Speed Elasticity of Mileage Demand

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Abstract

Vast amounts of public funds are invested to improve traffic infrastructure. One would thus assume that the effect of new roads on the growth of traffic (traffic demand) would be well documented. Unfortunately, this assumption is incorrect. Roads and other projects that improve traffic infrastructure are still evaluated based on models that ignore the "law of supply and demand".

The most important parameter determining the attractiveness of roads and other traffic infrastructure is the speed they permit. The relationship between speed V and vehicle mileage N is described by the speed elasticity ε_V of mileage demand (negative travel time elasticity ε_T of mileage demand).

The fuel price elasticity of mileage demand dominates the discussion on transportation policy. Surprisingly little attention is paid to the more important speed elasticity of mileage demand ε_V. It has frequently been reported that people tend to budget a fixed amount of time each day for travel. Improved transportation infrastructure that allows for increased travel speed does not result in less time spent travelling. Rather, improved traffic infrastructure allows for increased travel distance. Thus a constant travel time budget amounts to $\varepsilon_V = 1$.

For $\varepsilon_V < 1$ road or other traffic infrastructure allowing for higher travel speed would yield a reduction in the travel time budget. This has never been documented. Rather, all available information indicates that for passenger traffic, the elasticity of mileage demand is $\varepsilon_V \approx 1$.

The speed elasticity component is still widely ignored in models predicting effects from improved transportation infrastructure. However, in modelling the effects of improved road infrastructure, the values chosen for the constant ε_V will significantly impact predictions of fuel consumption, emissions, cost/benefit ratio and other effects. Selecting a correct ε_V therefore is an important precondition for any proper forecast of the effects of improved traffic infrastructure. Predictions and cost/benefit analyses ignoring the appropriate speed elasticity component are severely deficient and produce erroneous results.

Key words: speed elasticity, travel time elasticity, induced traffic, traffic infrastructure, cost/benefit analysis

1 Introduction: Traffic is more Sensitive to Speed Changes than to Price Changes

Speed has a very significant impact on traffic volume. In most discussions relating to transportation policy, this is largely ignored. Instead, the discussion is dominated by impacts of fuel prices as an appropriate means to steer consumer demand (fuel-efficient cars) and modal choice. Price changes considered in such discussions usually are too small to subject voters' travel budgets to monetary restrictions (e.g. the famous 5 DM per Liter of fuel price debate in the German Green party).

Price changes cause (small) speed changes. Thus the impact of price changes can be investigated by means of the speed elasticity.

In a society that considers unlimited travelling as a basic freedom ("Freie Fahrt für freie Bürger!"), the political sensitivity of measures that would restrict travel frequency or distance is obvious. Measures causing changes in traffic demand (frequency and average distance of trips) therefore play a minor role in discussions on transportation policy. However, political correctness is not a suitable justification for engineers/scientists to use obviously erroneous models in predicting impacts.

2 Definition of Elasticity

Elasticity is a measure widely used in economics to show the responsiveness of an economic variable to a change in an associated variable [1]. In a more formal way, an elasticity ε_Q is defined as the relative change in demand (consumption of a good) $\Delta D/D$ divided by the relative change of the determinant $\Delta Q/Q$ inducing that change:

$$\varepsilon_Q = (\Delta D/D)/(\Delta Q/Q) \qquad (1)$$

In economics the price is considered the most important determinant for demand (price elasticity of demand). If, for example, a price increase by 2 % causes demand to fall by 1 % then the price elasticity of demand $\varepsilon_P = -0.5$. Elasticity values are negative, if quantities associated with the demand are negatively correlated to the determinant, they are positive if this correlation is positive.

If the elasticity ε_Q is assumed to be constant for each value of Q, then this simple function describes the relationship between determinant and demand:

$$D/D_0 = (Q/Q_0)^{\varepsilon_Q} \qquad (2)$$

where D_0 and Q_0 describe the state prior to a measure being instigated (reference state).

3 Speed Elasticity of Mileage Demand

When translating the economic model into transportation science, traffic demand is expressed as mileage N covered, while the average speed V is the determinant.

According to (1): $\varepsilon_V = (\Delta N/N)/(\Delta V/V)$ (3)

Instead with the speed V it is likewise possible to operate with the travel time T and thus with the time elasticity of mileage demand:

$$\varepsilon_T = (\Delta N/N)/(\Delta T/T) = -\varepsilon_V \quad (4)$$

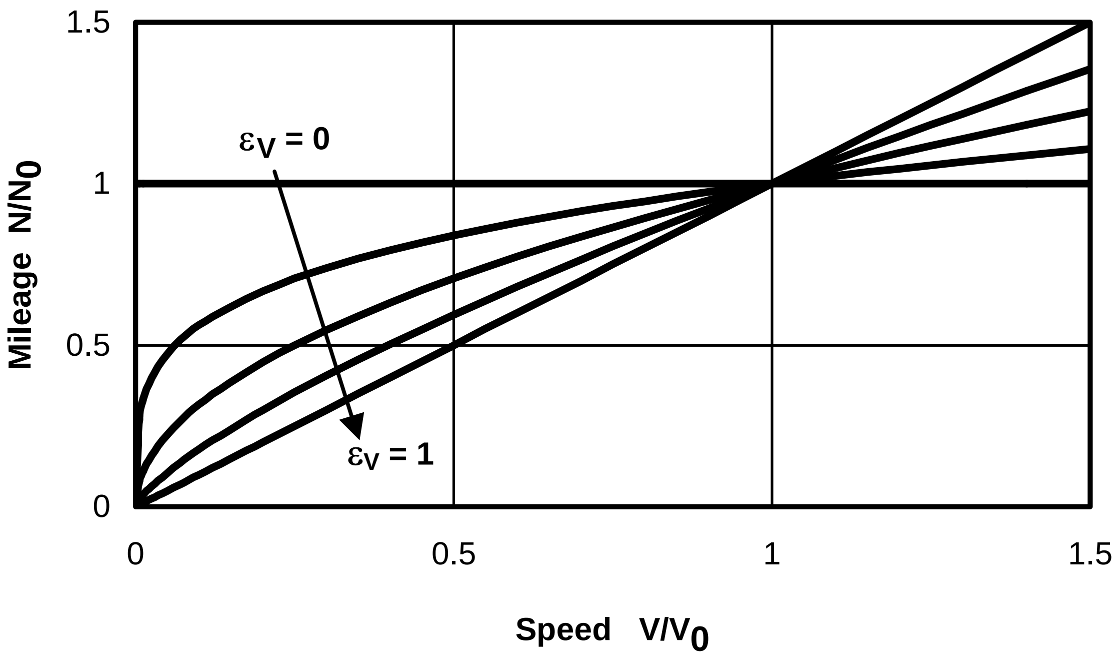
According to (2): $N/N_0 = (V/V_0)^{\varepsilon_V}$ (5)

Figure 1 illustrates this relationship for ε_V = 0, 0.25, 0.5, 0.75 and 1.

According to basic theory in economics, a price reduction will induce extra purchase of goods via two effects: (a) the income effect (rate of consumption increases) and (b) the substitution effect (purchase of the cheaper good increases relative to more expensive goods of the same kind).

Figure 1. Elasticity Functions $N/N_0 = (V/V_0)^{\varepsilon_V}$

ε_V = 0; 0.25; 0.5; 0.75; 1



Correspondingly, an increase in speed as a result of road improvements can induce extra vehicle mileage through (a) an increase in mileage within the given mode (additional trips or longer trips); and (b) by substituting slower modes with the newly available, more rapid mode of transportation (changes in the modal split). The speed elasticity in this paper only covers case (a).

4 Paradigms in Transportation Science

One would expect that the speed (or time) elasticity of mileage demand plays an important role in transportation science, and that one of the first chapters in any textbook on transportation is devoted to this topic. However, textbooks generally lack such a chapter.

Rather, a school of thought has been established in transportation science that, in the context of road traffic, ignores the impact of speed on traffic demand. For motorised road traffic, transportation science assumes $\varepsilon_V = 0$, i. e. improved infrastructure does not induce additional traffic. As a consequence virtually all traffic forecasts relating to major road construction projects in Germany have ignored induced traffic (German Federal Transportation Plan). Rather, these predictions are based on fixed origin-destination relationships, i.e. relationships that are independent of speed and, thus, travel time.

Ironically, traffic forecasts concerning public transport in Germany generally accept $\varepsilon_V = 1$. Increased speed induces a proportional increase in demand (economists will call this unit-elastic demand). Thus, transportation science supposes that in the case of public transport, doubling of speed will double traffic volume, while in the case of road traffic improved infrastructure is supposed to not change traffic volume at all ($\varepsilon_V = 0$, no elasticity). This discrepancy has never been discussed. Therefore, the huge impact of speed elasticity on road traffic volume has not been recognised.

5 The Traffic Becomes Faster and Faster, but we Save no Time

Measurements, statements of many transportation experts and common sense indicate that in the long run for passenger traffic, $\varepsilon_V \approx 1$. Before the invention of the means for convenient and rapid transportation a typical worker or employee could not commute more than 5 kilometres every day. This has changed. Today the average worker or employee commutes 50 kilometres each day, but spends about the same time travelling. Thus, the model of the fixed origin-destination relationship is unrealistic. More distance can and will be covered as speed of transportation increases. The tenfold increase in the distance covered is closely linked to a tenfold increase in travel speed.

As a result of improved traffic infrastructure, users (travellers) will initially save time. However, time savings sooner or later are reinvested into the transportation system (constant travel time budget).

“If there is a constant time budget, than any increase in speed will generate exactly that amount of extra travel which ... will use up all the initial time saving on extra travel. Therefore, on average travellers have saved no time“ [2]. Thus, $\varepsilon_V = 1$.

A simple calculation illustrates that the assumption $\varepsilon_V = 0$ does not correspond to past development. Over the past century, travel speed has approximately increased by a factor of 10. Associated time savings can be calculated as:

$$TB/TB_0 = (N/N_0)/(V/V_0) \qquad (6)$$

with (5)

$$TB/TB_0 = \left(V/V_0\right)^{\varepsilon_V - 1} \qquad (7)$$

with

TB travel time budget (time spent in traffic) at the beginning of the 20th century
TB_0 travel time budget (time spent in traffic) today
V_0 speed at the beginning of the 20th century
V speed today
N_0 milage (distance covered) at the beginning of the 20th century
N milage (distance covered) today

$V/V_0 = 10$ in (7)

$$TB/TB_0 = 10^{\varepsilon_V - 1} \qquad (8)$$

It can be assumed that at the turn from the 19th to the 20th century people typically allocated $TB_0 = 60$ minutes to traffic each day. Assuming $\varepsilon_V = 0$ in (8) this would translate into an average of just TB = 6 minutes currently allocated to transportation each day. This simple calculation shows, that assuming $\varepsilon_V = 0$ simply is absurd. Values in the order of $\varepsilon_V = 0.75$ have been published (see chapter 7). This would yield TB = 34 minutes currently allocated to transportation each day. A more realistic value, but still a gross underestimate.

6 Fuel Consumption as a Function of Speed

Figure 2 shows the fuel consumption C of a typical car engine (Otto engine) as a function of travel speed [4]. Consumption is lowest at about 70 km/h. Higher or lower speed causes fuel consumption to increase. There are similar functions to describe emissions. It is frequently concluded from this diagram that low speeds have to be avoided (after all, consumption is infinite at V = 0) and that congestion has to be eliminated, because it contributes to a waste of fuel and environmental pollution.

This assumption does not consider the speed elasticity of mileage demand. Motorists increase their mileage as travelling speed increases. Figure 2 is valid only based on the unrealistic assumption that $\varepsilon_V = 0$. Valid traffic forecasts are more appropriately based on Figure 3.

Figure 2. Fuel Consumption per Kilometer ($\varepsilon_V = 0$) of a Typical Motor Car (Otto Engine)

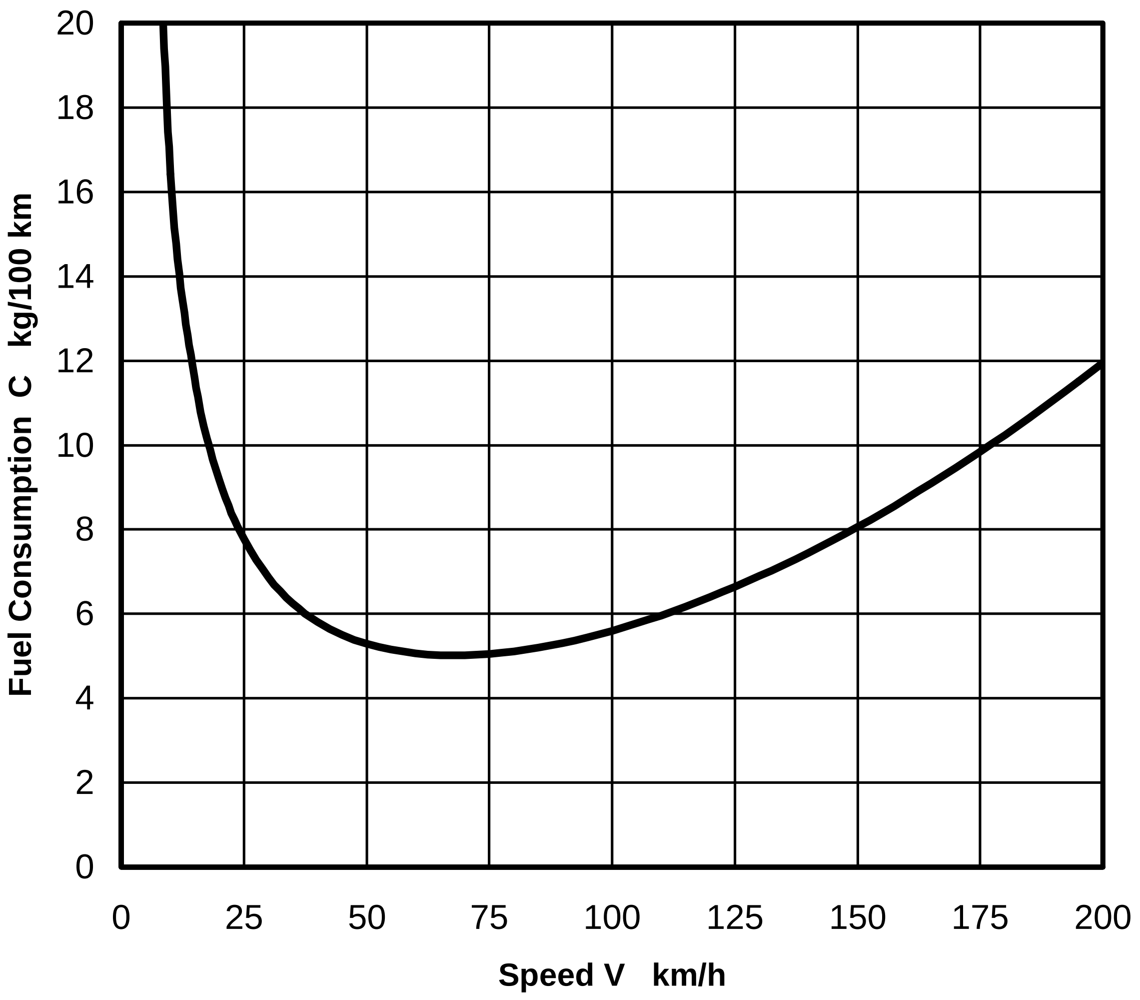


Figure 3 is derived from Figure 2 by a simple multiplication of the distance related effects with speed V. This produces time related effects (y-axis). Based on the assumption of a constant (speed independant) travel time budget ($\varepsilon_V = 1$), time related measures are more appropriate than distance related measures to link travel speed V to fuel consumption C and thus pollution.

In Figure 3 fuel consumption is lowest at a travel speed of 0 km/h. In addition, any deceleration of traffic reduces fuel consumption – even at low speeds. The effects of acceleration and deceleration are greatest at high speeds.

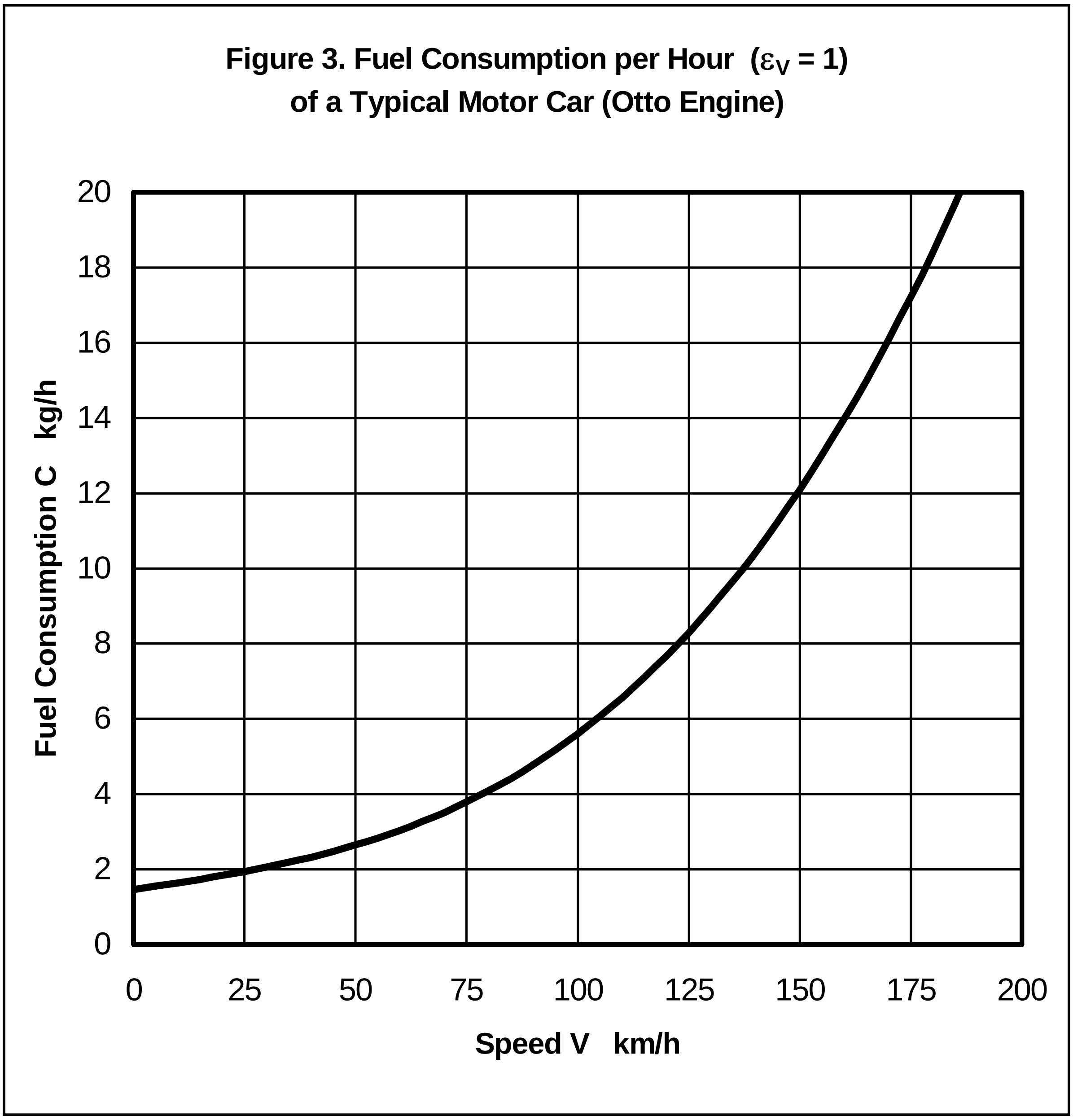
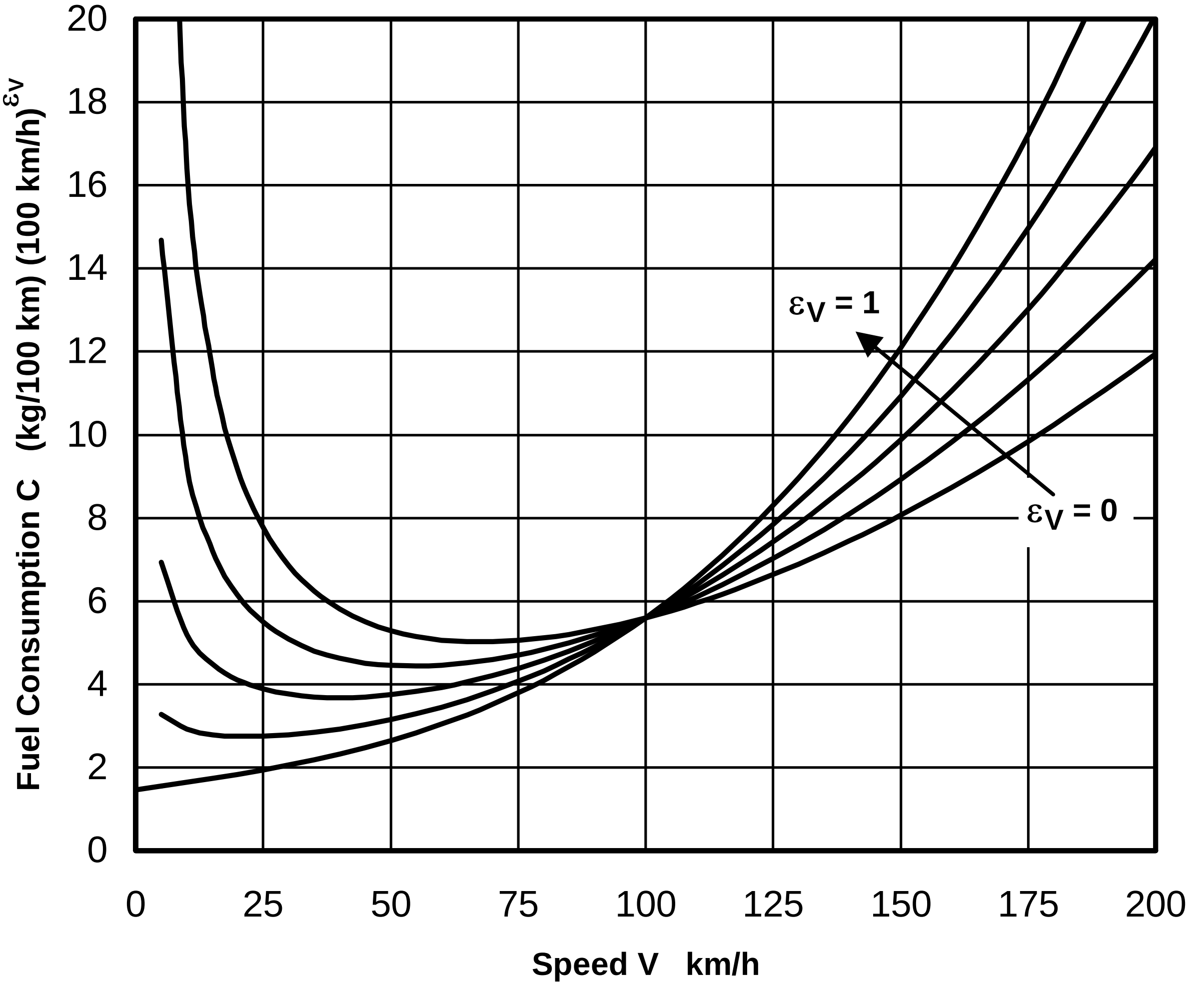


Figure 4 combines figure 2 ($\varepsilon_V = 0$) and figure 3 ($\varepsilon_V = 1$). In addition, fuel consumption based on different ε_V (ε_V = 0.25, 0.5, 0.75) was calculated by multiplying consumption C in figure 2 with V^{ε_V}.

Apparently fuel consumption functions differ largely depending on the choice of ε_V. If, for example, speed is increased from 25 km/h to 75 km/h as the result of a road construction project, then fuel consumption will drop significantly if the speed elasticity of mileage demand is assumed at $\varepsilon_V = 0$. However, in case speed elasticity is assumed at $\varepsilon_V = 1$ (which is closer to reality) then fuel consumption will increase significantly. Thus, a traffic forecast and therefore a cost/benefit analysis (project evaluation) [8] derived from that forecast can come to opposite results, depending on the choice of ε_V.

Fig. 4. Fuel Consumption of a Typical Motor Car (Otto Engine)
Speed Elasticities ε_V = 0; 0.25; 0.5; 0.75; 1



7 Speed Elasticity in Discussion on Traffic Policy

In his textbook “Modern Transport Economics“, the German translation of which is widely used in Germany, J. Michael Thomson [9] quotes a paper published in 1970 that sets the speed elasticity of mileage demand at $\varepsilon_V = 0.75$. Thomson, apparently not recognising the importance of ε_V, neither discusses this finding nor does he use the technical term speed elasticity.

According to Robert L. Morris transportation demand reacts elastically to the supply in terms of infrastructure [10]: “There is a clear relationship between the capacity of a system and the demand for the use of that system – capacity controls demand. Predictions of flood tides of vehicles overwhelming a road system do not, in ordinary circumstances, come true.“ Morris concludes: “Further, it should be seen that new highways in major urban areas often tend to be self-defeating. Rather than alleviate congestion and help to bring more people into the centre city, they generally work in a reverse manner: The new roads generate new trips, most of which will be oriented away from the concentrated centre, toward the periphery, and thereby contribute to the sprawl that threatens the centre city’s vitality.“

Morris' important contribution seems to have been forgotten and there is as yet no model in use, which allows to calculate or even considers the effects he describes.

Referring to Goodwin [11] the SACTRA report published in 1994 [12] specifically considers traffic induced by improving traffic infrastructure. Short-term travel time elasticity of mileage demand is estimated at about $\varepsilon_T = -0.5$, while long-term elasticity is in the order of $\varepsilon_T = -1.0$. These estimates represent the current state of transportation science.

A number of surveys on transportation elasticities and induced traffic have recently been published [13, 14, 15, 16, 17]. Most papers address price elasticities, however some also address time elasticities. Many findings agree roughly with the figures given above. But the data are neither discussed, nor compared with each other and thus no plausible explanations are provided.

For the revised German Federal Transportation Plan, average speed elasticity of mileage demand is set at $\varepsilon_V \approx 0.077$ for car traffic [18]. Or more accurately: for 7.7 % of the traffic (mainly recreational purposes) it is set at $\varepsilon_V = 1$, while for 92.3 % of the traffic it is set at $\varepsilon_V = 0$. For freight traffic the speed elasticity of mileage demand is set at $\varepsilon_V = 0$. No reference to empirical findings and thus no justification for the use of these constants is given. Papers [19, 20] provide a critical evaluation with respect to [18].

8 Conclusion

While research is still needed to establish a robust speed elasticity of mileage demand for freigth traffic, the impact of speed on average car mileage (passenger traffic) has been sufficiently investigated. However, available findings and results are not being used for predictions with respect to effects from road construction. Whoever assumes $\varepsilon_V < 1$ in traffic forecasts related to improvements of infrastructure should explain, why the time allocated to transportation has not steadily decreased over the past decades, but, rather, has increased or at least remained relatively much constant.

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