use
- estimate changes in exposure to air pollution
- relate changes in air-pollution exposure to changes in physical health effects
- relate changes in physical health effects to changes in economic welfare.

These are different ways of estimating the costs of pollution. An important factor for our consideration is that the marginal costs depend on the existing level of pollution, as stressed by Small and Kazimi (1995). This can happen at a particular point of time as well as over time as the level of pollutants builds up in the atmosphere.

Given our understanding that all costs of pollution are external costs, the main problem is estimation of social costs of pollution and how that is increasing over time. However, if Small and Kazimi (1995) approach of proportionality is reasonable, then marginal costs are the same as average costs.

3.3.1 Freight transport

Referring to the Department for Transport estimates, Piecyk and McKinnon (2007) report that road freight traffic in the UK accounts for 22% of all CO_2 emissions from the transport sector. Stern (2006) estimates that globally transport accounts for 14% of total greenhouse gas emissions. Within the transport sector, road transport accounts for about 76% of the total of which freight trucks account for 23%.

These statistics indicate that freight road transport contributes substantially to environmental effects. As noted earlier, all environmental costs in this context should be treated as external costs.

3.3.2 Other modes

Ministry of Economic Development (2007) estimated that in 2006 road transport accounted for 38% of CO_2 equivalent emissions from energy consumption in New Zealand, with rail, water and air transport contributing to under 5%.

The methodology for determining the external cost of pollution remains the same as in road transport. However, the emissions per passenger or ton km will be different for different modes.

4. Discussion and Recommendations

We have reviewed the literature on the basic factors which determine the level of costs internalised and external costs. We discuss below the methods for attributing costs between internal and external components. These are not necessarily the only methods. However, the discussion below should help developing appropriate methodologies according to data availability. This section only discusses the methodologies. Actual data collection and estimation is outside the requirement of the terms of reference.

4.1 Road congestion

4.1.1 Recommendations

We have noted that accident and pollution costs per km of travel change with level of congestion. While pollution costs are expected to increase with the level of congestion, accident costs may first increase and then decline due to lower speed and hence lower severity of crashes when they occur.

We believe, the accident and pollution costs related to congestion should be part of external accident and pollution costs. It will be convenient to confine congestion costs to the additional time taken to travel and the related vehicle operation costs. These costs will increase monotonically with the level of traffic inflow, even for the situation when the speed-outflow relationship is backward bending.

The congestion costs of road freight and road passenger transport can be determined in the same manner. The size of the vehicle is an important factor. A simple way would be to consider buses and trucks in terms of equivalent car units, since they contribute more to traffic density and congestion than cars.

Excluding the pollution and accident costs, the average private and social costs per unit of traffic volume are the same. The marginal cost increases with traffic as shown in Figure 4. The marginal social cost includes both the cost to the individual and the rest of society. The external cost, i.e., the cost to the rest of society is the difference between the marginal social cost and the average private cost.

Congestion may not be a serious problem for rail or maritime transport. However, congestion is related to capacity and the demand for services. They can be classified as operational external costs and are outside the scope of this study. If this problem exists and is an important issue for policy development, detailed methodology needs to be developed.

4.1.2 Further research requirement

- To estimate the marginal costs we need to develop empirically relationships between traffic volume and travel time, given network capacities. This will require data on traffic volume or density and travel speed for each network capacity.

- We have not considered any external cost due to a system failure, e.g., a signal system failure for rail or a traffic light problem in road transport. We consider these to be part of the operational cost of the system and not related to traffic volume[6].

4.2 Road Accident

4.2.1 Discussion

The main problem of identifying costs of internalisation appears in private transports and with respect to pedestrians and cyclists. For public transport, it is not clear to what extent the risk of injuries under normal circumstances is accepted by passengers. This can be estimated through a survey. In the absence of that information, our view is that costs internalised should include costs of injuries and financial losses suffered by the operator (including driver). All other costs should be treated as external costs.

Internalisation is also related to controllability. If an individual cannot control the cost imposed on others, it is very likely that the cost is not internalised. Exceptions to this rule occur when the cost generator is required to compensate the others, or there is a reasonable framework (regulatory?) allowing the individual to expect some minimum standard of risk control. This stems from the difficulty of the individual assessing the risk they are facing, other than in the cases discussed. It is related to the concept discussed briefly above in relation to passengers and drivers of implicit contracting and the way this ties to 'planning and foreseeability.'

To us the key concept in internalisation is the inclusion of the expected cost in the decision-making of the individual. If the individual cannot assign a situation specific estimate to the risks faced what would he/she do as a basis for choosing their actions?

We see this as a normal Bayesian problem. A rational individual will form prior expectations based on experience and norms and use these to make decisions. When the individual has specific knowledge about the particular situation they will incorporate it in their decision process, to form a posterior risk distribution, and use this as the foundation for their decision. This basis then effectively defines the boundary of internalisation/ externalisation as it can be used to establish the extent the individual took account of the risks that were in place.

[6] This is obviously a first order approximation; in practice, the traffic volumes present around the area of the failure will affect the impact it has on the way traffic flows.

One of the factors to be taken into the calculation is the institutional setting. For the road user the road code sets a minimum standard of behaviour that if obeyed reduces the risks inflicted by other users to a very token amount. In the real world, of course not every driver or user obeys the code at all times. But the effect of the institutional structure is to provide a basic risk estimation framework. The individual then populates this with their own assessment of the likelihood of other users conforming to their obligations under the code and thus as a rational agent form their expectations. These drive the boundary between their internalised and externalised costs.

Under a normal set of assumptions, then, the division between internalised and external costs is structured by calling all those which are consciously included in the decision as "internal" and all those not so covered as "external".

On the other hand if the person was not aware of the risk, or was not in a healthy mental state to make a rational decision, then we cannot say that the risk was internalised. This, however, does not mean it is an externality of driving, but we can say that it is an external cost to society. The same argument applies to vehicle drivers as well. When a drunk driver decides to drive and fails to follow the Road Code, most of the cost of an accident is external cost. A large part (if not all) of the social cost of injuries and property damage suffered by the driver is unlikely to be internalised.

This suggests that not all costs are ex-ante internalised, though they are suffered by those responsible for them when an accident occurs.

So to take as an example a common experience: the effect of the unknown road user who is sharing the highway. if we assume the normal driver can reasonably work on the assumption that other users are, at the least, highly likely to be obeying the Road Code. Risks are thus largely internalised under this view of the other driver's likely behaviour.

Consider the risk of an accident involving a car and a pedestrian or a cyclist. If both road users have taken all necessary care normally expected, then a large part of the cost of injuries to the pedestrian is an external cost assuming that is not considered by the driver. However, if an accident occurs due to risk-taking behaviour of a pedestrian or a cyclist, whose behaviour is the main contributing factor in the accident, i.e., the risk taken (the decision made) was outside the domain of normal behaviour of a rational road user, then at least part of the cost of injuries should be considered as internalised by them. It should be 100% internalised if they were aware of the risk.

While, on the other hand, anyone whose behaviour blatantly violates that assumption is imposing an externality not taken fully into account by the normal user.

The above discussion is developed further below.

A clear distinction can be made between private and public transport. In public transport modes, usually the risk of a crash is relatively small and the passengers have no direct experience nor control of the risk taking behaviour of the driver. We briefly present the link between various actors and their risks in the diagram below (Figure 6).

Here we assume that for public transport, each passenger considers the low risk of a crash under the expectation that the driver will take necessary precautions and will not take any undue risks. Thus the cost internalised by a passenger is small. Also, a passenger's contribution to risk of a crash is negligible in most circumstances[7]. We can examine the way the different 'players', the driver, the operator and the passengers may interact.

For private transport, things are more complex. There are many factors that impinge on way the costs have been taken into account. So cost internalisation by the passengers may depend on their understanding of the driver's ability and risk taking attitude, as well as on their assumptions about the safety quality of the vehicle. If the risk is known and acceptable to passengers, then the risk to passengers is internalised. In some cases, passengers may not accept the risk but are unable to avoid the ride – members of a family, for example. In such cases, driver may be internalising some or all of the passenger associated risk to himself/herself, or may not. We suspect that the 'family members as passengers' case is one where the driver is likely to be taking into account the fact that there are others in the vehicle into account in decisions (internalising them); this would then affect the degree of caution exercised at an intersection, for example. But any costs not internalised are externalities.

4.2.2 Recommendations

Accidents can occur due to natural causes, i.e., without any road user violating the Road Code. However, many accidents (perhaps most) occur due to some risky behaviour of road users. In estimating internal and external (social) costs, it would be better to treat these two cases separately.

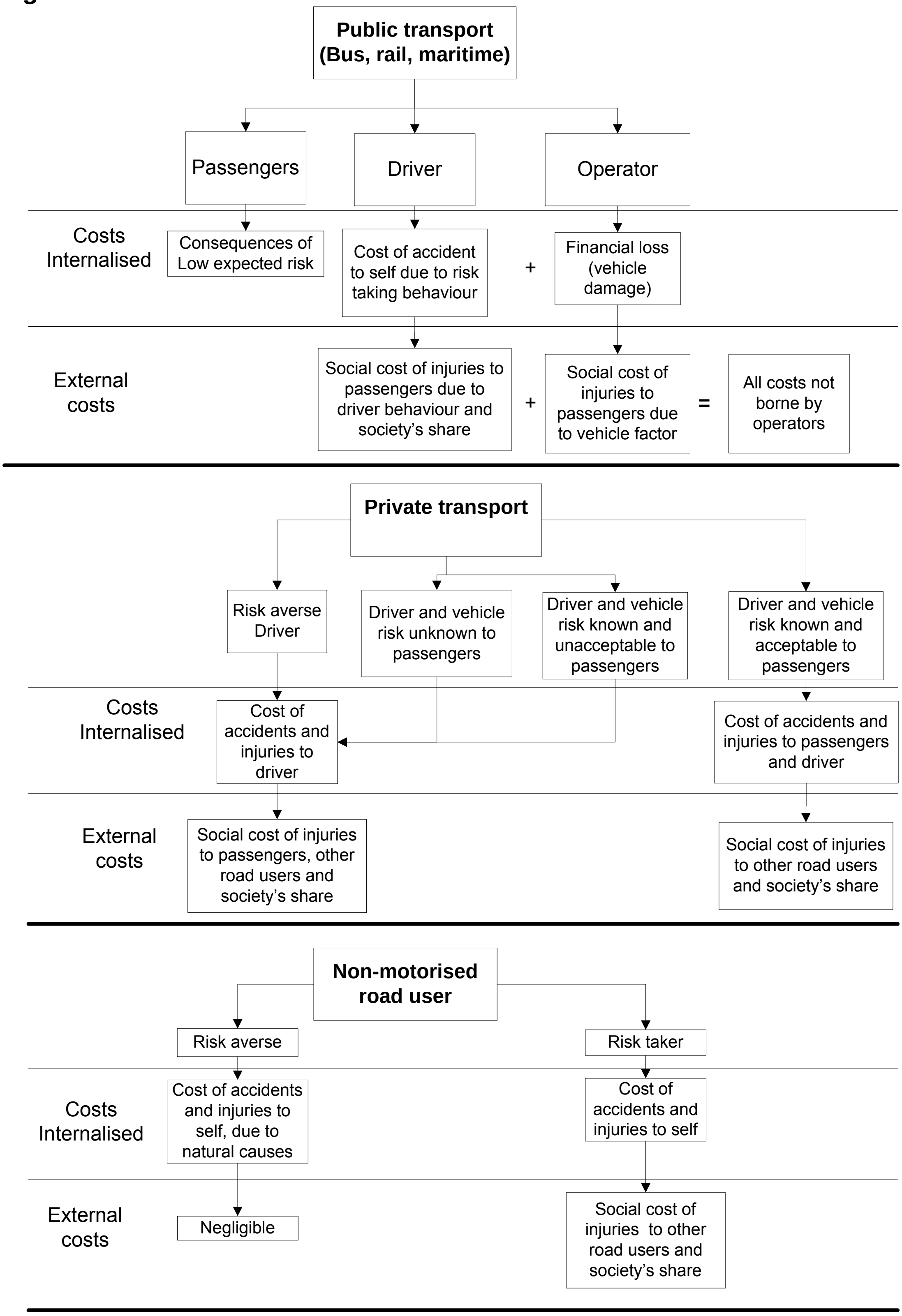
a) Natural causes

Assuming that road users are aware of the risk of crashes and injuries, they collectively internalise the costs, except part of the social cost incurred by society as a whole.

For single vehicle crashes, all except the society's part is internalised.

[7] Unless of course the passenger behaves unsuitably, so as to perhaps distract the driver or, worse, has a motive of creating a disaster, as in the case of a terrorist.

Figure 6 Internalised and external costs of accidents



Source: NZIER

For multiple vehicle crashes, studies indicate the loss to each vehicle depend on difference in masses of those vehicles. For two vehicles, say A and B, the damage to B is the external cost of A's driving and vice versa. Jansson (1994) and McInnes Group (1994) derive mathematically the marginal costs of a crash and then subtracts the cost internalised as the expected cost of an average risk to the vehicle and its occupants.

For each such accident, we can estimate the social cost of the accident. We can also estimate the share of society as a whole of this social cost. The rest of the social cost is suffered by vehicle occupants. The society's part of the social cost is the external cost. However, in a multiple vehicle accident, the cost to each vehicle is the external cost of other vehicles. Since each vehicle internalises the cost to themselves, the net external cost should be small. In this case, the total and average costs of accidents should be considered for policy development.

b) Human or vehicle factors

Accidents can occur due to risky behaviour of some other road users (other vehicles, pedestrians, cyclists). In such cases, the costs of such accidents minus the cost suffered by the risk takers should be treated as external costs of those risky behaviours. This holds for private transport as well. In our view all components of social costs should be treated in the same manner. This is in contrast to the approach taken by Parry (2004).

A major problem attributing internal and external costs in private passenger transport is determination of the level of risks internalised by the driver and passengers related to risks of accidents.

Accident risks are integral parts of road transport (in fact for any transport). Road Codes are developed to minimise the risks and the number of accidents would be considerably lower if all road users followed the Road Codes. While network safety improvement does reduce the risk of crashes, it is the risk taking behaviour of road users which is responsible for most accidents for a given road network.

It would be logical to assume that the risk of an accident, without any violation of the Road Code, is internalised by the driver and passengers. While in some cases, the consequence of risky behaviour of the driver is understood and acceptable to the passengers, in many cases it is not so. In the first case, the additional risk is internalised. However, in the second case all costs of injuries to passengers and other road users are external costs. How much is internalised may also vary from one society to another. One way to find the degree of internalisation in New Zealand would be to conduct a survey or include a question with other traffic surveys to determine the level of internalisation of such risks. In absence of the this information, estimates can be obtained varying the level of risks internalised (0%, 50%, 100% for example).

As far as costs suffered by other road users are concerned, these should be considered external costs if the driver or the vehicle is at violation of the Road Code.

Even though pedestrians and cyclists suffer most in accidents with a motor vehicle, cost internalisation should follow the same tests. That is if the accident is primarily due to the risk taking behaviour of a pedestrian or cyclist, then the cost suffered by themselves of that accident should be considered internalised by them.

4.3 Rail and maritime accidents

The internalisation process works in similar manner as discussed for public transport. The individual or the operator who is taking additional risk, causes external costs to others.

4.3.1 Recommendations

For rail outside level crossing, the all costs not borne by the rail operator is the external cost of rail accidents.

For rail level crossing, the external cost is determined by the risk taking behaviour of rail operator and vehicle traffic. If the accident is due to factors such as non-maintenance of clear vision or warning sound, light or barrier as expected, then the cost to all passengers and road traffic as well as the cost to society are external cost. On the other hand, if the accident is due to the risk taking behaviour of the road user, then all costs, other than those suffered by the road user, are the external costs of the road operator's travel and risk taking behaviour.

For maritime, if an accident occurs due to natural causes, then the risk is mostly internalised except the part falls on the society as a whole, unless the maritime operator fails to provide the facilities that are expected from the operation. In the second case, the cost due to that failure is the external cost.

4.4 Pollution

Recommendation: The cost internalised is negligible. So all pollution costs (associated with emissions and noise etc for all the three modes) should be counted as external costs.

4.5 Summary

The factors to be considered for estimating costs internalised and external costs are summarised in Table 1.

Table 1 Summary of internalised and external costs

Mode		Effects	Costs internalised	External costs
All modes		Pollution	Negligible	All costs of pollution
Road	Private vehicles	Congestion	Excess vehicle operation costs and cost of time delay to all occupants of the vehicle	Excess vehicle operation costs and cost of time delay to other vehicle occupants
		Accident	a. Cost of accidents suffered by the driver (i.e., driver does not take into account the risks to passengers)	Cost of damages and injuries to others and society's share of the cost of driver's injuries
			b. Cost of accidents suffered by the driver and part of the cost of injuries suffered by passengers	Rest of the cost of accidents
	Pedestrians and cyclists	Accident	Costs suffered by themselves due to accidents caused by natural causes (expected to be small) and their own risk-taking behaviour	All other costs of accident
	Public transport	Congestion	Excess vehicle operation costs and cost of time delay to all occupants	Excess vehicle operation costs and cost of time delay to other vehicle occupants
		Accident	Cost of accidents due to natural causes minus the cost borne by society	Cost of accidents due to natural causes borne by society
			Cost of accidents due to driver or vehicle factor minus the cost borne by society	All other costs of accidents
Rail		Congestion	Cost of rescheduling when there is capacity constraint	Cost of delay and inconvenience to passengers, if any.
		Accident	Same as in road public transport	Cost of accident risks due to driver or system fault
Maritime		Congestion	Cost of delay in loading and unloading at a port	Cost of delay to all other ships waiting for service
		Accident	Ship: Cost of accidents (due to natural causes) to the vessel and passengers minus the cost borne by society	
			Cost of damage to the ship and its property due to risk taking behaviour of the ship	All other costs
			Port: Negligible	All costs are external costs

Source: NZIER

5. Next step

In this report we have discussed methodologies for identifying and estimating external costs. To what extent the external costs should be disaggregated will depend on the purpose of determining the externalities.

While marginal social cost of congestion, for example, is an important factor for determining the optimal congestion price, there are other factors that should be considered to determine the impact of a congestion tax. It would depend on the distribution of value of time of vehicle users at that time and the availability of alternative routes or systems such as public transport. If there are no suitable alternatives, the demand for travel by road during the peak hours may be highly inelastic and a congestion tax may not have much impact on the level of congestion. Therefore, it is necessary to study the inter-linkage between these factors.

As far as pollution is concerned, it is the total pollution cost and its valuation, that should be of interest as most of these are external costs. The internalisation policy needs to find out the impact of that policy on the total pollution level as the health effect of pollution depends on the total pollution level, not just the amount emitted by transport.

Depending on the level of pollution and the composition of it, the health effects can vary from loss of life to chronic diseases with lingering effects over time. It is necessary to understand this and also develop a methodology for estimating the social costs of these outcomes. The social cost of pollution includes loss of life as well as loss of life quality. For economic evaluation of any intervention, it is necessary to develop tools for determining the value of loss of life quality. One important factor, in this context, is the value per quality adjusted life year saved, as chronic diseases may not only reduce the life span but also reduce the quality of life.

Accidents, particularly road accidents, occur mostly due to driver behaviour, i.e., risk taking behaviour of drivers and other road users for a given network. The variation in risk taken by road users is an important factor in the development of a policy to internalise the external costs.

As we have discussed earlier, there is uncertainty on the extent to which drivers take into account the risks they impose on their passengers when they take additional risks. This is an important factor in the determination of externalities. Therefore, it is necessary to determine the level of passengers' risk taken into consideration in drivers' risk taking behaviour.

Uncertainties also exist on the level of risk internalised by passengers in public transport. Studies should be carried out to determine the level of risks internalised.

6. References

AAA Foundation for Traffic Safety (1999). *Did You Know? Congestion and Crashes*. http://www.aaafoundation.org/pdf/congest.pdf .

Banfi, S., Doll, C., Maibach, M., Rothengatter, W., Schenkel, P., Sieber, N and Zuber, J. (2000). *External Costs of Transport: Accident, Environmental and Congestion Costs in Western Europe*. INFRAS/IWW, Zürich/Karlsruhe.

Baumol, W. J and Oates, W. E (1988). *The Theory of Environmental Policy*. Cambridge University Press, Cambridge, UK.

Dasgupta, P. (2007). *Discounting Climate Change.* University of Cambridge. http://www.econ.cam.ac.uk/faculty/dasgupta/pub07/stavins_june07.pdf

Delucchi, M. A. (2000). Environmental externalities of motor-vehicle use in the US. *Journal of Transport Economics and Policy*, 34(2), 135-168.

Edlin, A. S. and Mandic, P. K. (2006). The accident externality from driving. *Journal of Political Economy*, 114(5), 931-955.

Greenwald, B. E. and Stiglitz, J. E. (1986). Externalities in economies with imperfect information and incomplete markets. *Quarterly Journal of Economics*, 101(2), 229-264.

Guria, J. C. (1986). Traffic flow control for backward bending costs curves. *International Journal of Transport Economics*, 13(3), 331-350.

Jansson, J. W. (1994). Accident externality charges. *Journal of Transport Economics and Policy*, 28(1), 31-43.

Kinzel, C. D. (2007). Managing congestion through improved land use planning. *ITE Journal*, 77(7), 32-39.

Lemp, J. D. and Kockelman, K. M. (2008). Quantifying the external costs of vehicle use: evidence from America's top-selling light-duty models. *Transportation Research, Part D*, 13(8), 491-504.

Maddison, D., Pearce, D., Johansson, O., Calthrop, E., Litman, T. and Verhoef, E., 1996. *The True Costs of Road Transport*. Earthscan Publications Limited, London.

Mattiacci, G. D. and Parisi, F. (2006). *The Economics of Tort Law: A Précis*. George Mason University Law and Economics Research Paper No. 03-49, published in *The Elgar Companion To Law and Economics* (2nd ed.), Edward Elgar Publishing, Available at http://ssrn.com/abstract=458701.

Mayeres, S., Proost, D. V., De Nocker, L., Int Panis, G. W. and De Borger, B. (2001). *The External Costs of Transportation: Final Report*. Center for Economic Studies.

McCubbin, D. R. and Delucchi, M. A. (1999). The health costs of motor-vehicle-related air pollution. *Journal of Transport Economics and Policy*, 33(3), 253-286.

Maibach, M., Schreyer, C., Sutter, D., van Essen, C. D., Boon, B. H., Smokers, R., Schroten, A., Doll, C., Pawlowska, B. and Bak, M. (2008). *Handbook on estimation of external costs in the transport sector*, Produced within the study Internalisation Measures and Policies for All external Cost of Transport (IMPACT), Version 1.1., CE Delft.

McInnes Group (1994). *Safety Externalities in Land Transport*. Report to New Zealand Ministry of Transport, Wellington.

Ministry of Economic Development (2007). New Zealand Energy Greenhouse Gas Report 1990-2006. Wellington

Ministry of Transport (2008). The Social Cost of Road Crashes and Injuries: June 2008 update. Wellington.

Newbery, D. M. (1990). Pricing and congestion: economic principles relevant to pricing roads. *Oxford Review of Economic Policy*, 6(2), 22-38.

Noland, R. B. and Quddus, M. A. (2004). A spatially disaggregate analysis of road casualties in England. *Accident Analysis and Prevention,* 36(6), 973-984.

Parry, I. W. H.(2004). Comparing alternative policies to reduce accidents. *Journal of Urban Economics*, 56, 346-368.

Parry, I. W. H., Walls, M. and Harrington, W. (2007). Automobile externalities and policies. *Journal of Economic Literature*, 45(2), 337-399.

Persson, U. and Ödegaard, K. (1995). External cost estimates of road traffic accidents. *Journal of Transport Economics and Policy*, 29(3), 291-304..

Piecyk, M. and McKinnon, A. C. (2007). *Internalising the external cost in road freight transport in the UK*. Heriot-Watt University, Edinburgh.

Small, K. A. and Chu, X. (2003). Hypercongestion. *Journal of Transport Economics and Policy*, 37(3), 319-352.

Small, K. A. and Kazimi, C. (1995). On the costs of air pollution from motor vehicles. *Journal of Transport Economics and Policy*, 29(1), 7-32.

Stern, N. H. (2006). *The Stern Review of the Economics of Climate Change*. Cambridge: Cambridge University Press.

Stubbs, P. C., Tyson, W. J. and Dalvi, M. Q. (1980). *Transport Economics*. London, George, Allen & Unwin.

Tsolakis, D., Houghton, N., Lester, C. and Seethaler, R. (2003). *Valuing Environmental and Other Externalities*. Austroads Inc. Sydney.

Vickrey, W. (1968). Automobile accidents, tort law, externalities, and insurance: an economist's critique. *Law and Contemporary Problems*, 33(3), 464-487.

Walters, A. A. (1961). The theory and management of private and social cost of highway congestion. *Econometrica*, 29(4), 676-699.

Weisbrod, G., Vary, D. and Treyz, G. (2001). *Economic Implications of Congestion*. Transportation Research Board – National Research Council, Washington, D.C.

Weitzman, M. L. (2007). The Stern Review of the Economics of Climate Change. Book Review. *Journal of Economic Literature* 45(3), 703–724.

Zhou, M and Sisiopiku, V. P. (1997). *On the relationship between volume to capacity ratios and accident rates*. Presented at the TRB Annual Meeting January 12-16, 1997. Sponsored by Michigan Department of Transportation and the Michigan State University Department of Civil and Environmental Engineering.

Appendix A Mathematical explanation

The cost of travel includes vehicle operation cost and the costs of three externality factors we are discussing here: congestion, pollution and accidents. We will first develop the cost structure and then discuss the cost internalisation issues.

The vehicle operating cost per unit of travel in the absence of congestion does not vary with the level of travel. Fuel consumption per unit of travel may increase with congestion. At this point the vehicle operating cost per unit of travel increases.

When there is no congestion, the cost of travel time and operating costs are fully internalised, i.e., there is no external cost since a person's travel does not impose any of these costs on others. Congestion causes additional costs. The cost per unit of travel includes

- cost of time and vehicle operation
- pollution effect
- cost of accidents

Cost of time and vehicle operation

The cost of time and vehicle operation can be expressed as a function of Q – traffic volume; $V(Q) = C_0Q + CC(Q)$, where C_0 is the constant cost per km of travel when speed is not reduced by traffic density. When speed is lower than the free flow speed (say S_0) then congestion occurs. CC(Q) – a function of travel volume, is the total additional cost of time and vehicle operating cost.

Pollution effect

The cost of pollution mainly depends on fuel consumption. For simplicity let us express the pollution cost as P(Q) i.e., a function of Q. In practice there are complications. All vehicles do not have the same level of fuel consumption. Vehicles with higher fuel consumption obviously contribute more to pollution effect.

Accident cost

Accident cost is a complex issue. The total number of accidents increases with Q at least up to a certain level. As congestion builds up and speed reduces, the severity of accidents is reduced. On non-congested road, the cost may increase more than proportionately. Let us express the cost of accident as a function of Q, A = A(Q) now and then we will introduce other factors to identify costs internalised.

Total cost

The total cost which has an effect on the externalities can be expressed as

$$TC(Q) = CC(Q) + P(Q) + A(Q)$$

The Average cost can simply be expressed as

$$AVC = \frac{CC(Q) + P(Q) + A(Q)}{Q}.$$

The average congestion cost here is the average additional cost of time and vehicle operation due to congestion. P(Q) and A(Q) also contains elements of congestion costs. The pollution cost increases with congestion as that results in more fuel consumption per unit of travel. Accident costs may or may not increase with congestion. Beyond a certain level the average accident cost may even be lower following an inverted U shape (Zhou and Sisiopiku 1997, Noland and Quddus 2004).

We can now divide the total travel volume between those during congestion time and other times. Even though congestion occurs beyond a certain level of traffic at particular point on the network, for simplicity we assume that a certain proportion of total traffic occurs during congestion time or peak hours, to estimate the pollution and accident costs.

Thus $Q = Q_1 + Q_2$ and $Q_2 = \alpha Q$ and $Q_1 = (1-\alpha)Q$. Here we denote the level of traffic during congestion period as Q_2.

The total cost can now be written as

$$TC(Q) = CC(Q) + P_1((1-\alpha)Q)) + P_2(\alpha Q) + A_1((1-\alpha)Q)) + A_2(\alpha Q)$$

Where P_1 and P_2 are pollution functions for normal traffic and for congestion traffic respectively. Similarly, A_1 and A_2 are accident cost functions for normal and congestion traffic respectively.

Marginal costs

We can now write the total marginal cost as

$$\frac{\partial TC}{\partial Q} = \frac{\partial CC}{\partial Q} + (1-\alpha)\frac{\partial P_1}{\partial Q_1} + \alpha\frac{\partial P_2}{\partial Q_2} + (1-\alpha)\frac{\partial A_1}{\partial Q_1} + \alpha\frac{\partial A_2}{\partial Q_2}$$

While it is expected that $\frac{\partial P_2}{\partial Q_2} \geq \frac{\partial P_1}{\partial Q_1}$, the relationship between $\frac{\partial A_1}{\partial Q_1}$ and $\frac{\partial A_2}{\partial Q_2}$ is not straightforward. $\frac{\partial CC}{\partial Q}$ = 0, up to a certain level of traffic density. As we have discussed in the main report, social cost may decrease beyond a certain level of congestion.

There is one more complication for accident externalities. As we have discussed earlier, risks of accidents vary with individual road users. Some take additional risk beyond what is expected from following the Road Code. The marginal costs are higher for both during congested and non-congested periods for such road users. It is particularly higher in normal traffic, as the scope of taking risk may reduce when congestion builds up. Most studies do not differentiate between risk averse and risk taker road users in the estimation of external costs. In our view it is an important issue for accident externalities and while using external cost estimates in policy development.

For this let us divide the total travel level Q into Q_A and Q_T, where Q_A is the risk averse travel and Q_T is the risk taking travel. Now we can write accidents during these travels as A_A and A_T respectively. A problem with this approach is that Q_A and Q_T are not known and will be difficult to estimate. These would be necessary to estimate the marginal costs.