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Literature review

Road use charging & cost allocation

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Preface

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Executive Summary

This report presents a review of literature on cost allocation and charging for road use, prepared at NZIER for the Road User Charges Review Group. It includes:

- An outline of latest thinking on the theory of road funding and charging;
- A summary of the practical experience of different types of road charging and cost allocation in use;
- Identification of alternative systems that are likely prospects and the barriers to implementation in the near future;
- Identification of the approaches that appear most closely applicable and adaptable to New Zealand.

The literature search uncovered a wide diversity of literature. There was relatively little on road cost allocation, mostly from Australia and USA which use road cost allocation models with similarities to that used in New Zealand, but some distinct differences in detail. It also found a burgeoning international literature on road charging mechanisms, much of it technology-led and aimed at problems which are either less significant in New Zealand or outside the scope of the current National Land Transport Programme, which covers principally road maintenance, construction and safety programmes. These dominant motivators included:

- Congestion charging;
- Recovering revenue from foreign trucks in transit;
- Reducing the environmental impact of heavy vehicles;
- Inter-operability of proprietary technologies.

Such examples are nevertheless useful in demonstrating what approaches have been used for particular problems, how well they have worked, and what are the underlying factors affecting their performance.

The theory behind cost allocation and charging

The theory of road cost allocation and charging has not changed substantially over recent years. The efficient way of pricing roads would be to charge users the marginal social costs of their use, but this is difficult to do and does not ensure revenues from such charges would cover the full costs of road provision. In practice, highway agencies are constrained by cost recovery requirements and employ sub-optimal second or third best arrangements which cover only some of the externalities of road use: mostly road maintenance and construction costs, some safety and environmental costs and very little congestion costs.

What has changed is scientific understanding and technological capabilities which potentially allow more accurate measurement and charging of more of the full costs of road use. This could move charging closer to marginal cost based pricing,

rather than current practice of basing charges on average costs. There are potential efficiency gains from widening the scope of costs covered by road use charges.

Current practice

On cost allocation, New Zealand has a similar model to that in Australia and in the USA, and there are elements of similar approaches detected in European systems, which utilise various axle load/road-wear power relationships and variously attribute different types of cost to vehicle axle loadings, gross weight and related measures.

On road charging, there has been until recently widespread uniformity on the form of charging – fuel taxes plus a vehicle excise tax or registration fee differentiated by characteristics of the vehicle. New Zealand's Road User Charges are unique.

But recently special charges on heavy vehicles using electronic location and fee collection systems have been implemented in Switzerland, Austria, Germany and the Czech Republic, with others planned in Sweden, Hungary and Slovakia. There have also been numerous approaches to urban congestion charging, ranging from revenue-raising toll rings in Norway to the use-detering congestion charges in London and Singapore. There have also been trials in cities ranging from Stockholm to Portland, Oregon. Much of this literature has a focus on the characteristics of the different technologies emerging for these purposes.

Prospects

The literature warms to the prospect of a range of technologies becoming more cost effective in future for a range of potential uses. Broadly these are:

- Vehicle mounted tachometers for measuring distance-only travelled;
- Gantry mounted terrestrial detectors recording and identifying vehicles using or entering a defined area;
- Wide area tracking systems employing satellite GPS or cellular technologies, with potential to measure distance, weight and other parameters.

There are varied assessments of the accuracy and effectiveness of different approaches, and some evidence from schemes already in place. Satellite based systems are touted as the likely ultimate system, but there are still doubts about their cost and reliability in covering all areas.

For New Zealand, the usefulness of these approaches depends on the definition of the problem being addressed. Different approaches are suitable to different problem areas. There are various competing proprietary systems with interoperability incompatibilities, and there may be value in waiting until a clearer picture of the industry standard emerges. Proprietary GPS devices that firms already use for logistical purposes could verify distance travelled on particular roads. But this is less than electronic Road User Charges, for which road use must be matched with information on loads and cost impacts on different types of road.

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1. Introduction

This report presents a review of literature on cost allocation and charging for road use, prepared at NZIER for the Road User Charges Review Group. It is intended to outline latest thinking on the theory of road funding and charging, provide a summary of the practical experience of different types of road charging and cost allocation in use elsewhere around the world, identify alternative systems that are likely prospects and barriers to their implementation in the near future, and identify the approaches that appear most closely applicable and adaptable to New Zealand.

The scope of the literature review covers:

- Only activities covered by the National Land Transport Programme – provision and maintenance of roads, safety services and cross-funding of alternative modes
- Economic theory on efficiency and equity with respect to:
 - Charging mechanisms applicable to road use
 - Cost allocation between different users of shared road networks
- Practical experience of different types of road charging and cost allocation in use:
 - How do other countries charge for road use and allocate road costs between users?
 - Why have they chosen the methods that they use?
 - What problems have arisen with these methods, and what are the pressures for further change or improvement?
- Prospects for implementation of improved methods:
 - What methods are being considered in other countries, and why?
 - What are the barriers to implementation (technical, economic etc) and how likely are they to be overcome?

The literature review has proceeded with a library and web-based search of published documentation addressing the forms of road cost allocation and road use charging currently in practice or being considered for use. From an initial range of sources further leads have then been followed up to build up a picture of which countries are being innovative in their approach to road, cost allocation and charging, and why they have chosen the particular route they are following.

The search uncovered an extensive literature on road pricing and road use charging, much of it rather technology-driven in describing new approaches to charging vehicles for their use of public roads. There is rather less about road cost allocation, at least in English language publications, which implies that this is not where the main efforts are being directed in these other countries. Much of the

literature reflects preoccupations of the particular country which may not include cost allocation or the structure of road use charges. Directing specific questions to the ministries of transport or road controlling authorities in those countries could yield information to fill in the gaps in coverage, but that has not been done as part of this literature review.

This review proceeds by outlining principles for road cost allocation and charging, surveying the practice of cost allocation and charging in other countries around the world, examining the prospects for new mechanisms for cost allocation and charging, and concludes with an assessment of the most feasible approaches for consideration for adapting to New Zealand's conditions.

2. Principles of road cost allocation and charging

A crucial question underlying the current review of cost allocation and road user charges is “how to pay for the road system?”. A further question underlying that is “what are the costs of the road system?”. Road use costs comprise a number of private costs borne by the vehicle owner, and a series of costs external to the road user – road-wear, congestion, accident risk and environmental damage. Private costs can be left to vehicle owners to determine how to manage them, but external costs need to be recovered through charges from road users if they are to face the full marginal cost of their road use decisions, and achieve an economically efficient level of road use.

The costs directly related to the use of roads by vehicles have a number of distinct components, which can be categorised according to who bears them in the first instance. These are:

- Road user's own private costs of vehicular use, including fuel, operations and maintenance, travel-related depreciation, travel time costs, insurance premiums and claim excesses and a portion of crash costs not covered by insurance (particularly loss of life and life quality), all vary with the quantity and frequency of road use and trips (this includes insurance claims and crash costs, for although insurance premiums are commonly regarded as fixed costs per period covered, the expected value of accidental damage requiring claims to be made will vary with exposure to accident risk and the level of use made of the roads);
- Costs to other road users, principally congestion costs, delays and associated vehicle operating cost, and a portion of crash costs not covered by insurance;
- Costs to the wider community, including externality effects such as emissions, noise, vibration, visual intrusion and other effects on the environment, and a portion of crash costs not covered by insurance (e.g. increased use of emergency services and public health systems);
- Costs to the road agency, including infrastructure construction, maintenance and rehabilitation, traffic control and management.

The costs to other road users, road agencies and the community that are borne by those other than those who create them are termed external costs (or negative externalities). The externality view of road costs is well established in the literature, although there is some variation among authors as to the definitions of the different externalities (Maddison et al 1996).

A function for road charging and pricing is to internalise these external costs in a reasonable way which confronts road users with the full cost of their road use i.e. the marginal social cost of their road use. However, the true marginal social cost of a vehicle using the road varies with the type of vehicle and with the characteristics of the road, and there are high transaction costs in both establishing the full cost of road use for different vehicles and in translating these into a pricing device that enables road users to make decisions about their transport choices that are economically efficient. Road use charge mechanisms are generally not precise, reflecting only a portion of the external costs of road use and being based on total or average costs with limited differentiation between vehicle types and road characteristics.

Charging for road use by marginal cost is complex and has drawbacks. As networks, roads tend to have high fixed costs in installation and low marginal costs of use, so charging by marginal cost is unlikely to yield the revenue to recover the roads' total costs. A second issue is what counts towards the marginal cost? Many of the externalities are difficult to measure or to attribute precisely to varying units of road use, so in the past they have tended to be either ignored or dealt with indirectly through regulations or standards. Road agencies focus on the resource costs of repairing road-wear and other operational and maintenance activities on the road network, as failure to recover these costs has budgetary implications that impinge on their ability to keep the road network operational. But much of the current literature, particularly from Europe, reveals an intent to broaden the scope of road costs to be charged to road users, with explicit accounting for the costs of road-related externalities.

Another issue with road charging is how to collect the charges from vehicles without inordinately slowing the flow of traffic and defeating the purpose of having a road network. If traffic is light and slow and labour costs are low it may be feasible to have toll gates and turnpikes collecting fees manually for travel along sections of road, but as traffic volumes increase this becomes increasingly difficult to justify because of the high costs of the collection process in terms of the time cost of delay imposed on vehicles. Because of this, most roads have been provided as if they are public goods, with no direct charging in proportion to use. To the extent that users have been charged it has usually been indirectly through taxes on vehicle ownership, such as vehicle licence fees, and on vehicle use through fuel tax.

This conventional approach to road use charging is under siege, because of the growing pressures being placed on road networks by increasing vehicle ownership and use. Moreover, increasingly sophisticated technology is raising the prospect

of both more accurate measurement of effects from vehicles' use of the roads, and also of being able to translate this to charge mechanisms that do not impede the flow of traffic. The prospect is for charges to become more direct, more accurate, and less disruptive in their collection.

2.1 Theory of costs and charging

2.1.1 General principles for efficiency

There is an extensive and well-established body of economic theory about how to provide roads, but translating this into practice depends on how the problem is being defined and what objectives are of a cost allocation and charge system. The problem may be viewed in terms of how to pay to maintain roads in their current condition in face of increasing use and changing demands; how to improve roads to a more optimal configuration; how to achieve efficient choices in transport, both within road use by redistributing use between costly peaks and cheaper off-peak periods, and also choices between transport modes; or how to achieve a fair level of access to the mobility conferred by road at reasonable cost. Much of the literature implicitly focuses on how to pay for maintaining the road network, but some also looks at efficiency in the wider sense of accounting for externalities.

Efficient provision is difficult in practice so actual provision falls into the realm of second best and third best approaches. What systems are chosen depend on the objectives adopted: if cost recovery is paramount, first best efficiency may not be possible. Beyond this, the two crucial questions that this review should inform are, "how can the costs of the road system be allocated across their mix of users" and "what mechanisms can be practically implemented to charge users the costs they impose on the network"?

Most of the theory on road pricing is not new and has not substantially changed since it was articulated nearly 50 years ago in pioneering papers on road pricing (Walters 1961, Walters 1968). That the theory has not been put into practice since then is due partly to the transaction costs being prohibitively high, given the state of available technology. It is also due to some fundamental characteristics of road networks. They are a form of network infrastructure that are shared by a variety of vehicle types which put different demands on the network, and so impose different costs on it.

Marginal cost pricing is the undisputed mechanism to ensure the most rational and economically efficient allocation of infrastructure resources between projects and between modes (Austroads 2007). Toll charging can also be used to avoid the opportunity cost incurred when lack of public funds delays completion of necessary enhancements to the road infrastructure.

However considering only the resource costs of providing and maintaining roads, the efficient price for road use, based on the marginal cost of use, is unlikely to recover the full cost of the road network. The objectives of economic efficiency

and cost recovery are not strictly compatible. This leaves road supplying authorities the choice of either recovering their costs by charging more than the efficient price, which may deter some use that could be accommodated on the network; or else not recovering their full costs from use charges and making up the deficit from some other source (e.g. fixed entry fees and licences, general taxes). The principles to employ to get around this are:

- Road prices should not be less than the marginal cost a vehicle imposes on the network
- If there is a shortage of capacity on the roads, prices can rise above marginal cost to find the price at which the market clears
- If the above principles do not yield sufficient revenues to cover full costs, apply discriminatory prices with the greatest prices applied to the least price-sensitive users.

This last point is an application of Ramsey Principles, which is not an economically optimal pricing strategy, but the “second best” pricing strategy that will minimise the distortions and maximise efficiency of a pricing regime constrained to recover its costs.

2.1.2 “Second best” approaches to charging

The marginal cost for socially efficient pricing is the short run marginal cost, i.e. the incremental effect of a vehicle’s trip on the road assuming road condition stays unchanged. In other words, the efficient price for a trip should be no less than the incremental effect of that trip on the current road network. It excludes any provision for road improvement, which is part of long run marginal cost.

The cost of retaining a road network in its current condition over its lifecycle comprises the cost of road operations and maintenance, depreciation, and return on the capital invested in the network. Against that framework, the efficient price for road use would comprise the use-related parts of operations and maintenance and depreciation costs. The rest are costs unrelated to use (such as fixed administration costs and the repair of weather-related damage), which would distort the price signal if added to marginal cost and need to be recovered in the least distorting alternative way if the road system is to break-even as efficiently as possible. Hence the use of alternative revenue mechanisms such as:

- A surcharge on the marginal cost-based price to recover the unattributable and fixed costs of the network, including:
 - Ramsey pricing, which varies the surcharge for classes of road user in inverse proportion to their price elasticity of demand for use of roads (i.e. the more price responsive the class of users, the lower the Ramsey surcharge on marginal cost-based price, so as to minimise the deterrence on these classes’ use of the roads;
 - As elasticities are often not known with precision, an alternative would be to base the surcharge on some other distinguishing feature of the user classes,

such as basing it on each user class's proportional share of vehicles, or vehicle kilometres travelled, but these are arbitrary, potentially distorting and unduly burdensome on those users who make high use of the roads but have limited ability to pay (e.g. road users in rural areas with widely dispersed settlements and businesses);

- Multi-part charges in which fixed and unattributable costs are recovered through fixed access charges (like vehicle licence fees) so use-related variable charges more closely approach short run marginal cost –similar to club charges in which membership confers rights to access facilities but actual use is subject for a further charge, such multi-part charges can be efficient and are commonly found with other network services with large installation costs and low marginal cost of use (e.g. electricity and telecommunications);
- Recourse to revenue external to the pool of road users, such as general taxation.¹

Ramsey pricing can be applied to multi-part charges, by differentiating between vehicle classes according to their willingness to pay for access to the network and variations in their price sensitivity. With knowledge of the relative elasticities of demand for access and demand for use, in principle it is possible to spread the surcharge across both access and use charges as well as across user classes, although in practice elasticities are not well known.

However, whether applied to unitary or multi-part charges, Ramsey Pricing is second best, not first best optimality, which would charge at short run marginal cost. Second best pricing is necessary if the road agency is required to cover its costs, including fixed costs unattributable to individual vehicle classes' use of the roads. Then Ramsey pricing is the least distorting and most efficient means of recovering those unattributable costs. It has the effect of collecting most per unit use from those willing to pay most (i.e. the least price sensitive users). Put another way, under Ramsey pricing people with steeper demand curves pay more, as they consider the benefit of their consumption at a given level so much that they are unwilling to reduce the consumption unless the price becomes considerably higher. So the value of the product is higher to them at their consumption level than those who have higher demand elasticity. Whether Ramsey pricing is fair is a matter of opinion and economics has no decisive view on its distributional outcome. But loading the costs onto those prepared to pay most is arguably fairer than alternative ways of distributing these cost surcharges (such as by vehicle kilometres travelled), or than spreading them across tax-payers in a manner which bears no relation to individual tax-payers' use of the roads.

¹ Note that private companies have to recover their costs to stay in business but are not constrained to pricing in a socially efficient way, so they may load their fixed costs into road charges. This raises their prices but also gives incentive to find efficiencies elsewhere in their operation, unless they are in a monopoly position. Social efficiency is more relevant to public roads, which have recourse to various forms of tax funding to cover deficits that cannot be recovered in a less distorting manner.

2.1.3 Practical implications

Marginal cost pricing is data intensive and depends on complex models and assumptions about road use and wear relationships on different types of road which make it difficult to apply. The above principles remain theoretical and are impractical in the absence of the technologies to calculate marginal costs and translate these into prices that road users can act on. In such circumstances a system known as Pay As You Go (PAYGO) pricing has emerged in use in New Zealand and various other countries (including Australia, Germany, UK and USA). This sets the charges for road use in order to recover the current expenditures on road maintenance and construction, rather than calculating costs. This turns out to be a reasonable approximation of the revenues that need to be recovered to maintain the road network in a constant condition (Newbery 1990).

Annual road expenditure is a reasonable approximation of the annualised financial costs of road provision in any period (the costs of providing the existing road network smoothed over its useful life) under the following conditions:

- The network is neither expanding nor contracting, and pavement and bridge conditions are approximately constant;
- Network-wide expenditure does not fluctuate markedly over time; and
- Traffic growth is relatively steady and covered by the rate of capital investment in road capacity enhancement (Productivity Commission 2006).

A PAYGO system does not preclude efficient investment, but road investment will not be efficient if there is traffic growth and expenditures do not keep pace with it, or there is deterioration in road condition, or choices over expenditures are poorly made (Productivity Commission 2006). As capital costs are recovered by the infrastructure provider in the period in which they are incurred, road users fund the investment, bear the opportunity cost of capital and assume the risks. Consequently although PAYGO recovers depreciation and the capital cost incurred in maintaining the roads in constant condition, it does not need to incorporate an explicit rate of return on capital in the costs it recovers, and to do so would be double counting.

The literature shows the Australian and New Zealand PAYGO systems recover costs in this way. But PAYGO can recover cost in different ways. According to Prognos (2002), in the German system investment for new construction, upgrading, replacement and maintenance is written off, but imputed interest is charged on the depreciated value of net fixed assets - i.e. it recovers the cost of capital but not the capital costs as they are incurred, so there is still no double counting. This is probably closer to the approach normally taken by businesses which aims to cover depreciation (which recovers capital cost over time) and a return on investment, but it does depend on a reliable valuation of the road network on which to charge the interest. The Land Transport Pricing Studies in the mid 1990s showed that valuation of the New Zealand road network, particularly in the local government sector, is fraught with difficulty and

incomplete information as to its extent and condition, which may explain why the current approach has prevailed in Australia and New Zealand. The Australasian and German approaches, although not identical, are similar in what they are trying to cover.

The PAYGO approach has been criticised for providing weak price signals of the costs of roads imposed by current demands (Cox 1994). Critics often advocate an optimised life-cycle approach to funding road maintenance, which would be based on direct estimates of the efficient costs of providing road infrastructure services, rather than on actual expenditures. PAYGO has also been criticised on grounds of inter-temporal equity, as current road users pay for capital improvements that will benefit others long into the future. The costs of long-lived assets could alternatively be spread across all the generations that benefit from them through debt funding. However, if current users under PAYGO are paying for future assets, they are also benefiting from assets provided by their predecessors on a similar basis, so it is not clear that there are big advantages one way or the other. PAYGO is however an approach that can be put into practice more readily than one that needs to ascertain optimal future road conditions, and it underpins the charging regimes of New Zealand, Australia, UK and USA and, to lesser extent, European countries. The relative merits of PAYGO and alternatives have been examined recently by the Productivity Commission (2006), which broadly accepted the current Australian PAYGO, and by National Transport Commission (2007).

Use of toll charges for pure infrastructure financing purposes has been a widespread activity in many countries around the world. In recent years, a significant development has been the use of tolls to facilitate new forms of road provision, such as public private partnerships (PPP) which give private operators a concession over part of the public road network, and build-own-operate-transfer (BOOT) schemes which represent semi-privatisation of part of the network. Tolls are another form of road charge that can explicitly recover the cost vehicles impose on the roads.

2.2 Approaches to cost allocation

The problem to be solved by cost allocation is to identify the costs of road use and attribute the contributions of different users to those costs, so that the cost can be incorporated into the charge for road use. As roads are large networks it is difficult to identify just where costs are incurred and what causes them, without empirical data on how costs arise and where.

There are various approaches to undertaking cost allocation. The most widely applied is the incremental method, in which a base pavement is selected which is theoretically capable of sustaining the lightest vehicle class, and vehicle classes are then added sequentially, allowing a step-by-step determination of the incremental pavement thickness required for each additional class (Prozzi et al 2007). The power relationships between road-wear and axle load determined by

the American Association of State Highway and Transportation Officials (AASHTO) are central to this process, but the method can give different results according to the order in which vehicle classes are added. Various modifications to the process have been used to reduce this variability, including approaching the process in reverse order by incrementally removing vehicle classes from the full mixed use and estimating what savings in road thickness result.

An alternative approach that is commonly used because of its ease of application is to allocate cost among vehicle classes based on some standard measure or allocator, which may be vehicle-kilometres travelled (VKT) or equivalent standard axles (ESA). Cost allocation models may also contain elements of both, for example drawing on incremental principles to distinguish load-related costs from other costs, then allocating load-related costs proportionately to ESA or ESA-km and the rest proportional to the number of vehicles.

Another variant is described by Jaarsma and van Dijk (2002), who outline an approach to financing local rural road maintenance in the Netherlands, where many rural roads serve only a few rural homesteads, and varying levels of through traffic from other areas. Their approach defines a basic road level sufficient for access to the homesteads and attributes those costs to be recovered from the local property tax; then adds incrementally the costs of additional strength and width provision needed for through traffic, to be allocated to wider road funding instruments. The system depends on robust standard estimates of the cost of different types of work on rural roads, which may be more feasible in a densely populated and flat country like the Netherlands than in New Zealand with its more varied terrain and sparsely tracked regions.

2.3 Criteria for assessing cost and charging approaches

In assessing cost allocation and charging approaches particular attention is paid to their:

- Effectiveness in achieving what they are intended to achieve;
- Efficiency in providing improved price signals that internalise some of the external costs of road use;
- Equity in distributing costs across the population of road users in a way which appears “fair” without unduly disadvantaging particular groups.

Austrroads (2007) includes a discussion of the different types of equity to be brought into consideration in road pricing schemes. Having defined “horizontal equity” in a conventional way as “the impartial treatment of individuals in similar circumstances”, it then confuses the discussion by implying that revenues should be dedicated to providing road improvements or other benefits to people who pay the fee. The basic definition of equity makes no presumption about how revenues are used, only that like individuals should be treated alike; and questions of dedicated revenue recycling to the payers of charges are clearly problematic if

charges expand to reflect more of the externalities of road use, which are not borne by road users.²

“Vertical equity” requires that “less advantaged” people receive more public resources (per capita or per unit of service) than the “more advantaged”, and could be used to justify using road charge revenues to support alternative transport programmes (used by the less well-off and non-driving sections of the community), provide cash rebates, reduce taxes or fund other services that benefit disadvantaged populations. Austroads also identifies “spatial or territorial” equity which can be evaluated by measuring accessibility from and between different zones, citing other sources that address these issues (Litman 1999, Morisugi 2004). Austroads however does not address “inter-temporal or inter-generational equity”, which concerns the sharing of burdens across cohorts in different time periods. This is a major omission in the consideration of whether investments in long-lived infrastructure which will benefit successive generational cohorts, should be funded out of current expenditures (as in the current PAYGO approach used in Australia, New Zealand and elsewhere) or rely more on debt funding in which future cohorts of users would face more of the cost of providing the roads that they use.

2.4 The theory in brief

The theory of road cost allocation and charging has not changed substantially over recent years. The efficient way of pricing roads would be to charge users the marginal social costs of their use, covering all the externalities of road use i.e. the user’s incremental contribution to costs of road-wear, accidents, congestion and environmental degradation. But it is difficult to establish marginal costs for all externalities and there is no guarantee the revenues from such charges would cover the full costs of road provision, because of the large component of fixed cost which needs to be met regardless of use (e.g. from weather related road repairs). Therefore in practice, where highway agencies are constrained by budgetary considerations and cost recovery requirements, roads are provided under sub-optimal second or third best arrangements, employing Ramsey Pricing and PAYGO approaches limited to only some of the external effects of road use.

What has changed is scientific understanding and technological developments which create the potential for more accurate measurement and charging of more of the full costs of road use. As well as enabling charges to reflect more of the full costs of road use than maintenance and operational costs alone, this can move charging closer to marginal cost based pricing, rather than the current practice of basing charges on average costs of an average vehicle of a particular class across a defined area or jurisdiction.

² An example of this would be if road charges are structured to reflect environmental externalities (such as local air quality effects) which are a cost on the general community, not other road users: nothing would be achieved by charging heavy polluters more if the revenue so gathered was dedicated to providing them other benefits, and the incentives created by such an approach could be quite contrary.

Safirova et al (2007) modelled alternative second best policies and found that policies designed to internalise a broader set of externalities are more efficient than those internalising a narrower set. Their modelling suggested that efficiency gains would almost double when non-congestion related external costs are accounted for as well as road-wear and congestion. Moreover, while time-varying charging is most effective and efficient in reducing congestion alone, when other social costs are accounted for a vehicle-distance charge is almost as efficient. The implication is that accounting for a broader range of external costs can enable a less complex charging mechanisms to be used, with corresponding reduction in implementation costs.

In another study, Parry (2006) estimates that the optimal heavy vehicle charge in the USA to address externalities would have both weight-distance charges and a fuel charge (between 7 and 20 US¢ per mile across urban and rural areas and single unit and combination trucks, and 69¢ per gallon of diesel). Without the distance-related charge the second best option would be a fuel tax of almost double that amount (US\$1.12 per gallon), which is 2.5 times the current tax. Apart from restating an earlier finding that US fuel taxes are too low and UK taxes too high relative to their respective external costs of road use (Parry & Small 2005), this illustrates that the combination of charge instruments available can have a large influence on both the efficiency and price signalling conferred by the road use charges.

3. The practice of cost allocation and charging

3.1 Overview

Until recently, most countries have relied on a combination of vehicle taxes, registration fees and other fixed charges plus fuel taxes which vary with use to fund their road networks. Tolls have been used to help finance new specific road links, tunnels and bridges. More recent variations in road charges include:

- New Zealand's Road User Charges, which since 1978 have charged heavy vehicles for the weight carried and distance travelled on the roads, and replaced fuel tax for diesel powered vehicles;
- Cordon tolls around city centres have been employed since the mid 1980s, either for raising funds to bring forward completion of capital works or (more recently) as instruments of congestion pricing and travel demand management;
- Heavy vehicle charges for particular time periods, such as the Eurovignette, which are charges varying with vehicle size entitling use of roads over defined time periods;
- Weight distance charges for heavy vehicles, with Electronic Fee Collection (EFT), introduced into some European countries, particularly where there is a high proportion of foreign vehicles in transit;
- High occupancy toll or HOT lanes, with Electronic Fee Collection, used to provide vehicles with congestion relief.

Congestion type charges are not currently covered by the National Land Transport Programme and fall outside the scope of this literature review. But they provide examples of fee collection and enforcement approaches that have been applied in practice, and to the extent that they provide revenue to fund new roads or additional capacity they can complement the regular user charge instruments.

Austroad (2007) provides a useful survey of experience with new road pricing mechanisms across several countries, including Australia, Switzerland, Germany, Austria, Norway and the United Kingdom, and other countries. There are some inaccuracies in some of the descriptions: for instance, New Zealand's weight-distance charge is described as "now fully electronic (known as e-RUC)", which is not yet the case; and its focus on the cordon tolling in Trondheim, Norway, as a successful tolling scheme appears somewhat unusual, as Trondheim's is the only one of the Norwegian schemes to have been discontinued in 2005, it having served its purpose in financing improvements in the road network and being no longer required to tackle congestion. It is useful in drawing examples of road tolling and other charging approaches from a wider range of countries than Europe and North America, such as Singapore, Hong Kong, Mexico and South Africa, and including some schemes that have been proposed but not implemented for reasons of technical difficulty or political resistance.

3.2 New Zealand

New Zealand uses PAYGO approach based on a road cost allocation model to attribute different expenditures to different vehicle categories as a basis for setting road charges. For instance it distinguishes between those costs which are directly related to the passage of traffic, such as damage to road pavements (attributable to heavy vehicles) and to surface markings (attributable to all vehicles) from those costs relating to the strength of roads and structures (e.g. bridges), which are not related to traffic in the sense that the structures are built to given standards and provided those standards (e.g. weight limits) are not exceeded, deterioration is unrelated to traffic flows but rather the passage of time and environmental factors. However, these costs are traffic-related in the sense that the standards are determined by the vehicles likely to be encountered: some rural roads are unable to accommodate the largest vehicles in use today, but the cost of bringing them up to standard can be directly attributed to the increasing size of the largest vehicles.

In outline the road cost allocation model:

- **Takes all annual expenditures** in the national road programme (on both local roads and State Highways) and separates them into work categories, whose cause can be attributable either to all vehicles, gross vehicle weight or axle loadings.
- **Deducts from these totals** the fixed revenues from local government rates and licence fees, offsetting them against fixed cost components across all work categories. This means that the offset against the fixed costs of work categories caused by heavy vehicle axle loadings may be out of proportion to those vehicles' contribution to the fixed revenue streams – most licence fees come from light vehicle owners.
- **Distributes the remaining costs** across revenue bases reflecting the number of vehicles and forecast vehicle kilometres travelled in each vehicle class, attributing strength and wear costs to heavy vehicle RUCs and the remainder to all vehicles collected through a mix of RUCs and petrol tax.

This cost allocation model is sensitive to a number of input assumptions, in particular the extent to which costs are treated as fixed or variable with traffic use, and the initial allocation to different work categories. In the long run **all** repair costs can be regarded as variable, which implies that RUCs must meet the entire cost of road repair, and any fixed revenue credited to heavy vehicles should be used only to offset their contribution to the unattributable costs shared across all vehicles.

There are a number of uncertainties over the technical parameters in road cost allocation which make precision on this issue difficult (e.g. the extent of pavement deterioration which is weather-related rather than traffic-related). The cost allocation model has been in use since the introduction of Road User Charges in 1978, and it was officially reviewed in 2001. Since then, increases in government funding for roading and changes in the proportion of new construction work has altered the historic balance and changed the distribution of

allocated costs across vehicle classes, with large changes for some RUC vehicle classes.

TERNZ and Covec (2008) recently reviewed the current cost allocation process for RUC and identified a few issues related to use of equivalent standard axle (ESA), Reference weights, Fourth power rule, Vehicle configuration, Road friendly suspension. Most of these are hardy perennials which have featured in previous reviews of cost allocation (such as in 2001), and usually centre on claims that the current treatment in the model does not fairly attribute to certain types of vehicle which employ different technology from that when the cost allocation model was set up.

On the charging system, the report makes a brief discussion of a recommendation by the Road Transport Forum to introduce fuel excise on diesel and weight dependent registration fees in order to reduce compliance costs, noting that within the same category, fuel consumption does not increase linearly with weight and hence will not be related to actual road damage. It also reflects on alternative fuels becoming more widely used that would not be covered by diesel taxes (e.g. electric vehicles), necessitating an alternative RUC system for such vehicles.

3.3 Australia

Australia uses a PAYGO approach to road charging, in which the National Transport Commission (NTC) estimates the annual cost of road service provision from the average of road expenditure in the current budget year and the two previous years. It gathers expenditure data for the whole road network, including capital and maintenance expenditure at all levels of government, so that capital and maintenance expenditure is recovered in full in the period in which it is spent (Productivity Commission 2006).

The method of allocating costs and setting charges in Australia is similar to that in New Zealand. The Australian cost allocation model's broad components are:

- Total costs to be allocated are based on the average level of road expenditure over 3 years minus 39% deducted as "amenity costs";
- Costs that can be associated with use of different vehicle types are attributed to the different classes of vehicle;
- The remaining costs are allocated to different vehicle classes by way of a broad measure of road use (vehicle kilometres travelled, vkt).

The Australian charging model aims to recover expenditures allocated to each vehicle class through a combination of a fuel charge and fixed annual charges. An "access charge" and a diesel fuel charge are "selected" and revenues from these are deducted from the expenditures allocated to each vehicle class. The remaining expenditures become the basis for setting "mass distance charges" which, combined with the access charge, are wrapped up in the annual vehicle registration charge.

The Australian national heavy vehicle charging regime was introduced in 1992, but the diesel fuel excise was introduced in 1957 with the express purpose of contributing to road costs. Registration fees have also been in place since well before the introduction of the road use charging regime.

The Australian road use charge system applies only to heavy vehicles in excess of 4.5 tonnes. Charges recommended by the National Transport Commission (NTC) are set so that the aggregate charge revenue will recover heavy vehicles' estimated share of road expenditure, as determined with the NTC's cost allocation model. This model separates costs into non-attributable (common) and attributable costs. Attributable costs are distributed across all vehicle classes (including passenger vehicles) according to various measures of road use such as vehicle kilometres travelled or share of passenger car-equivalent units (PCUs). The charges on heavy vehicles comprise a per litre diesel fuel excise and an annual registration charge which varies by vehicle class (and hence by weight). Light vehicles contribute to their costs through petrol tax and registration charges. The registration charge for each vehicle class is set to recover the difference between the cost allocated to the class and revenue recovered from the class through fuel excise. As heavier trucks impose higher costs, the fuel excise alone is not sufficient to recover the costs allocated to these vehicles, so their registration charges are greater.

In aggregate charges recover from heavy vehicles their attributed costs of road maintenance, repair and capital expenditure on strengthening roads and bridges against the wear effect their use imposes on the road network, plus their allocated share of the common costs of road provision. The petrol tax and registration charges on light vehicles recover from them their allocated share of common costs. The NTC removes a considerable proportion of road expenditure from the cost base prior to cost allocation, including expenditure recovered through other fees and charges, interest on borrowings, heavy vehicle enforcement expenditure and a proportion of expenditure considered to account for other services provided by these roads, such as local access and amenity. The amount of local road expenditure excluded from the calculation on grounds of local access and amenity has exceeded 40% in some years, raising criticisms that this amount is too high and provides cross-subsidy to heavy vehicle users. Similarly there has been debate on the magnitude of common costs in relation to pavement maintenance expenditure, for instance the amount of road-wear that is attributed to environmental factors, such as weather, and hence treated as a common cost spread across all vehicles rather than attributed to heavy vehicles with the greatest impact on road-wear.

Productivity Commission (2006) argues that even though heavy vehicles are currently allocated a relatively low share of common costs (7 %), this would not imply a subsidy unless the costs borne by other parties (light vehicles and taxpayers) are higher as a result of heavy vehicles' use of the road network. In other words, if costs are truly common their allocation to different vehicle classes is purely a distributional matter of no significance for efficiency, and no real cross subsidies are created. There are various ways in which common costs could be

allocated to different vehicle classes, but all are essentially arbitrary. If common costs are correctly estimated, the rule for efficient allocation is Ramsey pricing, in which common costs are distributed in inverse proportion to the price elasticity of the different vehicle classes – i.e. they are allocated most heavily onto the least price sensitive vehicle classes. In this way the costs can be recovered with least distortion on road use, which is the most efficient outcome for full cost recovery.

Most independent studies of Australian road cost allocation attribute a greater proportion of costs to heavy vehicles than the current NTC model. In particular, in common with a number of other countries (e.g. New Zealand, Germany, UK, USA), most of these Australian studies attribute pavement maintenance costs on the basis of ESA-km, whereas the NTC uses AGM-km³, which results in a lower allocation to heavy vehicles. The Productivity Commission (2006) notes that while most of the assumptions made in the Australian cost allocation process are reasonable individually, their cumulative effect is to produce an allocation of costs to heavy vehicles at the lower end of the plausible range of values, and further work is required to verify the validity of these assumptions.

NTC (2007) proposes a method for calculating an incremental price that can be used to set a charge for allowing vehicles to exceed current regulated mass limits on particular roads. The aim of such incremental pricing would be to enable more efficient use of the road network by not letting a rigid standard on mass limits preclude the use of the most efficient vehicles available. This necessitates calculating the incremental cost specific to particular parts of the road network of exceeding current limits, and finding a way of setting charges for that cost that are compatible with the general road use charges based on network-wide averages. NTC compares PAYGO and Lifecycle cost approaches to determine incremental cost, and proposes a trial using approach, in line with one of the recommendations in the Productivity Commission's (2006) review. However, the Austroads Pavement Technology Review Panel (APTRP 2007) respond with some technical criticisms of the proposed trial approach, suggesting it may give the wrong incentives and result in lighter charges for vehicles which create the most damage. It illustrates the complexity of breaking down network-cost averages to facilitate location-based charging that more closely affects the marginal cost of road use.

NTC (2008) outlines a national transport policy framework which includes a number of other initiatives aimed at moving towards a preferred model for direct pricing of heavy and light vehicles to replace the current charges methodology. These include research and data collection to support direct pricing, developing the technology for fee collection systems, and investigating reforms to the institutional framework of road management to facilitate direct pricing.

³ Average gross mass kilometre

3.4 Cost allocation and charging in USA

The USA uses cost allocation and PAYGO charging through vehicle registration fees, fuel taxes and diverse other charges (e.g. tax on large tyres), but the overall charge structure is complicated by the overlay of Federal, State and local charges. Their road-related revenue is derived from different sources:

- Federal level: 90% from fuel tax, plus excise tax on truck sales, graduated tax on large tyres, and less than 3% of revenue from a heavy vehicle tax on trucks greater than 24.9 tonnes laden weight;
- State level: 50% from fuel tax, 33% from vehicle registrations, the balance from other assorted charges;
- Local level: 40% from vehicle registrations, the balance mainly from property taxes.

The Federal Highways Authority was responsible for constructing inter-state highways in the period after World War II, and since the Federal Highways Act in 1956 revenues from road charges have been passed into a Trust Fund for this purpose. But management of these roads once built passed to the relevant states, which still receive Federal assistance towards their upkeep. In 1991 the inter-state building programme was declared completed, since when these funds have been available to be diverted to other transportation applications. There have been calls to divert all revenues to roading and for Federal involvement in State-managed roads to cease.

Cost allocation models are run at both Federal and State level and used to assist the setting of charges. Federal level models were run in 1982 and again in 1997 and used to create ratios of user fee payments to allocated costs for different classes of vehicle (www.tfhr.gov/pubrds/janpr/cost.htm). As each level of government applies its allocation models and charge setting separately, the combined effect of the overlapping charge structures shows more variation in these ratios than looking at any one level.

Balducci and Stowers (2008) review 22 Highway Cost Allocation System reviews carried out during 1982-2007, identifying some variation between states. In most cases heavy vehicles were under charged with an equity ratio (ratio of total tax payment by a user class to its cost responsibility) less than 1, but in three cases, the ratio was more than 1 (Delaware 1992, Montana 1992 and Oregon 2007).

New charging approaches in the USA are prompted primarily by congestion management. High Occupancy Toll lanes have been operational in California and other states for several years. The state of Oregon has run a trial weight-distance charge to replace its fuel taxes – the Oregon Mileage Fee – which involves paying the distance fee as measured by an on board unit at petrol stations (Whitty 2007). While officially hailed as a success in proving the concept could be implemented, it has been criticised for having a small sample of drivers (less than 300) and only two participating gas stations, and for being oriented to testing acceptability of the

charging concept with a generous provision of onboard units and rebates for petrol taxes paid that is unlikely to be realistic in a situation where such charges are required for revenue collection.

3.5 Europe

Relatively little English-language literature has been uncovered on road cost allocation processes in European countries, although most countries appear to use such an approach with respect to setting heavy vehicle charges. While their systems approximate to PAYGO, there is an entrenched tradition in European countries of using road use taxes for purposes other than road cost recovery, e.g. environmental charges and above all revenue collection. An aversion to hypothecating road-related revenues to roading expenditures, on grounds that this could lead to revenue-generated expenditure which is not the most efficient use of funds, means that there is a wide divergence between what road users pay and what is spent on the roads. That aversion may be weakening, however, as public acceptance of new road use charges appears to be dependent on at least a substantial portion of revenues being directed to improvements in transport systems.

Particular drivers for road charge innovation in Europe include:

- Recovering costs from foreign vehicles in transit across countries;
- Ensuring fair competition among hauliers from different countries;
- Moderating congestion and environmental externalities.

In an attempt to increase revenues collected from foreign vehicles that might otherwise cross countries without contributing to road revenues, several European countries have required heavy vehicles to purchase windscreen-mounted stickers or “vignettes” that permit use of certain infrastructure within specified time periods (e.g. month, year etc). In 1995 a “Eurovignette” was introduced which provided a common system for charging heavy vehicles for use of motorways in six participating countries. As the revenue generated by temporal fees has been insufficient to sustain road maintenance and expansion in several countries, and responding to EC policy documents that call for fees which better reflect actual road usage, some countries have been moving to implement distance-dependent fees on which the Eurovignette Directive allows higher tariffs to be collected.

The White Paper on *Transport Policy for 2010 – time to decide* (European Commission 2001) foreshadowed a gradual replacement of existing transport system taxes with more effective instruments for integrating infrastructure costs and external costs. The charge for using infrastructure must cover not only infrastructure costs but also external costs, e.g. those arising from transport related accidents, air pollution, noise and congestion. It should also be capable of being levied without restricting freedom of movement or reintroducing frontiers and barriers to trade and competition. This arises from the recognition that transport is heavily taxed and unequally taxed, with different taxation structures in different

countries. For instance, the White Paper cites excise duty on diesel varying from €246 to €797 per 1000 litres in different countries.

Another motivation in Europe is the large differences in the cost structures of road freight between the longer-established member states of the former European Community and the new members from economies in transition in Eastern Europe. There is concern that freight hauliers in these new member states gain competitive advantage over those in the old member states not only from lower wages and associated labour costs, but also from less rigorous observance of environmental and safety regulation of vehicles, and the possibility that trucks from these countries can evade current payment systems when transiting other countries' road networks and thus avoid contributing to the costs they impose on those countries. Hence the White Paper's thrust towards more harmonised road charging across countries, and for the inclusion of a greater range of transport-related costs than has previously been the case, when road infrastructure costs have been the dominant, if not the only, cost components reflected in the charge structure.

The European Commission's principal intervention in the charging of road use is the Eurovignette Directive 99/62/EC which, although not requiring member states to charge tolls or other charges to road use, set upper and lower limits to such charges when they arise, in an attempt to improve the harmonisation of charges across the European Union. This has since been modified by a later Directive 2006/38/EC which sets common rules on distance-related tolls and time-based user charges for goods vehicles above 3.5 tonnes, for the use of certain infrastructure. The stated intent of these directives has been to improve the functioning of the internal market by reducing differences in toll systems and levels so as to improve competition in the transport sector, and also to provide for greater differentiation of tolls and charges in line with costs associated with road use by different types of vehicle.

3.5.1 Eurovignette

The Eurovignette is an integrated system of user charges for heavy vehicles of 12 tonnes Gross Vehicle Weight or more using the motorways in six EU member states. It was introduced jointly by Belgium, Denmark, Germany, Luxembourg and the Netherlands in 1995, and Sweden joined the system in 1998.

Its practical effect is to require vehicles of the qualifying size to purchase pre-paid entitlements to use the motorways in the participating countries for a defined period of time (month, year etc). It has been predominantly a manual process, with enforcement by random inspection at border posts and wayside checkpoints. Its intention is to ensure that heavy vehicles from outside those countries contribute financially to the costs they impose on the motorway systems. The costs it covers are those related to construction, operation and development of infrastructure.

Directive 1999/62/EC on the charging of heavy goods vehicles (HGVs) regulates road tolls and user charges that Member States can apply to HGVs with GVW exceeding 12 tonnes. It defines a toll as a “payment of a specified amount for a vehicle travelling the distance between two points” and states that “the amount should be based on distance travelled and the type of vehicle”. It defines a user charge as a payment of specified amount conferring the right for a vehicle to use the specified infrastructure for a given period. Under this definition the Eurovignette is a user charge.

The Directive puts lower and upper limits on the amount of user charges, in an attempt to improve harmonisation of road charges across member states. It also states that tolls and user charges may not be applied at the same time for the same piece of road, but they may be applied concurrently across a network – e.g. on a motorway network subject to Eurovignette, additional tolls may apply to specific bridges or tunnels. It does not, however, prevent member states from applying parking fees or specific urban traffic charges intended to tackle congestion.

In July 2008 the European Commission adopted a “Greening Transport Package” which includes proposals to revise the Eurovignette Directive. If enacted, these would move to including more of the costs of externalities caused by heavy vehicles’ use of motorways into the road use charges, but the current proposals have been criticised for excluding coverage of CO₂ emissions and accidents. However, CO₂ is more directly charged for through fuel taxes, and accidents are problematic for converting to a meaningful charge per use of the motorways.

The dismantling of border posts under the EU’s Schengen arrangement, and developments in other road charging instruments (particularly in Germany) suggest the current Eurovignette needs to become more fully automated (to improve monitoring and enforcement) and to improve inter-operability with these other instruments. The Eurovignette had 5000 points of sale in Germany alone, but when Germany seceded from the Eurovignette in favour of its own heavy vehicle charge (Maut) system, the economics of continuing with the existing vignette changed significantly. However, it has been suggested that a new electronic vignette with around 800 points of sale in the 5 remaining participating states and in some of the “belt states” surrounding them would be viable, using the technology to deliver additional services to users from telecommunications companies and oil companies.

3.5.2 Austria

In Austria, distance-based charging for heavy vehicles was introduced in 2004, in a system known as the LKW Maut. It was intended to attribute costs more fairly based on use, but there was also an urgent need to service debts on the road network and to gather greater revenues than were permissible under the EU’s Eurovignette Directive, which set limits on the charges that could be levied on purely time or distance based charges. A microwave DSRC technology was rolled out across the country’s motorway system, with windscreen-mounted on-board

units given away to ensure wide adoption. Distance travelled is calculated by microwave communication between OBUs and 430 toll portals along the road network, and fees are calculated on the basis of the weight and number of axles on the vehicle as entered by the driver prior to each trip. The system applies to trucks of 3.5 tonnes or greater and covers motorways and some expressways. It has reportedly operated efficiently with no insurmountable implementation issues, with operational costs consuming only around 10% of toll revenues (TCA 2007).

3.5.3 Czech Republic

The Czech Republic has a motorway charge system apparently similar to that in Austria, with DSCR deployed across the country's motorways and expressways. However, a second stage is intended to roll out the technology across a wider span of roads, for which DSCR appears a less suitable choice because of the mounting costs of acquiring sites and installing gantries across an increasing proportion of the road network. For this second stage a GPS-based OBU which requires no physical infrastructure at the road side would appear more appropriate (TCA 2007). When this became apparent the Czech government delayed implementation of the second stage indefinitely. TCA (2007) describe the Czech experience as a good example of the dangers of having no long term policy.

3.5.4 Germany

Germany introduced its own weight-distance charge on trucks larger than 12 tonnes laden weight in 2005, known as the "Maut" or toll. It applies to motorways and some expressways across the country.

Doll & Schaffer (2007) describe the principles for allocating the total road cost to individual vehicle categories, which involves 21 cost categories and 5 allocation steps, which are:

- Costs distributed in proportion to individual vehicle categories share of vehicle kilometres
- System-specific costs for cars and other vehicles below 12 t gross weight
- System-specific costs for heavy goods vehicles above 12t gross weight
- Weight-dependent costs
- Capacity-dependent costs.

Allocation according to causality is only possible for weight-dependent cost and is achieved using third and fourth power of axle loads derived from updated results of the US AASHO road test. Capacity related costs are assigned according to each vehicle class's equivalency factor defined in passenger car units. This is an arbitrary allocation and could be improved by applying principles of co-operative game theory, but this appears not to have been done.

Both Prognos (2002) and Doll & Schaffer (2007) refer to co-operative game theory as a means of improving on the arbitrary current allocation of capacity-

related costs in proportion to each vehicle class's share of passenger car units. Their descriptions of the approach are not detailed, but Doll and Schaffer identify it as involving a large number of calculations, and Prognos describes it as applying a fairness procedure to minimise the possible adverse effects on user classes, where a "fair" cost apportionment is one that minimises the incentive for classes to leave the partnership of all users. In short, it implies using game theory principles to find the distribution of capacity costs across vehicle classes where each class is least likely to be better off outside of the "partnership of user classes" - compared to distribution according to share of PCUs, in which some vehicle classes could bear disproportionately higher costs than others, and hence be better off outside the notional partnership of users sharing costs of providing the road network. This approach to avoiding cost allocations which would result in classes paying more in the partnership than they would in a self-contained scheme is similar to the common approach to identifying and eliminating cross-subsidy, so as well as being arguably fairer it is also likely to be more efficient than alternative approaches in which costs are allocated without regard to the alternatives available to each class in the partnership.

Wieland (2005) identifies the purpose of the HGV toll as primarily to remedy financial problems by bringing more funding into the transport system off the government's budget, with 50% of the revenues available to cross-subsidise rail and inland waterways. A further goal was to influence modal choice in favour of rail and inland waterways and to create "fair" competition between modes. It was also expected to further environmental objectives, as the toll includes some differentiation according to vehicle emission class: however, under EU Directive 1999.62.EC total revenue is still constrained to equal infrastructure costs, so the environmental differentiation is simply a weighting factor that redistributes cost liability away from environmentally friendlier vehicles to more environmentally damaging ones (Prognos 2002). There is no environmental cost added to the costs to be recovered (unlike in the Swiss heavy vehicle charge). The HGV toll also provides incentive towards optimal route choice and fleet management as the flat fee by weight class encourages high load capacity utilisation. German road hauliers were generally in favour of the scheme for ensuring greater contributions collected from foreign trucks passing through Germany, and there was strong support from industrial interests in developing a complex satellite based tolling system and sticking with it despite technological problems during implementation, because of the opportunities for selling the technology in other countries. A grand coalition of support built up which included environmentalists who welcomed the improvement of inter-modal competition, and private motorists who looked forward to reduced congestion on the road. But the German example also shows the importance for public acceptance of the toll being seen as not just another tax and that the revenues are used for purposes which the toll payers can see and gain some benefit from (e.g. cross-subsidy of other modes which reduce road vehicles).

According to first-best welfare theory user charges should be set equal to social marginal costs and the revenues should accrue entirely to the state. However, public acceptability and long-term-development considerations militate in favour

of earmarking revenues to the transport sector. Current practice in the German HGV scheme falls short of economic optimality. The German HGV toll scheme is currently based on an average-cost pricing rule with charges varying according to axle loads and exhaust emission standards. After 20% of revenues are retained by the private operator, Toll Collect, of the remaining revenues 50% are allocated to road, 38% to rail and 12% to inland waterways. Modelling by Doll & Link (2007) shows that when earmarking revenues to transport in this way, it is generally welfare optimal to allocate revenues to the road sector.

The German motorway tolling system uses GPS/GSM technology with an EFC on-board unit. While this has proved feasible for tolling, additional roadside beacons are required to support charging and enforcement functions. This system applies to trucks of 12 tonnes weight or greater, and requires higher OBU costs than the DSRC systems, and extending the system to smaller vehicles is expected to increase the costs and worsen the efficiency of collection. There were technical problems with the implementation of the scheme, the logistics of fitting 300,000 trucks with an OBU and a steep learning curve for Toll Collect, the operator of the system. There were also difficulties in the contract between the Ministry and the contractor. Some of the potential of the OBU for time and distance specific charging remains unrealised, as non-discrimination rules that prevent time-dependent charging for trucks without an OBU prevent this refinement of the OBU charging structure as well. The objectives of the German scheme seem to have mixed improved charging with the prospect of developing innovative market leading technology that might have export potential, but it is a scheme that has had implementation problems and no export opportunities have yet been realised.

3.5.5 Switzerland

The Swiss introduced a distance-based charge (LSVA) on heavy vehicles of 3.5 tonnes or larger in January 2001, to assist demand management and internalise external costs of heavy vehicles, with financing a secondary role. It is applied to all roads for distance travelled in Switzerland and is operated by the Swiss government Customs Authority, rather than out-sourced to private contractors. It employs several technologies, primarily a digital tachograph, DSRC, and chip-cards for ascertaining distance for charging, and GPS used as a back-up system. As operator of the scheme, the Swiss Customs Authority tendered for separate parts of the system rather than a single packaged system, which reportedly gave it flexibility and control. Revenue is comparatively high as trucks are also charged for external costs of noise, pollutant emissions and accidents as well as road construction, maintenance and financing. The Swiss Heavy Vehicle Fee is reportedly technically successful, and has also been effective in achieving several objectives, including sustaining revenues and reducing some heavy vehicle traffic from more environmentally fragile mountain regions. According to Perkins (2004) heavy vehicle electronic kilometre charge payment is enforced through 'customs checks at borders, roadside checks and checks in the accounts of Swiss haulage companies'.

According to Austroads (2007), the objectives of the Swiss LSVA were to internalise external costs associated with road freight transport, facilitate a modal shift from road to rail for goods crossing the Alpine region, protect the Alpine region by limiting an expected traffic increase when the national mass limit for trucks in Switzerland rose from 28 tonnes to 40 tonnes, and to finance new railway tunnels. The basic principle of the scheme is that heavy vehicle transport through the Alpine regions costs more, with scheme charges varying per kilometre and per tonne and with the emission characteristics of the vehicle. Effects observed from the Swiss LVSA include fleet adaptation, with replacement of high emission trucks and migration to a more optimal size of vehicle, and organisation changes evident in mergers in the trucking industry and changes in freight and fleet management. There has been little observed effect on route choice (the scheme applies to all public roads) or on the prices passed on to consumer products. The successful implementation of the scheme can be attributed to Switzerland being a relatively small country with defined freight routes, and to the choice of well-developed technology with relatively few teething troubles. (Austroad 2007).

3.5.6 Sweden

Sweden is located on the periphery of the European Union, with a large surface area and relatively low and dispersed population. The current road tax system for heavy goods is based on fuel tax and vehicle tax. The vehicle tax is differentiated according to vehicle characteristics such as weight, number of axles and the environmental rating of the engine (i.e. emissions). In addition, Sweden has been one of the 6 participating countries in the Eurovignette, which requires heavy vehicles to buy time-limited licences for using specified motorways and other roads in those countries.

Because the Eurovignette tolls only cover a limited number of roads, they are not considered an adequate tool for internalisation of external costs, which is a goal of both Swedish and European transport policy. The Eurovignette is also beginning to unravel, with the withdrawal of Germany in 2005 on introduction of its own heavy vehicle charge. As of 1 October 2008 Sweden has abolished the vignette, the sticker in the window that signifies payment. A new system records toll payments electronically on a central on-line database, which is available for officials in other Eurovignette countries to search to confirm that a given vehicle has paid the appropriate toll (www.skatteverket.se).

Between 2002 and 2004 an investigation was carried out in Sweden that reviewed all road and vehicle taxes. It proposed the introduction of a kilometre tax that would apply to all heavy goods vehicles (both Swedish and foreign) with a gross weight over 3.5 tonnes that use the public road network. The Swedish parliament voted in May 2006 to proceed with a national kilometre tax for heavy goods vehicles, with the objective of internalising external costs (Sundberg 2007). This is currently being developed under a project known as ARENA, which aims to achieve a system that both meets Swedish requirements and conforms with

Europe-wide guidelines for road tolling that the EU commission is currently working on (ARENA 2008). The section that ARENA is focusing on is the collection of the kilometre tax, which involves measuring, calculating and supplying all information needed to pay the correct tax. The actual payment processes will be defined through the European Electronic Toll Service (EETS). The Swedish kilometre tax will apply only to road use within the boundaries of Sweden.

A control system based on physical installations throughout the entire taxed road network, as in Germany, Austria and the Czech Republic, is considered too expensive in relation to the anticipated income of a Swedish system. Instead, the focus of the control mechanisms is on more intelligence and less hardware, more control responsibility to the Toll Service Provider, and on a supervisory authority with powers to undertake roadside checks. ARENA's proposal for a kilometre tax will require a mandatory On Board Unit for all vehicles, which is expected to be a very simple OBU for the Swedish system, but the precise technology has not yet been determined. It is also proposed to apply the kilometre tax across the entire Swedish road network, even though some roads may not be subject to tax and carry a null tax rate.

The ARENA project is being progressed through a consortium of players, and the intention is to let out separate contracts to separate parts of the system (as in Switzerland) rather than seek a single-supplier solution (as in Germany), to increase competition among potential suppliers. Sweden has also just completed a trial of congestion charging in Stockholm, which is about to be implemented as a full time operation.

3.5.7 United Kingdom

Road charges in the UK have two principal components, a Vehicle Excise Duty (VED, also known as Road Fund Tax) which is a tax on ownership of vehicles for use on public roads, and fuel excise duty, which is a tax on use of those vehicles. Vehicle Excise Duty accounts for around 16% of road-related revenues collected, with fuel duty making up the remainder. Most of these revenues are not returned to fund roading and transport, and a growing gap between revenues recovered from road users and expenditures on roads over the past 20 years in particular has been a matter of some concern. Road diesel taxes in the UK are now the highest in the EU, about 83% above the all-EU average.⁴

VED was first introduced for four wheeled motor vehicles in 1889, but although historically it was considered a Road Fund tax to pay for the building and maintenance of the road network, this has not been the case since 1937. The UK Treasury is strongly opposed to hypothecated taxes, and revenue from both VED

⁴ Butcher L, Seely A, Bolton P & Beale E (2008) "The road haulage industry: costs and taxes"; Research Paper 08/68, House of Commons Library, www.parliament.uk

and fuel taxes go into the government's consolidated fund from which appropriations for roading and other purposes are made. The UK's VED does differentiate between vehicles on the basis of gross weight and number of axles, but the linkage between cost allocation and road charge setting appears tenuous, as VED is a fixed charge per vehicle irrespective of the amount of use made of the road network, and bears no relation to each vehicle's contribution to road-wear.

A Lorry Road User Charge was proposed in the 2002 Budget for introduction in 2006, to ensure lorry operators from overseas paid towards using UK roads. This would have required foreign-registered hauliers to pay around 15p per kilometre travelled in the UK, assuming they bought their fuel outside the country, as most currently do. It would require all 430,000 lorries registered in the UK with gross weights over 3.5 tonnes to pay the same charge, with offsetting tax cuts in fuel tax to ensure the UK haulage industry was not disadvantaged. This would require a rebate system to be established to return an equivalent amount of fuel duty to hauliers, in the region of £3 billion per year. The LRUC was estimated to raise an extra £139 million per year for the UK Treasury. However, as the LRUC plans progressed it looked like being a costly solution to a relatively minor problem (McKinnon 2004). Unlike heavy vehicle charge systems in continental European countries, the proportion of foreign transit vehicles in UK is relatively low, so the LRUC would impose unnecessary costs on the majority of domestic vehicles to capture a minority of foreign free-riders on the system. And whereas other countries dedicate at least some of the revenues to improvements in the road system, the UK's position on non-hypothecation and revenue neutrality offered no such prospect of offsetting improvements.

After rising opposition the LRUC proposal was dropped. Currently the government is proposing a nationwide road use charge system by 2030, in which all vehicles will have satellite-based tracking devices that allow them to be billed for the precise use they make of the public road system, differentiating by both time and place to price both road-wear and congestion.

Other road charging initiatives in the UK include:

- London's congestion charge;
- An entry charge into the central area of the city of Durham, to reduce traffic and protect the historic heritage sites in the area;
- Trials on congestion charging in other cities, such as Edinburgh and Cambridge, none of which have yet become fully operative.

These schemes have proved the technical feasibility of charging over restricted areas, but there remains doubt about their overall success in economic terms.

3.5.8 Iceland

Iceland lies just below the Arctic Circle in the middle of the Atlantic Ocean, with an area similar to that of the North Island, and population is similar in size to that

of Greater Wellington or Christchurch City. About three quarters of the population lives in the south-west around the capital, Reykjavik, with the rest dispersed in smaller towns and villages, mostly around the coast, as lava fields, volcanic sand deserts or permanent ice sheets, cover much of the interior.

The public roads are managed by the Icelandic Road Administration (ICERA) which supervises road construction, services and maintenance. Although in the past ICERA undertook most construction work, now it is almost entirely tendered out to private contractors in each region of the country.

There have been moves in recent years to increase the revenue recovered from road users, in face of traffic growth and increasing heavy-truck traffic that has caused a noticeable increase in road-wear. No details have been found of the cost allocation process used in setting charges, other than that Iceland uses the fourth power rule in relating axle weight to road-wear.

Funding for ICERA is determined by earmarked sources of income determined by the Icelandic Parliament, i.e. a share of revenues collected from taxes on diesel and petrol and a kilometre tax on vehicles weighing more than 10 tonnes. In 2005, revenues from such taxes totalled 47 billion Icelandic Krona, of which ISK13.4 billion were allocated to ICERA (ICERA 2007)⁵.

Road use charges in Iceland comprise (OECD 2006)⁶:

- A weight tax on all motor vehicles regardless of fuel source;
- A weight distance tax on vehicles greater than 10 tonnes only, based on the weight of vehicle and kilometres driven;
- A tax on sales of petrol;
- A tax on sales of diesel, effective from 1 July 2005 and replacing a previous flat tax on diesel powered vehicles;
- Licence fees for commercial transport operators and taxi operators;
- A disposal tax at a flat rate per vehicle paid every 6 months up to age 25, to assist in disposing and recycling of discarded motor vehicles;
- Excise duty and VAT on importing of vehicles into the country.⁷

The all vehicle weight tax operates much like a vehicle licensing or registration fee, differentiated by vehicle weight rather than other measures (like engine cc rating). The weight distance tax is variable with road use and differentiates between heavy vehicles according to their expected share of road damage. Taxes on sales of petrol and diesel bear some relation to road use, but also significantly over-recover expenditures on roads and contribute to the national exchequer.

⁵ ICERA (2007) "Our roads" Vegagerdin

⁶ OECD (2006) "Consumption tax trends"; OECD, Paris

⁷ Icelandic Ministry of Finance: www.ministryoffinance.is/customs-and-taxes/nr/1764

Iceland's roads have no cross-border traffic and it has a practically closed vehicle fleet. Its government has sponsored research into developing alternative fuels to reduce its dependence on imported oil, such as hydrogen vehicles and electric cars, both of which would utilise the nation's abundant hydro-electric and geothermal resources for creating stored energy. While this could make it a contender for developing purpose-designed road charge instruments, its fleet of 214,885 registered vehicles, of which 187,442 are automobiles, is small and its road network dispersed, and it would have few economies of scale in doing so. There have also been recent proposals to review and reform its road charge system, transferring more of the taxation from vehicle charges to fuel charges to more explicitly reflect greenhouse emissions and encourage the uptake of alternative fuels for transport use (Svanbjornsson 2008).

The recent world financial crisis has hit Iceland particularly hard, and is likely to increase the price of imported petroleum fuels. It is likely to halt the recent rise in vehicle registrations (which grew by 63% between 1995 and 2005) and slow the development of alternative charge mechanisms.

3.5.9 Norway

Norway is a long mountainous country on the periphery of Western Europe, with a lower proportion of vehicles from outside the country compared to those closer to the core regions. Congestion became a significant problem in the larger cities and at bottlenecks caused by topographical constraints around the country.

There is little literature (in English) about the cost allocation processes used in Norway. As in other countries, there is an attempt to attribute costs of road-wear to heavy vehicles and reflect these in the charges for those vehicles. Norway uses a power relationship of 2.5 rather than the usual 4 to relate road-wear to axle weights (Eriksen 2000). Given its northern location, environmental factors such as freeze-thaw action, snow cover and meltwater may be expected to account for a higher proportion of repairs and maintenance than in more temperate countries.

Road related revenues in Norway predominantly come from fuel taxes (43%), vehicle purchase taxes (28%), ownership (annual registration) taxes (17%), tolls (9%) and other sources (3%). These revenues do not go into a dedicated road fund and only about half of them are returned to road funding uses. Distance charging is predominantly achieved via the fuel tax, while weight is charged with differentiation of vehicle licensing fees.

Norway's contribution to road use charging is its extensive experience of tolls, which have been used to fund public roads since the 1930s. In 1986 the tradition of tolls on link roads, tunnels and bridges was extended with the first cordon toll ring implemented on existing streets in the city of Bergen. This was followed in 1990 by a similar scheme in the capital Oslo, and in 1991 in Trondheim, and others have since been used in smaller cities. In all cases the purpose of the tolls was primarily to raise revenue to accelerate implementation of road improvement

projects that were already planned, but which would take up to 30 years to complete in the absence of the alternative funding provided by the cordon toll scheme. All schemes were for a finite period only, usually around 15 years, and required agreement of the local councils and dispensation from the national government. The Trondheim scheme was terminated in 2005. The schemes in Oslo and Bergen were granted extension to raise funds for further work (including public transport improvements) and debate is still on-going on whether to change the schemes to time-differentiated congestion pricing.

The significance for road use charge development is the integration of toll financed roads, tunnels and bridges into the overall road network, and the practical implementation of electronic charging systems to facilitate the toll collection schemes. While early toll plazas involved manual collection of tolls, most tolls now use an Autopass system with prepaid tickets, with coin operated booths only for infrequent users (such as foreign tourists). Tolls generally differentiate between private cars and heavy commercial vehicles, although the differential is generally more related to space requirements than its wear effects on the roads.

Braethen & Odeck (2006) examine the experience of private toll companies in the funding of road construction in Norway, where around 25%⁸ of highway funds come from road toll revenues. Although toll financing has been used in Norway since the 1920s, its proportional contribution to funding was consistently around 5%, until it started rising about 30 years ago. Reasons for the increase in toll funding include increasing maintenance costs for expensive road projects, greater focus on traffic safety and political constraints on funding for transport projects, combined with constantly increasing traffic creating pressure for new roads. The political funding constraint is not due to scarcity in Norway, which is generously endowed with revenues from exploitation of its oil and gas resources, but from the risk of distorting the Norwegian economy from large tax-funded infrastructure investments. Although tolling is well established in Norway, the average Norwegian motorist is not in favour of road tolling. While public acceptance of the urban toll rings has increased since they have resulted in visible improvements in transport networks, with new roads, tunnels and public transport interchanges built, there remains widespread opposition to their spread.

3.6 Other countries

The literature survey uncovered several other countries associated with innovative road charging instruments, but limited details have emerged. Conventional link tolls are commonly employed in many countries, particularly in France, Italy and Spain where substantial portions of the motorway network are provided on this basis. Also in Europe:

⁸ This refers to toll revenue as a share of spending on roads, in contrast to the 9% mentioned earlier is the share of tolls in total road-related revenues, including fuel taxes and sales taxes diverted to other uses.

- The Dutch government is reported to be planning a satellite-based charge on all roads in the Netherlands in 2011, differentiating charges according to time, place and environmental factors;
- Slovakia is planning to introduce a satellite based heavy vehicle toll system, to replace the coupon-based system currently in place, from 2009;
- The Hungarian Transport Ministry has called a public procurement tender for creating and operating a national electronic toll payment system based on a GPS platform for heavy vehicles, to commence operation in 2009.

Further details, such as they are, are to be found on www.eroad.co.nz . Another source of information on road pricing is the UN Commission for Integrated Transport (CFIT), found on www.cfit.gov.uk . Both these sites appear to be enthusiastic advocates for electronic road charging in all its forms, and provide little basis for comparing the costs and benefits of the different options or why they have developed as they have.

Appel and Jordi (2005) provide an overview of the system in Europe and in Finland where the road budget is determined as part of the state budget. Taxes are collected for general use and are not related to ‘costs of road keeping or social costs of transport’. Their road related taxes are:

- Automobile tax: it is a vehicle registration fee
- Vehicle tax: it is an annual fee paid by cars and vans
- Fuel tax: a levy is included in the retail fuel price
- Propulsion tax: levied on diesel vehicles, electric and gas driven vehicles based on weight. The vehicle and propulsion taxes are calculated on per calendar day basis.

Beyond Europe, literature on road pricing usually starts on Singapore, which since 1975 has had a system of urban road pricing, along with other high taxes on vehicle ownership intended to reduce congestion in the city. Elsewhere in Asia, Japan has a long history of tolls to finance link roads.

In Chile, Santiago has variably priced toll roads, introduced with manual fee collection in 2004 and with electronic charging based on Dedicated Short Range Communications technology since 2007.

3.7 Current practice in brief

On cost allocation, New Zealand has a similar model to that in Australia and in the USA, and there are elements of similar approaches detected in European systems, which utilise various axle load/road-wear power relationships and variously attribute different types of cost to vehicle axle loadings, gross weight and related measures. In such schemes the devil is in the detail and the literature review has not uncovered the basis for a close comparison of different models, although the Productivity Commission (2006) provides extensive discussion of

the Australian model, with many of the same issues as those encountered in New Zealand such as the appropriateness of the power rule, the deduction of amenity costs from the amounts to be recovered, the suitability of current arrangements for vehicles with different types of tyres, or the equity of charging average network-wide costs when some vehicles predominantly use highways with lower road-wear costs. There is also some discussion of the merits of alternative cost allocation models in Prozzi et al (2007).

On road charging, there has been until recently widespread uniformity on the form of charging – fuel taxes plus a vehicle excise tax or registration fee differentiated by characteristics of the vehicle. Apart from charging heavy vehicles more to reflect contributions to road-wear costs, the charging strategies have been more on an equity basis than an efficiency basis, although in the recent interest in congestion charging there is perhaps more emphasis on efficiency. Again there is little literature that documents in detail how one country's scheme compares with another. Such comparative analysis has become most apparent with the special heavy vehicle charging schemes that have been implemented in recent years, both for heavy vehicle charges in Switzerland, Austria, Germany and the Czech Republic, and for congestion pricing instruments. Much of this literature has a focus on the characteristics of the different technologies emerging for these purposes, further discussion of which follows in the next section of this review.

There are some distinct characteristics about the interest in new road charging devices that is emerging in Europe:

- It is predominantly motivated by congestion concerns, although with other objectives explicit to varying degree, such as alleviating environmental impacts and overcoming public funding constraints on road development;
- It is also heavily influenced by concerns about extracting contributions from foreign trucks in transit – the Eurovignette and heavy vehicle charges to date have all been located in central states with a high proportion of through traffic – and directives on charge limitation coming from the European Commission, which are largely concerned with fair competition among member states;
- It is technology driven rather than service driven, with an explicit component of capability development, driven in turn by the explicit expectation of companies or countries gaining first mover advantage from innovative systems that can establish an industry standard and be exported;
- There has arisen a plethora of local systems for specific needs, with limited inter-operability, achievement of which is now a dominant theme in documentation coming out of the European Commission;
- There has also been some lack of foresight about long term needs, with systems installed that are best suited for localised applications, but prove to be limited for longer term development and more widespread deployment;
- But across the various schemes that have been tried, continued or abandoned, the European experience has proven the practical uses of more direct road charging in many situations.

4. Prospects for cost allocation and charging

In considering the prospects for new approaches for cost allocation and charging in road provision and their application to New Zealand, it is necessary to consider the characteristics that are emerging, the conditions in which they work best, and match these against the conditions and issues arising in New Zealand's road user charge system. It is also necessary to consider the ease of implementing and enforcing each system, as without a high degree of compliance a new charge regime will not reap the full benefits of more direct charging, and will be seen as unfair among compliant users.

4.1 Technologies

4.1.1 Pricing possibilities

Cottingham et al (2007) survey technologies that might be suitable for implementation of national-scale road user charging, examining the strengths and weaknesses of the different vehicle tracking technologies, the types of pricing that they enable, security and privacy, enforcement and networking issues. They identify the types of charging available to road authorities as divisible into the following classes:

- Point pricing: charging a vehicle when passing a given point e.g. toll booth;
- Cordon pricing: charging a vehicle when passing a border or cordon;
- Zone (or area based) pricing: charging a vehicle moving within a defined zone, usually by detecting it passing a series of internal monitoring points;
- Distance-based charging: charging in proportion to linear distance travelled;
- Time-based charging: charging vehicles for travelling at specific times;
- Time and distance-based charging: a per distance rate that varies with time (e.g. time of day, peak/off-peak etc);
- Parking charges.

Other variants can be devised, such as distance-based charging differentiating by the weight of the vehicle, either assumed (based on maximum loading capacity) or actual (based on declaration and or measurement and verification). Another variant would be to differentiate by location, which is what point pricing, cordon pricing and zonal pricing already do as that they apply to specific stretches of road or areas of the network. Being able to differentiate by location across the network is the Holy Grail of road pricing at present, for instance the UK Department for Transport has cited time, distance and location based charging as its goal, the key to which is a fully national road pricing scheme with a technology that can charge by time, distance and place to target costs, including environmental costs.

Point pricing is common on bridges, tunnels and other individual links of toll roads, and in some schemes regular users may install a radio transceiver tag in

their vehicles to enable automatic payment (e.g. UK's Dartford Tunnel in London). In the USA, an E-ZPass system operates within several states, while the Melbourne City Link in Australia uses fully electronic tolling over 22 kilometres of arterial highway.

Cordon tolling is most well-known from the toll rings introduced in several Norwegian cities, first in Bergen (1986), then Oslo (1990), Trondheim (1991), Stavanger (2001) and Namsos (2003). The Bergen, Oslo and Trondheim rings were initially set up as 15 year schemes, and while these have been extended in Bergen and Oslo, the scheme in Trondheim was discontinued at the end of 2005 having achieved its objective of funding improvements of the transportation system. Before that, the Trondheim scheme had evolved into a multi-sector cordon scheme. The technology has moved from windscreen stickers and manual coin payments in the early years to fully electronic charging with an Autopass.

The UK Government has proposed a national road user charging scheme for all vehicles by 2030. The goal is to introduce variable charges per kilometre to change social attitudes and promote public transportation, as it is felt that at present the fixed costs of motoring (road tax, insurance, vehicle depreciation) dominate in total costs over the variable costs (fuel, wear and tear) so that the average driver has little incentive to be prudent in their use of the road. Such a comprehensive and large scale road pricing scheme will require much more accurate positioning than is currently achieved in existing charge systems, even the elaborate German initiative (Cottingham et al 2007).

Pricing for road use can either be static, in which road users pay a fixed fee for use of sections of road which vary with their characteristics, or dynamic pricing in which the fee varies with the actual conditions on the road network. An obstacle to dynamic pricing is the need to present road users with up-to-date pricing information so that they can respond to the prices, which generally require an on-board communication device indicating prices on road sections as the vehicle approaches them. Static pricing is easier to implement as prices do not change and no on-board signalling is required.

Another approach to road pricing would be to require users to purchase in advance the right to travel on a particular route at a particular time. Such slot reservation works in similar fashion to fishing quotas and emissions trading in limiting the number of slots and then requiring users of these scarce slots to pay for them. Like other services with strictly limited slots to fill – e.g. airlines, hotel capacity – considerable flexibility could be offered in the way slots are sold, with advance purchase, bulk discounts and packages that tie outward journeys to returns at particular times. Such a slot reservation approach has been proposed to limit traffic over some Alpine passes in Europe in a scheme known as the Alpine Exchange.

Another example of distance-based pricing in the literature that would be facilitated by new positioning and electronic charging systems is pay as you drive

insurance. Such systems would pro-rate premiums on the basis of distance travelled, on the grounds that risk increases with time on the road, but could retain other rating factors in the premiums offered. This is claimed to give more accurate insurance pricing and increase insurance affordability, particularly for those who travel less than the average (see www.vtpi.org/tdm/tdm10.htm). It could be offered as an option for clients in the similar way as car hirers can elect a flat fee or distance based rental charge. However, although some insurance companies have trialled this approach, others are resistant because it adds complications to their processes for uncertain benefit to them. It has generally been raised in the context of travel demand management as a pseudo price for use of roads, and has little relevance to the task of raising revenues to pay for the roads.

4.1.2 Choice of technologies

Global positioning systems (GPS) are the most ubiquitous positioning systems currently available. Accuracy depends on the quality of the GPS receiver, the almanac it contains (describing the movement of the orbiting satellites) and its ability to model atmospheric conditions. Four systems exist to help increase GPS accuracy: Differential GPS (with a network of accurately located ground stations transmitting corrections to timing signals), Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay System (EGNOS) and the Japanese Multi-Functional Satellite Augmentation System (MAS), all of which use geostationary satellites to transmit correctional information. A European Space Agency programme known as Galileo, scheduled to be in service by 2010, is intended to provide a more accurate service than GPS while being interoperable with it. However, there remain issues over signal shadowing and canyon effects among urban high rise buildings, and risks of map matching not correctly identifying the road travelled on. A further concern with GPS is the relative ease by which publicly available signals can be jammed by unintentional or deliberate interference by other transmission devices.

Cellular systems are widely available in developed countries, and raise the prospect of low roll out of systems because most people already possess a handset. However, the locating function of cellular networks does not yet have sufficient accuracy to enable differential charging by time and place, and there are also issues around linking handsets to particular vehicles for charging purposes.

Localised schemes make use of cameras and gantry-mounted sensors to locate cars as they enter or exit a zone. Installation and maintenance of such systems is relatively expensive, so they are best suited for schemes over limited areas with sufficient traffic to justify the high costs involved. Automatic Number Plate Recognition (ANPR) has an accuracy of at least 85% in London (i.e. the percentage of plates correctly identified), and can be increased with greater density of cameras. ANPR is not suitable for accurate location at all times since the required camera density is infeasible. It is also not as robust as some other systems, being affected by dirt and other obstructions to view.

Other gantry-mounted “tag and beacon” systems use Dedicated Short Range Communications (DSRC) based on microwave or infrared-based sensors. A tag placed in the vehicle is queried as it moves past the gantry. Tags may be passive and depend on the gantry transmission to respond, or active and powered internally, and some tags are able to communicate two ways. In USA, DSRC is governed by the IEEE 802.11p standard using an assigned frequency band at 5.9 GHz. No such standard applies in Europe, where many proprietary protocols exist, all utilising the 5.8 GHz band. Interoperability amongst microwave-based toll systems is consequently a key issue for EU integration.

Microwave based systems have a recognition accuracy around 99% and have applications in several countries (e.g. Australia, Austria, Chile, Germany, Switzerland, UK, USA). But being gantry based, they face escalating costs when rolled out over large areas, which makes them unlikely to be feasible for national road charging systems.

The future is likely to lie with satellite navigation units, which will continue to increase in accuracy as the technology improves and the number of satellites visible at any one time increases. Cellular networks are also improving their performance in handset location, but there are limits which are pushing some operators to incorporating GPS units into cellular phones. ANPR systems continue to increase their recognition success rate but are unlikely to match that of DSRC tag and beacon technology. As long as tolls are limited to specific road links or locations DSRC is likely to be the preferred technology for the foreseeable future, as long as interoperability between different proprietary systems can be achieved.

Another review of emerging technologies is given by TCA (2008), who characterise the private telematics market in Europe as low-volume, bespoke solutions for small segments of the transport market, with specialised “island” or “silo” applications tailored to the needs of individual fleet operators or modes. Most national initiatives, and those at a European level, are being driven by the public sector interests. New technologies are the focus, with applications standing in their shadow. Companies are trying to sell new advanced technologies such as Global Positioning Systems or the Galileo Satellite Tracking System, rather than developing innovative applications. A failure to put service before other considerations, or to focus on business processes rather than hardware, has led to a remarkable number of failures and inefficiencies.

Elaborating on the view that applications follow in the shadow of new technologies rather than drive them, TCA (2008) cite examples where the technology does not fit the intended solution. The Czech Republic copied Austria's motorway-only Heavy Vehicle Charge scheme, although its aim was to eventually cover all main roads across the country, for which the Austrian DSRC-based system, dependent on road-side monitoring devices, would prove very expensive to roll out nationwide. In another example, the German Heavy Vehicle Charge system is not used to its full capability for location-specific fee collection,

because it needs to accommodate some manual fee collection which has less flexibility, and EU rules prevent discrimination between manual and electronic fee payers – a case of the technology being over-designed for what's currently legally possible, and probably more costly as a result. Another example is the UK's Lorry Road User Charge, which was abandoned as it required high investment in technology compliance across UK vehicles to tackle the perceived problem of foreign vehicles in transit across the UK, which is relatively small in the UK compared to the problem faced in more centrally-located European countries which have implemented heavy vehicle charges.. In Europe in particular, the race among countries and companies to be first off the block with a fully functioning technology has contributed to proliferation of proprietary technologies and concerns about limits to inter-operability, which perhaps would have been less had the problem and required solutions been defined first to direct the search for appropriate and compatible systems. Defining the problem first may point to relatively low-tech solutions as being more effective and efficient than developing high-tech solutions, particularly in circumstances where traffic volumes are relatively low and problems are relatively localised and small-scale.

Telematics has its origins in military applications but is now mostly used with respect to Road Transport and Traffic Telematics (RTTT) and Intelligent Transport Systems (ITS). Applications can be grouped in terms of their intended markets, e.g. individual cars, commercial freight traffic, transport infrastructure and public transport, and within these broad headings for a range of different uses, such as vehicle tracking and tracing, navigation, fleet management, remote diagnostics for maintenance, anti-theft measures and monitoring of vehicle properties. Only navigation services can as yet be regarded as having mass market appeal.

Electronic Fee Collection (EFC) is a potential driver for wider deployment of standardised telematics in Europe. The EC Directive 2004/52 on the introduction of a European Electronic Toll Service (EETS) requires tolling systems in member states to become inter-operable. Another factor driving standardisation is increased attention being paid to tracking and tracing animal movements across the EU, in accord with Council Regulation (EC) No 1/2005 in December 2004.

Cheng et al (2003) note that commonly used GPS receivers do not have sufficient accuracy to differentiate between roads in close proximity, and discuss alternative technologies that might overcome this, such as differential GPS (DGPS). The US Coast Guard has established a maritime DGPS (MDGPS) which the US Department of Transportation has decided to expand for land applications (Pruitt and Fly 2008). In their assessment of DGPS, Pruitt and Fly (2008) note that when carefully controlled the accuracy is better than 1 metre.

Forkenbrock and Hanley (2006) emphasise the increasing need for distance based charging system as cars become more fuel efficient and electric cars or alternative fuel cars become more prominent. Forkenbrock (2004) suggests the use of an intelligence transportation system (ITS) technology, in which each vehicle will

have a GPS receiver, a basic geographic information system (GIS) data file and a vehicle odometer to be used for back up data on distance travelled, can be used for both light and heavy vehicles.

4.2 Compliance and Enforcement

Compliance with new charging mechanisms requires the incentive to comply to be greater than the incentive to evade. In economic terms this means making the fee less costly than the expected value of penalty if found out to be evading, which in turn depends on the probability of detection and size of penalties if caught. Penalties can range from simple fines to more serious suspensions of the right to operate, and in some cases to criminal prosecutions. The literature search has uncovered little documentation on the structure of penalties, other than some fines for minor infringements, but rather more on the susceptibility of new technologies to evasion.

Enforcement of road charging requires a capability to detect vehicles that have not paid, or have tampered with their on-board equipment. A vehicle with a tag not installed or an OBU disabled will not be detected, so other methods are necessary to verify the on-board technology. The Swiss heavy vehicle charge primarily relies on a digital tachograph, but supplements this with a GPS unit to check the approximate distance travelled. Cameras have the potential to capture all vehicles which is why ANPR has been a preferred technology in dense urban charge schemes such as the London Congestion Charge and the Norwegian Toll Rings.

Enforcement requires a technology that can be used in multiple locations and does not require properly functioning hardware in the observed vehicles. At present cameras are the only feasible method for enforcement, but are not deployable nationwide at reasonable cost. Deploying cameras at strategic locations and employing spot checks at random locations is one way to increase detection of non-compliance (Cottingham et al 2007).

FHA (2007) report the findings of an International Technology Planning Program which assessed procedures and technologies for enforcing commercial motor vehicle size and weight laws in Belgium, France, Germany, the Netherlands, Slovenia and Switzerland. In particular it examined emerging vehicle size and weight enforcement technologies, including but not limited to Weigh-In-Motion (WIM) devices that can produce reliable evidence of violations that withstand legal challenge. It found that European countries use various technologies, such as bridge weigh-in-motion systems, to improve the effectiveness and efficiency of motor vehicle size and weight enforcement. It also found a greater use of mobile enforcement activities and fewer fixed roadside weight facilities in Europe than in the United States.

Recent trends of increasing growth in domestic and international road traffic, with associated congestion and delays, threaten the timely and economic movement of freight without resort to larger and heavier loads, and also challenge the limited

resources available to monitor and enforce vehicle size and weight compliance. Countries are increasingly looking to automated systems for WIM-based vehicle size and loading enforcement to improve the effectiveness of enforcement, improve commercial vehicle productivity by reducing the number of vehicle stoppages, reduce the emissions that arise from unnecessary deceleration, idling and acceleration of vehicles, and improve safety from greater control over compliance of vehicles.

In Switzerland an automated profile measuring device is used to assess vehicle size and weight in low-speed applications (less than 10 km/hour) which officials claim gives an accurate dimensional picture of the vehicle and allow inspections to focus on other aspects of compliance. In Germany, a gantry-mounted laser system is used to assess trucks in high-speed applications which give results sufficiently reliable to enable size-questionable vehicles to be selected from the traffic stream for more detailed examination. These and other European countries have relatively few fixed roadside weighing facilities but make greater use of mobile enforcement activities, which results in more efficient and effective enforcement effort, with a lower volume of trucks being inspected and flexibility to respond to seasonal or longer term changes in freight routing patterns. Mobile enforcement is also generally able to respond to vehicles attempting to by-pass monitoring points.

Fully automated commercial vehicle size and weight enforcement using high-speed WIM is estimated to be 5 to 20 years in the future, as reported in France and the Netherlands. Aside from the technical capabilities of such systems, in France, Germany and the United Kingdom national measurement authorities have certified low-speed WIM for use in enforcement, but there are still obstacles to securing the statutory endorsement required to enact this practice.

The benefits from the technologies and procedures use are not yet precisely quantified but are expected to be positive because of more effective enforcement and less disruption of traffic. Usually toll schedules reflect a fixed registered weight which does not distinguish between fully loaded and empty vehicles. This has been credited with encouraging freight operators to become more efficient to avoid paying tolls on empty vehicles.

Prosecution procedures and fine amounts differ between and within countries in Europe, varying with such factors as the assumed degree of culpability of drivers, carriers or both, and with the time allowed for responding to the fine. The European Traffic Police Network (TIPSOL) is working to harmonise co-ordinated enforcement activity across countries.

Skove (2007) reviews some of the measures taken by US states to improve revenue collection from tolls without infringing privacy laws. Replacing toll collectors and police enforcement with electronic tolling and roadway cameras faces potential legal challenges in dealing with those who equate data collection with government surveillance, and those who pay tolls only under duress. States

have responded by changing their laws to reassure the public about privacy security and strengthen the incentives for compliance. For instance, in July 2007, the Ohio legislature empowered its Turnpike Commission to collect tolls electronically and reclassified non-payment from a minor misdemeanour to a civil penalty, increasing the probability of facing court costs for those who refuse to pay. It also passed restrictions on camera systems in face of political pressure from constituents, which the governor vetoed in part because it would have impaired Cleveland's contract with the company which installed the cameras.

4.3 Assessment of prospects

The literature reveals six broad classes of technology for road charging, with a larger number of proprietary variants. Broadly these are:

- Digital tachometer, hubodometer or other device for measuring distance and/or times of vehicle use;
- Automatic Number Plate Recognition (ANPR), in which vehicles are identified at a location by terrestrial based cameras and information is relayed to a central processing unit to match against payment records;
- Dedicated Short Range Communication (DSRC) devices, either micro-wave or infra-red, in which on-board equipment is read by terrestrial based sensors and information relayed to a central processing unit;
- Systems based on cell-phone technology, in which the vehicle's location is identified from signals transmitted from the on-board equipment via existing cellular towers;
- Geographical Positioning Systems (GPS) in which the vehicle's locations are identified by satellite and transmitted either via satellite or terrestrial systems to a central processing unit;
- Advanced GPS systems which achieve greater precision from a higher density of satellites and higher standard of equipment.

It also identifies four broad applications for road use charging. Express lanes are a form of point to point charging, as are high occupancy HOT lanes which have the added requirement of needing to identify that the vehicles using them have high occupancy.

Inferring from the literature reviewed, Figure 1 outlines the technologies and the applications for which they could be suited. For instance, a tachograph or hubodometer only measures distance travelled and times of travel, so it would not be suited to charging that requires precise locational information. Standard cellular and GPS systems also lack precision and probably could not be reliably used for identifying use of HOT lanes, but could be used for broader area-based or point-to-point charges. ANPR, DSRC and advanced satellite tracking appear to have the widest potential applicability, but have different costs for establishment, operation and enforcement, and would not be equally cost effective for all applications: e.g. although satellite tracking could be used to verify payments for

use in a period, it has wider capabilities and would be over-elaborate system to be used just for that purpose.

Figure 1 Technologies and applications

Application	Payment per period	Point to point distance-charging (pay on passing)	Cordon tolls (Pay on entry)	Area (or zonal) charging (Pay within)	HOT Lanes
Technology					
Digital tachograph or hubodometer	X	X			
Automatic Number Plate Recognition (ANPR)	X	X	X	X	X
Dedicated Short Range Communications (DSRC)	X	X	X	X	X
Cellular systems		X	X	X	
Global Positioning Systems		X	X	X	
Advanced satellite tracking, Galileo etc	X	X	X	X	X

Source: NZIER

The economic choices between these technologies depend on the objectives for charging, and the relative cost effectiveness of the different technologies in use. The relative strengths and weaknesses of the technologies depend on the need for investment in terrestrial infrastructure, the need for tamper-proof on-board equipment in each vehicle, and the need to verify that any such equipment is fitted and working in order to ensure compliance.

A broad comparison on these points is presented in Figure 2.

Figure 2 Relative costs and effectiveness of technologies

Application	On board unit	Terrestrial infrastructure	Location accuracy	Enforcement	Suitable for
Technology					
Digital tachograph or hubodometer	Low cost	None	None	Low cost	Distance-only charges
Automatic Number Plate Recognition (ANPR)	None	High cost	Moderate	High with multiple sightings	Limited areas, high volume
Dedicated Short Range Communications (DSRC)	Low cost	Moderate to high cost	High	Depends on secondary system	Limited areas, high volume
Cellular systems	Low cost	Low	Moderate	Depends on secondary system	Wide area charging
Global Positioning Systems	High cost	Low	High, but some shadow areas	Depends on secondary system	Wide area charging
Advanced satellite tracking, Galileo etc	High cost	Low	High	Depends on secondary system	Wide area charging

Source: NZIER

Such an assessment is consistent with current practice, in that ANPR has been preferred for limited area urban charges (e.g. London congestion charge, Norway toll rings), while when there are fewer vehicles to identify (e.g. in heavy vehicle charges) DSRC has been preferred (Austria, Germany). It would also explain why TDM (2008) are critical of the Czech scheme, which has adopted DSRC while intended to be rolled out across the whole country, requiring escalating costs in roadside infrastructure. Similar conclusions are reached by ARENA (2008) which concludes that differentiation by type of road across an entire road network requires a locational technology such as GPS; if a kilometre charge is applied to only limited road lengths DSRC may suffice; and if the entire network is covered

but without differentiation by road characteristics (i.e. a pure distance charge) a digital tachograph may be the most cost effective option.

A comparison of data on the New Zealand, Australian, Austrian, German and Swiss schemes from the literature review is presented in Figure 3. This shows the basis of cost attribution in the various countries' schemes, which variously spreads costs across vehicle groups in proportion to vehicle kilometres travelled, passenger car units, weight measures (gross vehicle weight or average gross weight) and equivalent standard axles.

The table also shows the aggregate economic data for the three European Schemes – installation cost, revenue for one year and operating costs for one year. This shows that the German system is by far the most expensive, although it also covers the largest area. If the schemes' installation costs were converted to an annualised cost at 10% discount rate over a 10 year lifetime for the equipment, the German scheme would have a slightly higher net return in a year than the Austrian scheme, although still only about half the return achieved by the Swiss scheme.

Figure 3 Comparison of road charge characteristics

	New Zealand	Australia	Austria	Germany	Switzerland
Cost attribution variables					
Common costs	By VKT through fuel tax & RUC	By VKT through fuel taxes	By VKT through fuel taxes	By PCU-km, through fuel taxes	
Space costs	By VKT through fuel tax & RUC	By PCU-km through fuel tax			By PCU-km via fuel tax
Roadwear & strength costs	By ESA-km, through RUC	By Average Gross Mass & ESA km, through registration fee	By Gross Vehicle Mass and ESA km, through registration fee	By ESA-km, through registration fee and heavy vehicle charge	By ESA-km via registration fee
Amenity maintenance	By property value rates	By property value rates			New investment by GV mass via registration fee
Other attributions					
Road charging instruments					
Fuel tax (tax on use)	On petrol only	Petrol & diesel	Petrol & diesel	Petrol & diesel	Petrol & diesel
Distance-weight charge (tax on use)	RUC: on diesel vehicles only; weight variation only on heavy vehicles >3.5 t	None	Heavy vehicle motorway charge "LKW Maut" (see below)	Heavy vehicle motorway charge "Maut" (see below)	Distance-related heavy vehicle fee "LSVA"
Tolls (direct use charge)	Rarely used on specific bridges	Mainly on urban expressways	Some tunnels & bridges		
Vehicle registration fee (tax on ownership)	Differentiating by engine size on light vehicles, by axle weight on heavy vehicles	Differentiating by engine size and weight: set to recover from each vehicle class the attributable cost not recovered through fuel tax	Differentiating by engine size (cars) & weight (trucks)	Differentiating by engine size (cars) & weight (trucks)	Differentiating by engine size (cars) & weight (trucks)
Heavy vehicle charge					
Coverage of vehicles	Above 3.5 tonnes GVW	Above 4.5 tonnes GVW	Above 3.5 t total GV weight	Above 12 t total GV weight	Above 3.5 t GV weight
Coverage of roads	All roads	All roads	Motorways & expressways	Motorways & expressways	All roads
Tariff	Per tonne kilometre, varying with distance, axle configuration and actual loads	Per kilometre; varying with GVW	Per kilometre; varying with distance & number of axles	Per kilometre; varying with distance, number of axles & vehicle emission rating	Per kilometre varying with number of axles and vehicle emission rating
Date of first operation	1978	1992	Jan-04	Jan-05	Jan-01
Technology mix	Paper based		DSRC & OBU	OBU, GPS & GSM	DSRC, tachometer, GPS OBU as confirmation
Stated objectives	Recover costs of road system imposed by weight carried on it		Finance O&M & extension of motorways; recover from foreign trucks, up to 90% of traffic on some roads	To finance extension and operation of motorways & achieve more efficient trucking	To limit truck traffic growth, finance rail tunnels, charge external costs & protect Alpine region
Revenues (2007)			€ 900 million	€ 3,400 million	CHF 1,500 million
Operating costs/year			€ 90 million (8-10%)	€ 700 million (20%)	CHF 50-60 (6-8%)
Installation costs			€ 350 million	€ 1,000 million	CHF 300 million

Source: NZIER; compiled from TCA (2008), Schelin et al (2005) and others

4.4 Implications for New Zealand

The literature on road cost allocation and road use charging has implications for New Zealand. Not least is that the choice of solutions depends on the definition of the problem. The literature covered in this review reveals that all countries have their own perceptions of road issues that are influential on how they approach the issue of how to pay for the roads. Even in Europe, where EU-wide policy might be expected to provide some common ground in perceptions, there is a wide variety of motivations, objectives and instruments across countries.

New Zealand's cost allocation model is not dissimilar to that employed in Australia and USA, although details may differ. But the road user charge system in New Zealand is unique in the sense that the charge is related to actual axle load carried by the vehicle. The closest practice elsewhere is distance charges based on laden weight and number of axles. In many countries mainly in Europe and also in the USA, there is a trend in electronic charging of road user charges based on the designed maximum axle weights. So the charges are not differentiated by the actual axle load. A vehicle pays the same charge irrespective of actual load being carried.

New Zealand's road user charges may be more accurate in reflecting the weight on the road, but it comes at the cost of greater difficulty in detecting if vehicles are under-paying, and greater transaction costs in administering the refunds for charges paid in excess of weight. Also, although charging for actual weight may seem fairer to the RUC-payers themselves, if it results in reduced detection of those who over-load or under-pay, there will be a loss of revenue that can only be recouped by adding extra costs onto the compliant payers. Whether this is a significant problem is an empirical question beyond the scope of this literature review. However, the less accurate weight-distance charges in European heavy vehicle charge mechanisms have been reported as providing incentive for more efficient choice of trucks and higher utilisation which in turn (other things held equal) should reduce the number of vehicles on the road to perform a given transport task.

Many of the innovative road use charging mechanisms being considered overseas are oriented towards problems that are of lesser significance in New Zealand. In particular:

- Congestion: this is a growing problem the world over, but effects are time-limited and localised, and local solutions of varying degree of complexity have been shown to work in cities of comparable size and traffic density as those in New Zealand, from which lessons can be learned should it be considered here;
- Recovering revenue from foreign trucks in transit: of no direct relevance to New Zealand with its closed vehicle fleet, but indirectly these countries will be

gaining experience in ensuring compliance and enforcement that may be useful elsewhere;

- Reducing the environmental impact of heavy vehicles in mountain areas: this appears to have been a strong motivator in Switzerland, and has also influenced scheme charge design in Austria, Germany and Sweden, and may indirectly have relevance if impacts of heavy traffic through small towns becomes more critical here;
- Inter-operability has lately become a dominant concern, particularly in Europe, but with lesser relevance to New Zealand except to the extent that the viability of new charge systems depends on being able to package them with add-ons (like navigation systems).

Beyond this, the literature shows that many of the new charge mechanisms overseas are being driven by industry-led concern to be first with a new technology standard with export potential, which has led to a variety of schemes. All are in the relatively early stages of operation, and it may take some years before a full picture of their relative performance becomes available. For New Zealand, where previous assessments of electronic Road User Charge systems have indicated the costs are still quite high for the size of the vehicle fleet, there may be advantage in waiting to see how the different systems develop over time and pick the approaches most suited to New Zealand conditions. This in turn depends on a clear definition of the problem to be addressed and the objectives to apply to road use charging in New Zealand.

The literature search turned up relatively few references to these areas of road use charge implementation:

- Enforcement regimes and compliance: as compliance is likely to be a function of the probability of non-compliers being detected and the penalty faced if they are, more detailed examination of the enforcement regimes was expected than was found in the current search – in other contexts, studies indicate the probability of detection has more deterrent effect than the size of the penalty;
- Price signalling to users before they make their transport choices is important for influencing behaviour, but there was little attention in the literature to how that is done (e.g. with posted prices or on-board monitors) nor on what compromises might be needed in presenting a charge schedule that is readily understood and responded to;
- Means of improving choices between modes (and routes), which is about getting the relative prices between modes (and routes) right to achieve more efficient transport choices and use of transport networks.

4.5 Prospects in brief

A range of technologies is becoming available that have the potential to improve the monitoring of road use and the electronic charging of that use. The choice of technologies depends on the objectives to be served, and particularly the roads to be covered, as the costs of installation and operation vary with the technology.

From the literature review the broad choice is between:

- Tachometers or hubodometers in the vehicle, which can be used to measure distance travelled across a network, but no other details about load or exact route. This is the principal device used in the Swiss heavy vehicle charge.
- Terrestrial monitoring systems provide geographical information and can be cost effective for limited areas, employing either:
 - Photographic recognition of number plates which have slightly lower accuracy rate but less likelihood of evasion by non-compliant vehicles; or
 - Automatic tag and beacon technology, which depends on a way of enforcing compliance with on-board vehicle equipment requirements;
- Wide area locating systems give coverage across potentially all roads with low cost on ground infrastructure, employing either:
 - Existing cellular phone networks, which have some shadow areas and low locational precision; or
 - Satellite (GPS) systems which are potentially more accurate, but may still have some shadow areas until technologies and satellite coverage improve.

Many road-freight firms already have proprietary GPS devices fitted for logistical management purposes which, following the Swiss example, could be used to verify distance travelled and supplement the current hubodometers. This could enable different types of road to be distinguished and associated with different costs for charging purposes, if such cost variations are known. However, some recent literature (Cottingham et al 2007, Schelin et al 2005) still questions the reliability of current proprietary systems for accurately identifying the use of different roads with different costs in close proximity (e.g. motorways and local roads). Such use of GPS is also some way short of eRUC proposals, in which load information as well as distance would be recorded electronically. It would also raise issues about handling the cost of certification across different proprietary systems, which is likely to involve elements of fixed and unattributable costs in maintaining the capability for audit, testing and verification and may require cost spreading across different systems.

As noted by Austroads (2007), government objectives and local conditions often determine the charging systems employed. A key policy issue is whether the objective is one of managing demand for road space and associated effects (congestion, emissions, pavement damage) or one of revenue generation. There can be efficiencies in pursuing these in combination, but these need to be pursued in light of the expectation of economic theory that charging the marginal cost will not necessarily generate the revenues required to pay for road expenditures. Austroads (2007) suggest cordon and link-type tolling of specific roads may make an interim contribution, but the long-term solution lies in more comprehensive application of road pricing across entire networks, which points to satellite or at least cellular systems amongst the known technologies.

The ability to charge accurately depends not only on the charging technology but also on the cost estimates on which those charges are based. The literature in this

review makes little reference to this, although it may be difficult to move from a system based on network-wide average costs to one that reflects the more accurately the costs of use made of specific sections of road (NTC 2007).

New Zealand has a Transport Strategy and Government Policy Statement with aims that include increasing the mode share of rail and coastal shipping, promoting efficient logistics management, and investing in critical infrastructure that remains affordable to use. These imply the need to move to road use charges that improve the competitive signalling between transport modes. Whether the priority should be tackling urban transport issues or inter-city transport is a policy decision to be resolved, but the literature review reveals there are different technologies that can be adapted to these different purposes. They can be expected to become more cost effective as the technologies mature.

5. Conclusions

This literature review of road cost allocation and road use charging relevant to the National Land Transport programme has inevitably touched on wider issues of road pricing and congestion charging, as this is where the international focus of road charging currently lies. Those wider issues are nevertheless useful in identifying technologies and approaches that can be adapted to the current road charging in New Zealand.

Road pricing is an umbrella term that can be used to describe a range of applications of charging for road use, including heavy vehicle charging (for pavement damage), congestion charging, pricing at the marginal social cost of transport, road taxes and charges, pricing to fund infrastructure provision. There is an important distinction between charging for revenue generation purposes versus charging to disincentivise cost generation (e.g. congestion pricing). Internationally road pricing is increasingly being viewed as a means with potential to improve road transport efficiency and reduce congestion and other unwanted effects such as air pollution and noise, i.e. road charging is being viewed as having more uses than simply raising revenue and recovering cost.

The literature review, particularly from Europe, also shows increasing concern with broadening the basis of road use charging from just cost recovery of roading expenditures to also charging for other externality effects on environment and accidents. Location-specific charging as permissible with some of the new technologies would provide a powerful mechanism for internalising these costs, as well as being able to more accurately charge vehicles for the costs they impose on the particular roads they use.

The current challenge is to develop systems that provide the information required for local purposes while being inter-operable with other systems with which they interface. In Europe, a variety of competing proprietary systems has led to inter-operability being a dominant concern. Conversely, competing suppliers provides a means of ensuring competition and price restraint and avoiding potential monopolistic pricing behaviour by suppliers. Both Sweden and Switzerland have sought to develop systems with a variety of suppliers, and avoid the large costs experienced in Germany where a contract was let to a single supplier.

Much of the literature on road charging appears to have a proprietary interest in advocating such systems, and contains technical detail that is beyond the scope of an economic review. This review however has identified the broader characteristics that affect each technology's effectiveness, efficiency and implications for affordability with which to assess the new developments.

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