Research in Transportation Economics 49 (2015) 55–64

Contents lists available at ScienceDirect

Research in Transportation Economics

journal homepage: www.elsevier.com/locate/retrec

Estimation of the marginal cost of road wear as a basis for charging freight vehicles

Tim C. Martin*, Thorolf R. Thoresen

ARRB Group Ltd, Australia

A R T I C L E I N F O

Article history:
Available online 8 May 2015

JEL classification:
D4
R42
R48

Keywords:
Heavy vehicle charging
Load wear costs
Marginal wear cost
Life-cycle costs
Freight productivity

A B S T R A C T

In Australia one option for improved freight vehicle productivity, as part of major road reform, is increasing the allowable freight vehicle axle loads above current load limits and reduce the transport cost per tonne-km. This can also potentially reduce greenhouse gas (GHG) emissions by reducing the number of freight vehicle movements for a given freight task. Decisions regarding increased axle loads on the existing road infrastructure can be founded on the marginal cost of road wear as the basis of a price for increasing axle loads. These prices can provide a clear signal for targeting maintenance and rehabilitation funding and works provided the revenue raised by the price is directly linked to the funding.

The Freight Axle Limits Investigation Tool (FAMLIT) is a pavement life-cycle costing model that can be used to estimate load-wear-cost (LWC) relationships for a range of typical roads and pavement types for six heavy vehicle axle groups. Loads were incrementally increased above current load limits to estimate the LWC relationships. Life-cycle road wear costs were based on the present value (PV) of the routine and periodic maintenance and rehabilitation costs associated with managing each road type within agreed functional and structural conditions. The PVs of these costs were subsequently converted into equivalent annual uniform costs (EAUC) which were used to form LWC relationships with axle load (tonne-km) and standard axle repetitions (SAR-km), providing alternative independent variables. The marginal cost of road wear was determined by the first derivative of the LWC relationships.

The estimated marginal road wear costs, in both short-run marginal cost (SRMC) form and long-run marginal cost (LRMC) form were found to vary across a range of road types and were highly dependent on the pavement/subgrade strength and traffic load. The marginal costs based on the LWC relationship using SAR-km as the independent variable were a constant value until axle group loads were increased significantly above current limits.

1. Introduction

Historically, improvements to Australia's road freight productivity have been brought about by increasing freight vehicle payloads and allowing road access for vehicles with longer, wider and taller configurations that still comply with safety standards. Most state and local government road agencies are concerned about allowing greater heavy vehicle access to the road infrastructure because of the cost consequences of increased pavement wear. Agencies expect that increased road wear will be appreciable once the current legal axle limits are exceeded. Consequently, the following significant questions need to be resolved: (i) can the current road network be used more productively; and, (ii) can road network access be managed in a way that enables the additional cost of this improved access to be fully recovered to allow preservation of road network capabilities.

Following an inquiry (Productivity Commission, 2006) into road and rail infrastructure pricing, Australian governments have engaged in a process of exploring improved road infrastructure pricing models for heavy vehicles. The main thrust of this that more efficient price signals to heavy vehicles using the road infrastructure has the capacity to improve the use of the road network by encouraging use of the right vehicle on the right road. Further investigation was also undertaken into pricing schemes that enable access by vehicles carrying loads greater than the current mass limits provided the charges reflect the additional road wear costs.

This paper presents the research findings of Austroads (Australian and New Zealand association of state, federal and local

* Corresponding author.
E-mail addresses: tim.martin@arrb.com.au (T.C. Martin), thorolf.thoresen@arrb.com.au (T.R. Thoresen).

http://dx.doi.org/10.1016/j.retrec.2015.04.006
0739-8859/

government road agencies) and the National Transport Commission (NTC) and other agency research work in this area directed at estimation of the marginal costs (MC) associated with higher axle loads for heavy vehicles. A range of different road and pavement types and climatic zones typical of the Australian road network were considered. MCs could provide key inputs into the proposed road infrastructure pricing reform.

2. Approach and definitions

2.1. Marginal road wear cost definition

Economic efficiency requires that prices are set equal to MC as interpreted by Walters (1968) for road user charging. In the case of roads, MCs are considered appropriate for both new and in-service pavements (Jones & Nix, 1995). The total and marginal costs of road usage, excluding congestion and other external costs, typically take into account two sets of factors: (i) the impact on road users in terms of vehicle operating costs; and, (ii) the impact of heavy vehicles on the road infrastructure.

The focus of this paper is on estimating the MC on the road infrastructure resulting from additional units of road usage due to increased heavy vehicle axle loads. Increased heavy vehicle axle loads increase the consumption of available structural pavement life as well as increase the deterioration of pavement surface functional conditions. Both of these outcomes need to be addressed by maintenance and restorative works to retain acceptable levels of service for the road users. The cost impact on the road users has not been estimated, although the MC on road users is considered to be close to zero provided road conditions are not allowed to deterioration to unacceptable levels of service (Newbery, 1988; Small, Winston, & Evans, 1989).

This paper details a robust and reliable approach used to estimate the MC of road wear cost resulting from increased axle loading on heavy vehicle axle groups beyond current legal or agreed axle load limits. MC estimates were computed to measure the additional whole of life road agency wear cost associated with either an additional axle group load (tonne) pass, or a Standard Axle Repetition[1] (SAR) unit. The approach used in estimating the MC was a pavement life-cycle costing analysis based on engineering principles. This ensured that the level of service (LOS), in terms of the road roughness and rutting (functional conditions) and strength (traffic load capacity) of the road pavement, was maintained to fall within defined bounds to ensure that the MC impact on road users was close to zero as noted above. Since the focus was on the impact that additional axle loading had on road wear costs, this paper is based on estimates of the MC of road wear which is defined as including all the relevant road agency costs that are impacted by road usage. Two types of MC in the context of road infrastructure are considered:

1. The short-run marginal costs (SRMC) of road wear take into account the cost of maintaining a road within its defined roughness, rutting and strength level (LOS) and within its original design capacity. No pavement strengthening was allowed beyond its initial design strength.
2. The long-run marginal costs (LRMC) of road wear take into account the cost of maintaining a road within its defined roughness, rutting and strength level and allow pavement strengthening of any nature (including reconstructions) to occur at any time during its life-cycle.

It should be noted that pavement strengthening under LRMC conditions was timed so that the road agency life-cycle costs were reduced as much as possible. Optimisation of total life-cycle costs was not possible as road user costs were not directly considered. The LOS, as noted above, was used as an alternative indirect measure of achieving optimisation by reducing the LOS with reducing levels of traffic on the various road types in the network.

3. Scope of analysis

Initially the SRMC and LRMC were derived from the estimated increased road wear costs on various road and pavement types in three climatic zones, representing the Australian sealed road network, including local access roads. Increased road wear costs were caused by incremental axle load increases across six common axle groups used by the bulk of Australia's heavy vehicles.

Road wear cost estimates were made for each different axle group for each road and pavement type, including local roads, over a 50 year analysis period using the Freight Axle Mass Limits Investigation Tool (FAMLIT), a pavement life-cycle costing analysis model that is described for users in Austroads (2014). Road wear costs comprised the present value (PV) of the routine, periodic maintenance and rehabilitation costs incurred by maintaining each road type in the network within set LOS conditions for roughness and strength over the life-cycle analysis period (Hirshhorn, 2002).

3.1. Estimation of equivalent annual uniform costs (EAUC)

The PVs of the aggregated road wear costs over the analysis period were converted (Hudson, Haas, & Waheed, 1997) into equivalent annual uniform costs (EAUC, Australian dollars, AUD/lane-km/year) to simplify the subsequent marginal cost analysis. This approach is similar to that used by Hajek, Tighe, and Hutchinson (1998), although a different approach is used here to determine the cost functions that the MC is derived from.

Fig. 1(a) shows the life-cycle cost profile example of a pavement over an analysis period of 50 years. It includes fixed annual maintenance expenditure and a rehabilitation cost at year 12.

The above life-cycle costs are discounted to a present value using a real discount rate (5%) which can be converted to equivalent annual uniform costs (EAUC) as shown in Fig. 1(b). The EAUC of a future cost stream ($\$Fx_i$) over an analysis time period, N, is determined using the following:

$$\$PV = \sum \frac{r \times \$FX_j}{[(1+r)^n - 1]} \tag{1}$$

r = real discount rate (fraction).
i = time when cost is incurred (years).
N = analysis period (years) when the expenditure occurred ranges from 1 to 50 for the example in Fig. 1(a).

The impacts of increasing axle group load increments on road wear were quantified by developing separate load-wear-cost (LWC) relationships for each of the six axle groups for each of the designated road and pavement types representative of the Australian sealed road network. Load-wear costs, in terms of EAUC, were estimated using FAMLIT for one tonne increments for each group axle load over a range of axle group load increases ranging from their tare weight to well in excess of those allowed under the

[1] SARs represent the traffic load impact (wear) on the pavement. SARs are based on a standard axle equivalency estimated by the ratio of the actual axle group load to the axle group reference load, this ratio is raised by a damage exponent ‘n’ whose value depends on the pavement type. For granular (GN) pavements, n = 4; for asphalt (AC) pavements, n = 5; and for cement stabilised (CS) pavements, n = 12 (Austroads, 2010c).