PAPER NO. 15*

COAL TRANSPORTATION ROAD DAMAGE

1. INTRODUCTION

Heavy trucks are primarily responsible for pavement damage to the nation's highways.[1] In this paper we evaluate the pavement damage caused by coal trucks. We analyze the chief source of pavement damage (vehicle weight per axle, not total vehicle weight) and the chief cost involved (the periodic overlay that is required when a road's surface becomes worn).

This analysis is presented in two stages. In the first section we present a synopsis of current economic theory including simple versions of the formulas that can be used to calculate costs of pavement wear. In the second section we apply this theory to a specific example proximate to the reference environment for the Fuel Cycle Study in New Mexico in order to provide a numerical measure of the magnitude of the costs.

Theory

Pavement Cost

Road overlays define the endpoints of a pavement's life. The configurations and number of axles on a vehicle matter -- as a rule, the more axles that a vehicle has to distribute its weight the less damage it will cause.[2]

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*Based largely on a working paper by Dallas Burtraw, Ken Harrison, and JoAnne Pawlowski.

[1]We refer specifically to trucks weighing more than 80,000 lbs. *Heavy Vehicle Cost Responsibility Study, Report of the Secretary of Transportation to the United States Congress Pursuant to Section 931 of the Deficit Reduction Act of 1984*, U.S. Department of Transportation, Washington D.C., November 1988, p. iii.

[2]Many State laws, however, penalize trucks with a greater number axles. Fuel taxes punish, because trucks with a greater number of axles require larger engines and get lower fuel economy. Many State turnpikes charge more for a given weight if it is carried on a vehicle with many axles. From: Clifford Winston, "Efficient Transportation Infrastructure Policy", *Journal of Economic Perspectives*, Vol. 5, No. 1, Winter 1991, pg. 116

The life of a road surface (i.e., the interval between road overlays) is affected by the number and type of the axles that pass over it.

The following equation yields the number of axle passages that the road will withstand before requiring an overlay:[3]

$$Nj = \frac{A_0 \, (D + 1)^{A1} \, (L2j)^{A3}}{(L1j + L2j)}$$

Where:

L1j = the weight borne by axle j (in thousands of pounds)

L2j = the type of axle weight. L_2=1 for single axles, L_2=2 for tandem axles (two axles close together),

D = the road's durability. (For rigid pavements, D equals the pavement's thickness in inches. For flexible pavements, D is a linear combination of pavement, base and subbase thicknesses with coefficients 0.44, 0.14 and 0.11. [i.e., D = 0.44(pavement) + 0.14(base) + 0.11(subbase)].

A_j = structural coefficients that describe the durability of rigid and flexible pavements, derived from an empirical study by the American Association of State Highway Officials.[4] For rigid pavements, $A_0 = e^{13.505}$ or 733,073; A_1 = 5.041; A_2 = 3.241; A_3= 2.270. For flexible pavements, $A_0 = e^{12.062}$ or 173,165; A_1 = 7.761; A_2 = 3.652; A_3 = 3.238.[5]

C = the cost of the overlay per mile

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[3]Kenneth A. Small, Clifford Winston and Carol A. Evans, *Roadwork: A New Highway Pricing and Investment Policy*, The Brookings Institution, Washington D.C., 1989, p.24

[4]The study evaluated 264 rigid and 284 flexible experimental pavement sections, using previously estimated values of N as dependent variables. Cited in *Roadwork*, Small, Winston and Evans, p. 25, from Highway Research Board, *The AASHO Road Test: Report 5, Pavement Research*, Special Report 61E (Washington, D.C.: National Research Council 1962) pp. 36-40.

[5]Small, Winston and Evans, *Roadwork*, p. 27. The authors reanalyzed and revised figures from the AASHO report.

This cost estimate per mile includes all the lanes that must be resurfaced. Typically, for a multiple-lane highway all lanes will be resurfaced simultaneously whenever the lane in greatest disrepair requires resurfacing.[6] The examples we consider in this study involve two-lane highways, so we assume both lanes will be resurfaced when the lane bearing the fully-loaded coal truck requires resurfacing. If this can be avoided, for example, if the road is a divided highway, then separate calculations should be done for each leg of the truck's round-trip journey.

To accurately describe the pavement damage one truck can cause, we need to find values for N for *each* of the truck's axles. These values (Nj) are evaluated against the cost of the overlay per mile. The following equation yields the cost of pavement wear per axle per mile[7]:

$$C/Nj = Cj$$

We sum the values of Cj to obtain R, the cost of the pavement wear per *truck passage* per mile.

To understand what this figure tells us about the social efficiency of electricity produced with coal, we relate the damages caused by coal during transport to the energy coal produces in a power plant. To begin, we divide pavement wear costs by the weight of the load of coal carried by the coal truck (W) to obtain a cost for each round trip mile that a pound of coal travels on the road way:

$$R/W_{coal} = C_{wt.m} \text{ (\$/lb miles)}$$

We divide $C_{wt.m}$ by the heat value of the coal (measured in Btu's) and then multiply that figure ($C_{Btu.m}$) by the heat rate of the electrical generating facility (i.e., the efficiency of the utility plant measured in Btu/kWh):

$$\frac{C_{wt.m}}{H_{val}} = C_{Btu.m} \text{ (\$/Btu miles)}$$

$$C_{Btu.m} \times H_{rate} = C_{kWh.m} \text{ (\$/kilowatt hour miles)}$$

[6]See Small, Winston and Evans (1989), p. 15.

[7]Modified from *Roadwork*, p. 15.

To achieve a cost per kilowatt-hour for a site-specific analysis, we multiply $C_{kWh.m}$ by the number of one-way miles travelled in a single journey by a fully loaded truck:

$$M \times C_{kWh.m} = C_{kWh} \quad (\$/kWh)$$

A Hypothetical Case In New Mexico

The Quemado mine in New Mexico uses trucks to transport coal along a thirty mile stretch of U.S. Route 60. The trucks possess five axles (a single axle plus two tandem axles) and carry 48,000 lbs of coal. They weigh 80,000 lbs when fully loaded.[8] We use this example to suggest the possible method of transporting coal to the reference power plant in New Mexico.

Pavement Costs. The likely route for coal transport, like U.S. Route 60 in the case of the Quemado mine, would involve a two-lane asphalt highway. A recent contract for resurfacing 10.5 miles of U.S. Route 60 cost $402,334 per mile. This sum included all materials, labor, and road preparation necessary for the overlay. A highway engineer for the State of New Mexico suggested that a better figure to use would be $485,000 per mile on average for the State, which reflects inflation and the remote location of our reference facility. We assume the surface includes 4 inches of pavement, 8 inches of base, and 8 inches of subbase.

Table 1. Characteristics of axles on a fully loaded coal truck

Axle	Single Steering	Tractor Tandem	Trailer Tandem
L1: Weight (thousand lbs)	12	17	17
L2: Axle type (1 = single 2 = tandem)	1	2	2
N_j: number of passages	2,686,869	6,340,078	6,340,078

[8]Anecdotal and "off-the-record" information suggests that in many cases, though not necessarily in New Mexico or involving the Quemado mine, coal trucks will be loaded far in excess of their legal limit. Since damage to roadway surface increases exponentially with the weight per axle, excess weight can have a significant impact.

To satisfy our first equation, we need to specify D and $L1_j$ for each axle j. Since the road has an asphalt pavement, its durability, D, is measured by summing the pavement, base and subbase thicknesses with coefficients 0.44, 0.14, and 0.11.

$$D = 0.44\ (4) + 0.14\ (8) + 0.11\ (8) = 3.76$$

Table 1 reports the characteristics of axles on a fully loaded coal truck. L1 takes a value of 12 (thousand pounds) for a single axle and 17 (thousand pounds) for each axle in a tandem. The final row of the table reports the numbers N_j representing the number of passages the roadway surface will withstand for each axle of type j for a fully loaded truck. These calculations are:

$$N_{\text{sngl axle}} = \frac{173{,}165\ (3.76 + 1)^{7.761}(1)^{3.238}}{(12 + 1)^{3.652}}$$

$$= 2{,}686{,}869$$

$$N_{\text{dbl axle}} = \frac{173{,}165\ (3.76 + 1)^{7.761}(2)^{3.238}}{(17 + 2)^{3.652}}$$

$$= 6{,}340{,}077$$

Combining these estimates and accounting for each axle on the truck produces a number NT = 996,922, the number of passages of the fully loaded truck until the road will require resurfacing, absent any other vehicle traffic. The annual needs of the coal power plant will require 79,167 passages of a truck per year. Absent the coal trucks, the roadway will require resurfacing about once every ten years, so current vehicle traffic imposes damage equivalent to about 99,692 coal trucks per year. Including the coal trucks, total vehicle traffic will be equivalent to 178,859 coal trucks per year.

These numbers provide a basis for estimating the present discounted cost of the additional truck traffic per mile of travel for a fully loaded truck, accounting for anticipated resurfacing schedules. Recall that the cost of resurfacing the two-lane highway is estimated to be $480,000 per mile. If we assume the roadway surface is halfway through its useful life at the start of the analysis, then the present discounted cost of an infinitely lived ten year resurfacing schedule (the scenario absent the coal trucks) is $984,261. When the coal truck traffic is included the road must be resurfaced every 5.57 years. Assuming that coal truck traffic continues over the forty-year life of the facility, after which it ceases and total vehicle traffic reverts to the pre-truck scenario, the present discounted cost of the infinite resurfacing schedule is $1,665,372 per mile. The difference is the net present discounted damage estimate per mile attributable to the coal truck traffic, or $681,110.

The estimated distance to be traveled from the mine mouth to the generation facility by the fully loaded coal trucks is 30 miles. The total annualized cost of the damage that results is $1,190,816 per year. Expressed as a levelized cost per kilowatt-hour this estimate of road damage is equal to 0.354 mills/kWh. This is the midpoint estimate of maintenance costs for the roadway that are likely to occur, but it is an under-estimate of total damage due to the absence in this analysis of related effects on congestion, road safety, vehicle maintenance, and other factors that have not been quantified.

There are two uncorrelated sources of uncertainty in this analysis. One is the calculation of Nj, the number of passages the road surface can withstand for each axle type, and the other is the cost of resurfacing. We focus exclusively on the calculation of Nj, which is the greater uncertainty. Making use of standard errors reported in Small, Winston and Evans (1989) we calculated an upper and lower bound for Nj. A 95% confidence interval ranges within factors 0.28 and 3.52 of the point estimates of Nj. Carrying these bounds through the calculations provides lower and upper bounds for a 95% confidence interval for the estimate of damages in this example ranging from 0.101 mills/kWh to 1.241 mills/kWh.

PART V

ISSUES