Optimisation of LGV weight: an enforcement policy?

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Goods vehicles perform a function that is part of the wealth generation activities of a nation. However, the selection of maximum operating weights has been the subject of as hoc political debate. Even the offence of overloading is like much traffic law, being classed as a criminal act. If a premise which assumes the choice of consignment weight is only a function of product density and the economic utility of the operator the whole process of regulation and control becomes more amenable to analysis. This paper examines how the economic case can be modelled. For the purposes of brevity the analysis is primarily algebraic but the case could yield greater validity and relevance by using numerical simulation with empirical data. The analysis shows some interesting and controversial optimum weights.

INTRODUCTION

1. The lorry and small van are essential elements to the existence of the modern way of life. Mr Kipling (R)[1] made *exceedingly* good sense in his epic phrase "Transportation is Civilisation".

2. Each year this truism is demonstrated only too well in the Road Freight Statistics[2] which have shown that over threequarters of Britain's freight movements are by road. Although current total activity is expected to show a fall, the tonne-km of road freight has tracked GDP throughout the 80's.

3. Over a decade ago, December 1980 saw the publishing of the "Armitage Report"[3] which represented the first attempt to comprehensively assess the impacts of heavy lorries on society. Within his report Armitage included recommendations for a review of lorry weight limits.

4. Subsequent discussions on these proposals by the Secretary of State for Transport announced (Nov 82) that the maximum weight of the heaviest vehicles to be allowed on Britain's roads would be raised. Increasing from the 32.5 tonnes for a four axle articulated lorry to 38 tonnes over five axles or six. *"This will ensure that no new type of lorry will cause more road damage than presently permitted maximum weight lorries, and overall there will be a reduction in road damage"*, he said.

5. Using the mid-eighties as a period of some stability the savings made by the activity of these heavier vehicles is shown by the DTp's data displayed in Figure 1.

Table 1. Est. Savings in lorry numbers (at '87 prices)[2]

Year	Numbers	Miles travelled (mill.miles)	Operator cost (mill.£)
1984	3000	150	50
1985	4800	250	80
1986	6200	320	100
1987	7800	410	140

6. The aim of this paper is to explore the apparent policy objectives and examine the economic justification of the present weight limits. Being a discussionary document most of the detail has been omitted.

POLICY IMPLICATIONS

7. In addition to the quotation of the Secretary of State for Transport cited earlier he also said, "These measures....reconcile the needs of our economy with those of people and the environment".

8. The conclusion we might draw from these remarks identifies the basic policy objective in economic terms as one of minimising the nation's total road freight costs.

9. For the purposes of this paper, road freight costs are defined as the direct costs of operating all of the vehicles required to satisfy the nation's needs, i.e. in 1987, this meant converting approximately 1500 million tonnes into 100 billion tonne-km plus the externality costs imposed upon the infrastructure by these vehicle movements. Therefore, in theoretical terms:

UK Freight costs = Operating costs + Externality costs

10. For the purposes of discussion it is assumed that fuel tax charges represent the price of supplying a useable infrastructure and hence maintenance costs are the variable element which is a function of the tonnage moved by the "fleet". Thus:

Externality costs = Additional road damage + Enforcement costs

<u>Equity Vs Efficiency</u>

11. Once having specified, by regulation, a given maximum weight limit the government has a choice of how to control the use. It can develop a strategy of enforcement which either seeks 'equity' under the law, or is 'efficient' in terms of the overall policy objective of

minimising transportation costs. The enforcement is an additional cost incurred by the nation as we attempt to ensure private operators do not exceed the maximum and so consume the infrastructure at a higher than planned rate. The operators, however, do not have full information and so the mechanism of enforcement tries to alter their perception of their operating costs, i.e. the risk of being detected while overloaded and fined. The government, therefore, chooses a probability through expenditure on vehicle testing and sets a fine that courts use as an imperfect transfer mechanism. The policy maker's view of enforcement will distort the balance in the probability/fine relationship. The following sections explain the extremes[4].

Equity

12. If the chosen strategy is one of equity then the enforcement rationale must be set so that society is fully compensated for the actions of the transgressors. This will, if successful, mean that the 'punishment fits the crime' and there is in fact an additional 'price' for the illegal part of the activity: remember normal fuel and licence "tax" the acceptable element at appropriate rates. Under this situation the following rationale, where society is fully compensated and operators are fully aware, holds:

Private costs of overload = Damage + Enforcement cost

Then if it is assumed that the operator has full information and makes rational decisions his business objective will aim to minimise his expected costs, the enforcement system must be such that:

$$\text{Private benefit of overload} = \text{External cost of overload} = \text{Expected cost of sanction}$$

If this sanction is achieved then operators satisfying the condition below still overload.

$$\text{Private Benefits of overloading} > \text{Expected cost of sanction} = \text{Additional social cost of activity}$$

Importantly for our aim the basic of minimising transport costs is not violated by this - their transgressions, since presumably the greater utility of the overload to the operator will represent a welfare addition to society. Observing from Becker [6] and Posner[7] that in their economic analysis of law:

$$\text{Expected cost} = \text{Probability of being apprehended} \times \text{Value of (fine) sanction}$$

A few will still decide to overload. Alternatively, the punishment value is:

$$\text{Penalty or fine} = \frac{\text{Social cost of action}}{\text{Desired probability that fine is imposed}}$$

The problem with this tact is that the detection must be certainty which increases the social cost through the enforcement costs. In basic terms we will never be willing to test and punish truck operators to the extent that they operate up to our chosen maximum but not beyond, which in optimisation terms is as bad as under-utilization. Consequently the policy goal must be approached from that of economic efficiency.

Efficiency

13. The strategy of efficiency (exploiting economic resources in such a way that 'value' - human satisfaction for goods and services is maximised)[7] - is less easily quantified: implicity suggesting some form of optimisation. The complete system interaction now becomes important, as both controller and controlled will measure efficiency in terms of their individual objectives. The government will attempt to minimise real costs. Operators, however, will measure their efficiency in terms of minimising private costs; those of direct operating costs and the expected costs of the penalty for violation. Providing that the perceived expected cost of the operator also considers fully the damage costs attributable to his actions, the optimum he tends to approach, would in an unregulated state also approach optimum policy conditions. The additional 'deterrence element' of the expected sanction would not be required as competition ought to provide the incentive to seek optimum and, therefore, higher efficiency with minimal expenditure on enforcement.

14. Assuming that total transportation costs can be condensed and modelled by:

Operating cost/km (Oc) + Externality per km (Rc),

then,

$$\text{Cost} = \frac{q}{T}\left\{Oc + \frac{Rc.T^4}{(10.N)^4}\right\} \text{ Cost/km} \qquad (1)$$

Where it is assumed that T = approximate tonnage of each vehicle -

Oc = operating cost is £/km
N = no. of axles (assumed near 10 tonnes cap.)
Rc = road damage cost per standard axle
q = quantity of goods to be moved, tonnes

Then, differentiating equation (1) with respect to T, to explore the behaviour of the marginal costs, yields:

$$\frac{d.C}{} = \frac{3q.T^2}{(10N)^4}\frac{Rc}{} - \frac{q.Oc}{T^2} \quad \text{cost/km/tonnes} \qquad (2)$$

which has a minimum at, $T = \left\{\frac{(10N)^4 Oc}{3.Rc}\right\}^{0.25}$ tonnes (3)

e.g. for a six axled articulated vehicle with Oc = £0.987/km (1991 Motor Transport Cost Tables, for 60,000 miles per year[8]), setting Rc at £87 per 1000km SADU. Such a vehicle has an optimum weight of 83.67 tonnes over 6 equally laden axles (theoretical).

15. Recognise that T is not payload, unladen weight is approx. 30% of vehicle weight

Payload = T - 0.3T

Further, as total weight, T, is spread, in practice, over differently rated axles (i.e. for four axled articulated 6100, 10170, 9400, 9400 kilo respectively) then equation (1) can be modified accordingly to:

$$\text{Cost} = \frac{0.0c}{0.7T} + \frac{0.RcT^3(\text{sum}(pn))^4}{0.710^4} \qquad \text{£1km - £.km}$$

where pn = proportion of weight carried by axle'n. Again, differentiating w.r.t'T' it is possible to further explore the effects analytically, i.e. the minimum is now represented by:

$$T = \left\{\frac{10^4\ 0c}{3Rc.(\text{sum}(pn))^4)}\right\}^{0.25} \qquad \text{Tonnes}$$

The tables below show how changes in the rate of road damage costs and operating costs affect the optimum gross weight.

Table 2 Gross Weight and Road Damage

Road Damage	60	70	80	90	100	£per1000SADU
Gross Weight	91.8	88.3	85.4	83.0	80.8	

Table 3 Gross Weight and Operating Cost

Operating cost	0.70	0.80	0.90	1.00	1.10	1.20	£per km
Gross weight	76.8	79.4	81.8	83.4	85.7	87.8	tonnes

The reader will observe that tonnage is relatively insensitive to the changes in either the cost of road damage or operating costs.

15. The effect of "road friendly" suspensions can be evaluated using the marginal cost equation. Assume that such a system increases the capital cost of the vehicle by £5000 and adds 5% to annual maintenance costs whilst reducing the damage to the road by 10% For example 38 tonne six axle artic £5,000 spread over 7 years at 10% real interest causes an annual increase of £1,320 per year, or 1.37 pence per km. The increase in maintenance charges of 5% on current running costs (17.9p per km) add a further 0.89p per km. Thus the original 0c for this vehicle of 0.987 £/km becomes 1.0096 £ per km.

16. The assumption that the rate of road damage decreases by 10% reduces the 87 £ per 1000SADU to 79 £ per 1000SADU. Note, the reduction is in the rate of damage not the effective weight of an axle. Recalculating, using the above value in formula 3 yields the new optimum truck weight.

T_{new} = 86.20 tonnes, cf

T_{old} = 83.7 tonnes

17. The gain provides a benefit of approximately 2.5 tonnes, effectively 2 tonnes payload for those operators who are weight rathe than volume constrained. Naturally more operators will find themselves in this position as vehicle volume becomes the critical performance element. However, the analysis shows that where possible dense products should be carried on appropriate weight lorries.

18. Once such optimum levels are set, there is a real cost to society when these weights are exceeded and, therefore, fines and enforcement must track the increasing cost.

19. What these purely economically predicted evaluations show is a necessary rise in vehicle operating weight (not size!). The situation exists because the decreasing operating costs (per tonne) is greater than the increasing externality caused (per tonne), at the current limits. Thus, since the rate of change of private costs is negative and the resultant rate of change of total transportation costs is also negative at the legal limit then the situation is shown below:

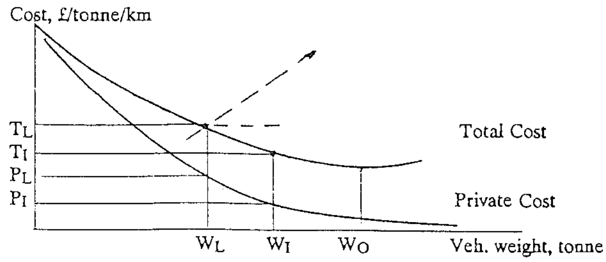

Fig. 1. Diagrammatic presentation of the interacting cost functions

20. Presently the effect of operators transgressing the weight limit, W_L, and operating at illegal weight W_I, generates a private gain (P_L - P_I). In order to deter the illegal activity the operators expected costs must be raised by enforcement.
If the sanction attributes the full cost of the externality, as the expected additional cost, operators will perceive cost T_I. But: $T_I > T_L$ so there is currently still a net benefit through the overload.

21. "Effective" enforcement must, therefore, attempt to raise P_I to level T_L, at least. The price of deterrence, however, is not constant as distance P_I to P_L is function of weight **W**. A fixed fine cannot, therefore, meet the demands of this system. Ideally, the sanction should cause:

$\frac{dTc}{dT} = 0$ at W_L, the positive gradient of $\frac{d.Tc}{dT}$, which is then required will be a function of operators' risk preference. Because, in order to be effective, the sanction must include the externality and also allow for the enforcement costs: as well as artificially locating the Wo at W_L. Society experiences an efficiency loss T_L instead of T_I.

CONCLUDING REMARKS

22. The optimum weight of a goods vehicle should be based on purely economic principles, that is not the same for size and therefore this paper had only addressed weight.

23. Assuming an entirely economically driven system allows overloading to be viewed as a simple variation in operators utility functions. If a policy seeks to optimise it must do so within the real world where businesses attempt to externalise costs. Road damage is one cost they can externalise unless society forces them to respond. The mechanism of control is through the regulation. Spending time weighing vehicles adds to costs; very high

costs if equity is the goal as the detection must achieve certainty. However, lowering the detection rate but raising fines by a proportionate amount may reach the similar deterrence level without consuming resources to the same degree.

24. The 'expected' costs of overloading must be raised by increasing the probability of being check weighed but with a rise in enforcement costs. It appears that currently the few vehicles which are weight constrained contribute a net benefit when overloaded. The strategy must balance the economic benefit of an illicit act with the need to show illegal activity being punished.

25. The model can be used to explore the impact on the optimum by technical fixes to the vehicle design that modify the rate at which the road surface is damaged. The marginal cost function is relatively insensitive so the changes do not yield dramatic weight changes. If evidence suggests the power law should change according to road class, the model will respond by varying the fourth power as necessary.

26. The direction and detail of the current work in this area has only been lightly covered by this paper - hopefully raising interesting conflicts to stimulate a lively discussion.

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