The ProgTrans/IWW infrastructure cost calculation model

An analysis of three road categories

Cornelia Bange[1]

Gernot Liedtke[2]

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Abstract

In 2005 the German parliament has introduced a distance-based toll-system for Heavy Good Vehicles (HGV) on German motorways. By the end of 2010 the toll revenue cumulated to more than 21 bn. €.(BAG (2006), BAG (2008), BAG (2010)). Due to similar quality standards federal roads have emerged as an alternative to motorways in order to avoid paying road user charges. Therefore in spring 2011 the German parliament decided to extend the toll-system to federal roads with more than four lanes and direct connections to motorways (BMVBS (2011)) In the present paper the infrastructure costs of the aforementioned federal roads, motorways and other federal roads are examined. For this purpose an infrastructure cost model is presented, which has been developed by ProgTrans AG Basel and the Institute of Economic Policy Research (IWW) Karlsruhe in 2002. The present paper describes the ProgTrans/IWW infrastructure cost model with an emphasis on the economic depreciation. Afterwards the results of the application of four lane federal roads, motorways and other federal roads are presented.

Keywords: Infrastructure cost calculation model, economic depreciation, four-lane federal roads

[1] Karlsruhe Institute of Technology, Waldhornstraße 27, 76131 Karlsruhe, Phone: +49 0721 608-45753, E-mail: bange@kit.edu

[2] Karlsruhe Institute of Technology, Waldhornstraße 27, 76131 Karlsruhe, Phone: +49 0721 608 44415, Email: gernot.liedtke@kit.edu

1. Introduction

Since introducing a distance-based toll system for Heavy Good Vehicles (HGV) in Germany in 2005 the toll revenues have amounted to more than 21 bn. €.(BAG (2006), BAG (2008), BAG (2010)) Due to similar quality standards federal roads have emerged as alternatives to motorways in order to avoid paying road user charges. Therefore in spring 2011 the German parliament decided to extend the toll-system to defined federal roads with more than four lanes and direct connections to motorways BMVBS (2011). For the determination of the adequate road user charges the ProgTrans AG Basel and the Institute of Economic Policy Research have been commissioned by the German Ministry of Transport, Building and Urban Development. The present paper introduces the ProgTrans /IWW infrastructure cost model by explaining the model's premises with an emphasis on the economic depreciation. Afterwards different calculation steps are introduced before presenting the results about a infrastructure cost comparison of different road types.

2. The ProgTrans/IWW Infrastructure Cost Model

The ProgTrans/IWW Infrastructure cost model has been developed in 2002. It has already served as a basis for calculating adequate road user charges in 2003 (ProgTrans/IWW (2002)) and 2007 (ProgTrans/IWW (2007)). In contrast to previous infrastructure cost model, this model is characterised by following premises.

2.1 Premises

This infrastructure cost model implies a theoretical business model of a public enterprise**.** Thus financing on terms of public market conditions is feasible. Further the public enterprise is required to maintain a long-term high-quality and self-financing road infrastructure, which is reflected in a full-cost calculation and a long-term maintenance of the network's assets. (ProgTrans/IWW (2007))

Moreover the infrastructure cost model fulfils the premise of a market-based, sustainable appraisal affecting the asset evaluation, depreciation and interest determination. This premise is implemented in the infrastructure cost model by using the concept of economic depreciation. Thereby, the market-oriented valuation is regarded by current depreciated values. Based on this valuation the reinvestment cycles are determined in order to maintain a long-term high quality infrastructure. (ProgTrans/IWW (2011))

A further premise is the efficient and fair cost allocation to individual user categories. Efficiency, in terms of cost allocation, means using existing infrastructure capacities (static efficiency) as well as an extension of the network according to demand (dynamic efficiency). Economic fairness can be sub-divided into usage-based, intergenerational and causative fairness. Usage-based fairness exists if the deterioration caused by a user category can be clearly assigned to that user group. Intergenerational fairness means that a user generation bears only costs proportionately to their individual usage period. Causative fairness is met if a user category, which is responsible for the design or provision of infrastructure elements, bears proportionate costs, even if this user category does not use the infrastructure itself. (ProgTrans/IWW (2007))

A way to implement the premises intergenerational fairness and sustainability of substance is to use the economic depreciation. It is an open depreciation method, so that changes of infrastructure costs resulting from changes in prices, quality or safety rules can be taken into account. Roads are characterized by very long service lives with changing economic, technical and political conditions and they are prone to unexpected failures. These exogenous changes can be considered in the valuation of the net stock of fixed assets by special depreciations or appreciations. (ProgTrans/IWW (2011))

For this purpose the gross asset GA(t) is evaluated by current replacement prices at the beginning of the period t. By subtracting the loss in value from the gross asset, the net asset on period t is calculated. The loss in value is based on engineering specifications. It is defined by residual service time or load divided by the total performance (ProgTrans/IWW (2011), p. 4f.):

$$NA(t) = GA\,(t) * \frac{T-t}{T}$$

NA(t)	net assets at time t
GA(t)	gross asset at time t
T	total service life
t	period t

The depreciation in period t is calculated by the difference of the net asset at the beginning and at the end of period t. Moreover reinvestments in period t reduce the depreciation.

$$D(t) = NA(t-1) - NA(t) + RI(t)$$

D(t)	economic depreciation in period t
NA(t)	net assets in time t
RI(t)	reinvestments in period t
t	period

Assuming a linear abrasion the depreciation D(t) in period t is (Knieps et. al (2000)):

$$D(t) = GA(t-1) * \frac{T-t-1}{T} - GA(t) * \frac{T-t}{T} + RI(t)$$

D(t)	economic depreciation in period t
GA(t)	gross assets in period t
RI(t)	reinvestments in period t
T	total service life
t	period t
RI(t)	reinvestments in period t

The application of an economic depreciation has several advantages.

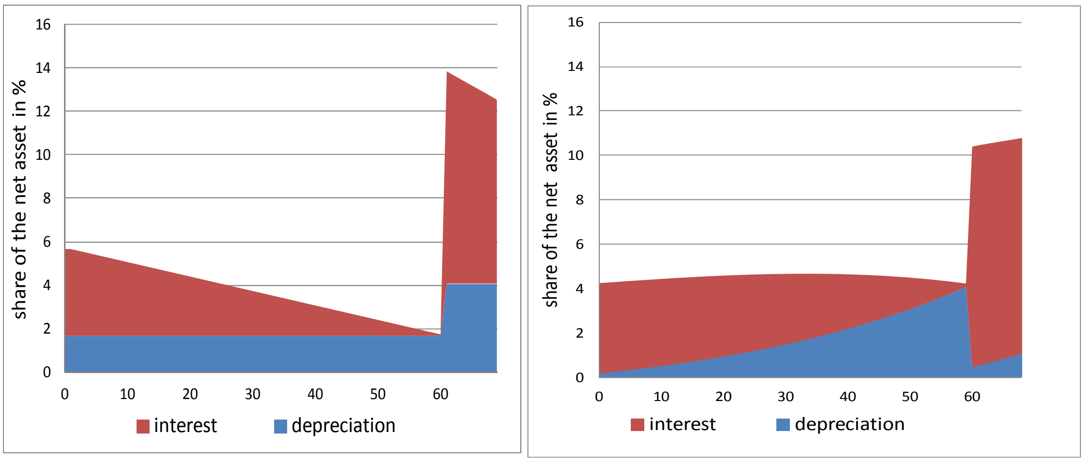
When using an economic depreciation a synthetic method can be applied for the evaluation of transport infrastructure. This method is based on detailed inventory data, which is evaluated with unit prices from real infrastructure investments. Thus, the results correspond to the current costs of asset acquisitions. Furthermore there is no necessity of reconstructing historical data about acquisition expenses. Statistical breaks during decades of infrastructure's service life can make this undertaking very difficult. For instance, due to the German reunification there is no complete data basis for the infrastructure in East Germany. (ProgTrans/IWW (2011), p. 6)

Success neutrality is an International Accounting Standard, requiring that the sum of all depreciation values and interest equal the initial investment expenses. Thus it contains no element of profit or loss. In this way market changes do not affect the present value of the cumulated depreciations and interest. Hence, the success neutrality allows a very flexible integration of long-term trends in the asset valuation. In order to comply with the requirements of the success neutrality the economic depreciation uses a nominal interest rate. (Knieps et. al. (2000)

In line with the principles of the ProgTrans/IWW infrastructure model the economic depreciation method fulfils the premises intergenerational fairness and sustainability of substance.

The economic depreciation meets the premise of intergenerational fairness by equally distributing the costs among all user generations. In contrast, in a linear depreciation the first user generation bears relatively more capital costs than the following generations. Furthermore, following user generations have to bear higher costs after reinvestments because of increasing prices-, quality- and safety-requirements, which are not considered in the linear depreciation. (ProgTrans/IWW (2011), see figure 1 as an example for capital costs of bridges)

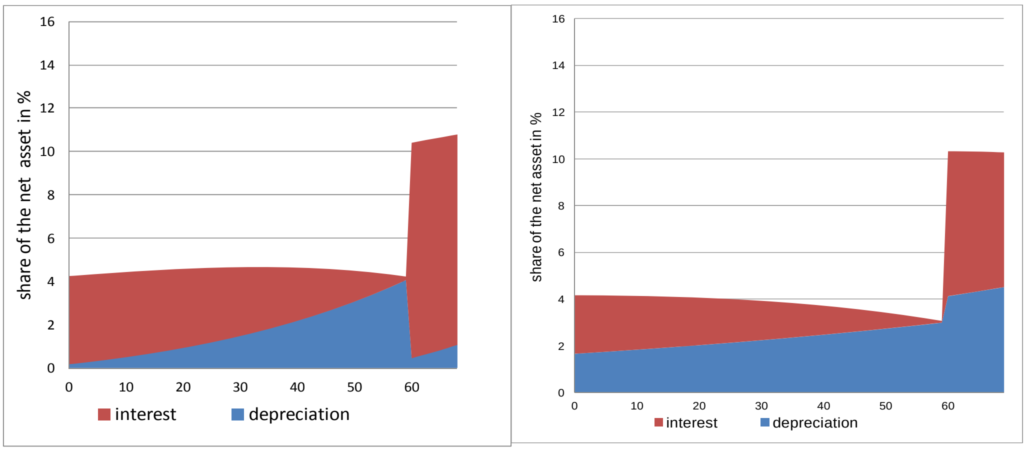
Figure 1: Comparison of economic and linear depreciation



Source: ProgTrans/IWW (2011)

Additionally the economic depreciation fulfils the premise of sustainability of substance**.** This premise is met, if the toll revenues suffice to ensure a long-term powerful road infrastructure. Also the depreciation method, which uses replacement costs, considers changes in prices and quality up to the current period. However, it does not ensure intergenerational fairness, because future costs are shifted into the present. (ProgTrans/IWW (2011), see figure 2)

Figure 2: Comparison of economic depreciation and depreciation of replacement prices

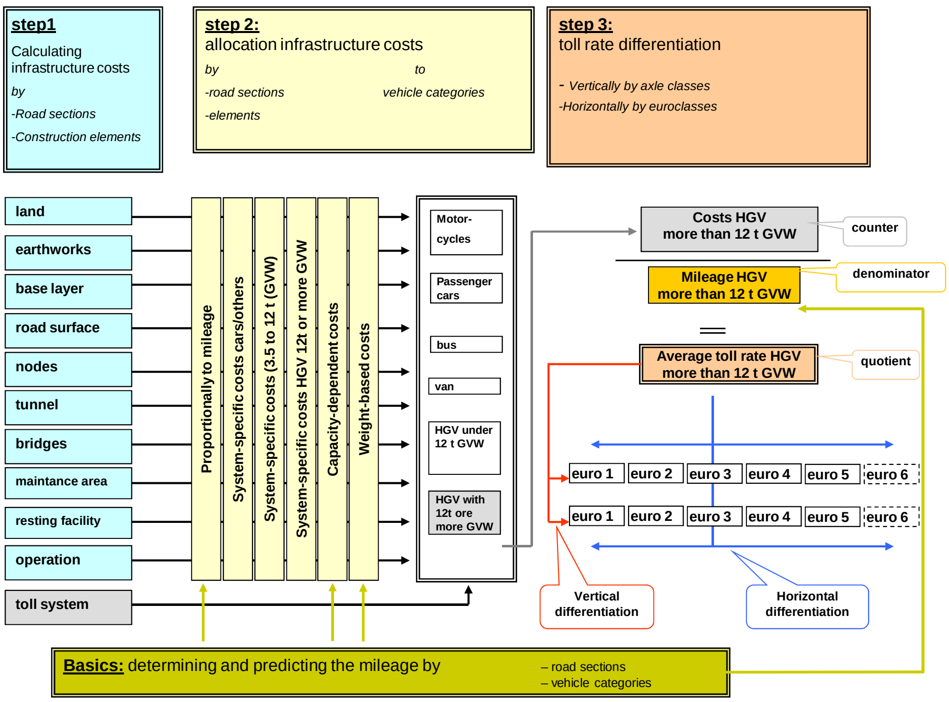


Source: ProgTrans/IWW (2011)

2.2 Model description

The ProgTrans/IWW infrastructure cost model is a disaggregated, full cost model. The costs include calculative depreciations, interests as well as operational costs. In total the infrastructure cost model consists of three calculation steps: the infrastructure cost calculation, the cost allocation and the cost differentiation (see Figure 3). In the following these steps are explained in detail.

Figure 3: overview steps of ProgTrans/IWW infrastructure cost model



Source: ProgTrans/IWW (2011)

The infrastructure cost calculation first requires a detailed inventory of different infrastructure elements, here, -for the base year 2005. Based on this inventory the road assets are calculated for the fiscal year. Simultaneously, unit cost rates are determined to assess replacement values for the base year. (ProgTrans/IWW (2011))

Afterwards the physical inventory has to be projected into the future by using information about mid-term financial planning and the current Federal Transport Infrastructure Plan (BMVBS, 2003). In this way projected reinvestments and new constructions can be identified and considered. Information about service lives and depreciation development originate from statistics and studies of the BMVBS. Furthermore, information about investment costs serves to create unit costs rates, which are predicted on the basis of expected developments of civil engineering prices. (ProgTrans/IWW (2011))

The replacement values result from the multiplication of the predicted assets and the predicted replacement unit cost prices. By adding up all replacement values the gross stock of fixed assets is determined. Subsequently, the current depreciated value of each infrastructure element is calculated by subtracting the depreciation from the replacement values. Thereby it is affected by the extrapolated and forecasted status of assets considering terms of age, quality and constructive status. The net stock of fixed assets results of the aggregation of all current depreciated values. The predicted mileage, the asset erosion, new constructions and other factors influence the net assets and hence the amount of capital. Finally the total infrastructure costs are composed of periodical depreciations, interest, operational costs as well as by reinvestments for tunnels and bridges. (ProgTrans/IWW (2011))

Afterwards the calculated infrastructure costs are allocated to six distinct vehicle categories (motorcycles, passenger cars, van, heavy good vehicles (HGVs)<12t, HGVs>12t). Depending on the characteristics of the infrastructure costs these costs are allocated based on six allocation principles. In the following these principles are explained in more detail. (ProgTrans/IWW (2011))

The allocation of weight-dependent costs causation fulfils the premise of causation. Especially HGVs destroy the road superstructure disproportionately compared to ordinary passenger vehicles. To reduce these damages roads are dimensioned in such a way, that initial expenditures are higher. But the excess expenditures are relatively low with regard to the disproportionately better load-resistance and services lives. The cost allocation by causation regards mainly HGVs and applies the principles of cooperative game theory. Therein it is assumed, that different prospective user categories have to negotiate about the dimension and cost distribution. Solutions for these negotiations can be found by Shapley values, which rely on axioms reflecting efficiency and fairness criteria

The weight-dependent cost allocation of use regards the vehicle category's mileages. It is based on engineering scientific knowledge resulting from the American Association of State Highway Officials (AASHO) road test in the USA, which refers especially to road superstructur. The costs are allocated by weighting the mileage with the load-specific equivalence factor of the AASHO function. This function describes the functional connection between the stress reversals and the deterioration of road superstructure depending on different axle loads. Considering the results of the AASHO road test the weight-dependent allocation of costs by usage is primarily relevant for HGVs since heavy vehicles are mainly responsibly for destroying the road's superstructure.

After attributing the costs by the principles of use and causation the remaining infrastructure costs are mainly "real overhead costs". For the allocation of these overhead costs capacity-based and proportional-based distribution keys are applied. Corresponding to the principle of causation certain user groups require more capacity compared to other groups. For expressing this circumstance of different capacity necessities the capacity-related cost allocation uses equivalence numbers, which are weighted with the mileage of the respective vehicle category. Costs, independent from the vehicle mileage, are distributed by a proportional key to every user group.

Certain costs incur due to specific system characteristics of vehicle categories. Thus these vehicle categories have to bear these costs. For this kind of allocation the vehicles are distributed in three vehicle categories: light HGV, HGV < 12t and HGV >12t. Thereupon a certain share of costs is attributed to each vehicle category without any consideration of mileage. Table ... shows an overview of the cost allocation of different constructive elements by six allocation principles. (ProgTrans/IWW (2011))

Table 1: distribution of cost categories by allocation principles

Construction categories		Allocation principles					
		P	Sc	Slgv	Shgv	C	AASHO
Land acquisition						100	
Earthworks/ drainage	(B)					100	
	(M)					100	
Base layers	(B)		X	Y	Z		
	(M)						
Binders	(B)						
	(M)						
Road surface	(B)					100	
	(M)						100
Tunnels	(B)	45			5	50	
	(M)	80			20		
Bridges	(B)				15	85	
	(M)				15	85	
Equipment	(B)	33				67	
	(M)	33				67	
Branches, nodes	(B)	20	20	10	10	40	
	(M)	15			10	40	35
Motorway maintenance depots	(B)	33				67	
	(M)	33				67	
Service areas and lay-bys	(B)	20	15	5	60		
	(M)	20	15	5	60		
Administration/police		33			67		
Upkeep		35		15	50		

Total for each row = 100; P: Proportionally distributed costs (linear by vehicle kilometres), Slgv: System-specific costs (goods vehicles up to 12t GVW), Shgv: System-specific costs (HGVs 12t or more), C: Capacity-dependent costs (equivalent values), ASSHO: Weight-dependent costs. Source: ProgTrans/IWW (2011)

The third step of the infrastructure cost model is the differentiation of costs. It regards only HGV>12t, which are currently subject to the toll in Germany. The costs allocated to each vehicle category are differentiated in a vertical way by two axle classes (up to three axles and more than three axles) and in a horizontal way by six different emission classes. Based on the Toll Level Regulation (MautHV) four toll rate categories A to D have to be created as follows:

- A: Enhanced Environmentally Friendly Vehicle (EEV), Euro 5, Euro 6
- B: Euro 4
- C: Euro 3
- D: Euro 2 and worse

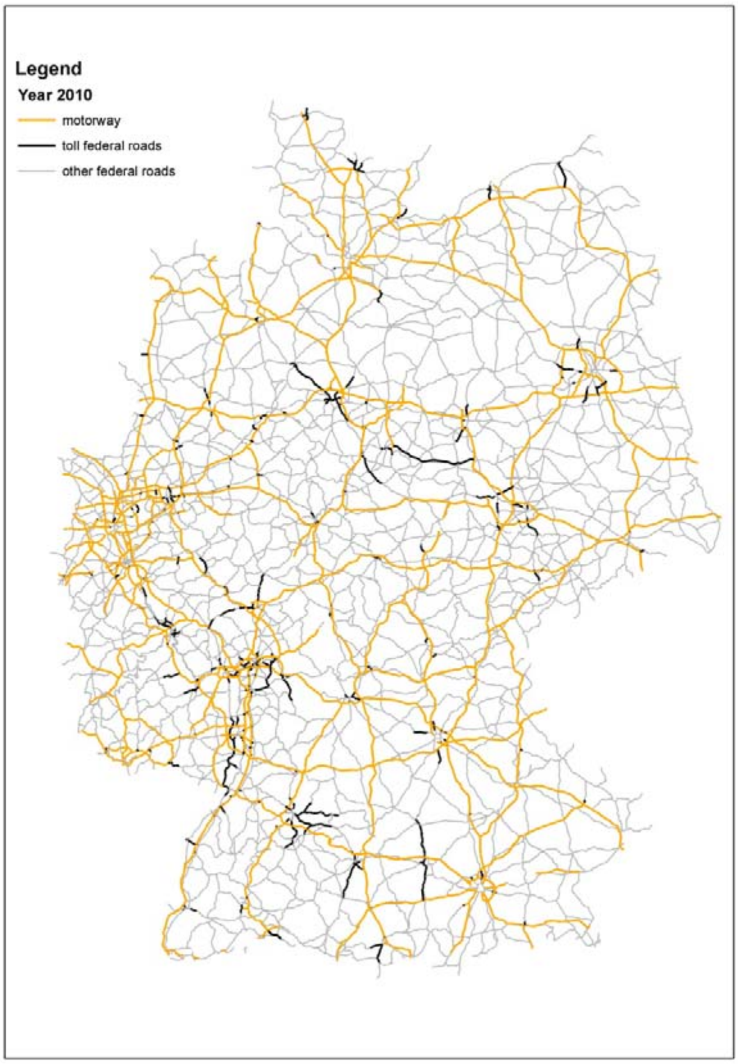
In accordance with the Toll Level Regulation (MautHV) the spread of the average toll rate between category A and D is maximum 100%.

The horizontal differentiation of the average toll rate takes place by using toxicity equivalents to nitric oxide or by using external costs of specific pollutants. The toxicity factors base upon information of the Recommendations for Economic Studies on Roads published by the Research Society for Road Traffic (FSGV (1997)). This factor is multiplied by the emission per pollutant and subsequently aggregated for every emission category to a category-specific total toxicity. Alternatively, external costs may serve for the differentiation of the average toll rate. For particles as PM10, PM25, nitric oxide and carbon hydride external costs are quantified on the basis of different scientific studies. These costs are multiplied by emissions of each emission class resulting in total weighted external costs per emission class.

3. Results of the application to selected federal roads

Based on information of the Federal Ministry of Transport, Building and Urban Development the analysed roads have been divided into three road categories: motorways, four-lane federal roads with a direct connection to motorways and other federal roads. The selected four-lane federal road sections are predominantly located in agglomeration areas like Frankfurt, Stuttgart or Ruhr (see figure 4). Moreover, there are several road sections of national-wide significance. All in all the total length of four-lane federal roads is 2138 km. This corresponds 4% of the total length of all highways (federal roads and motorways). For calculating the infrastructure capital costs the ProgTrans/IWW infrastructure cost model has applied a nominal interest rate of 4.5%.(ProgTrans/IWW (2011))

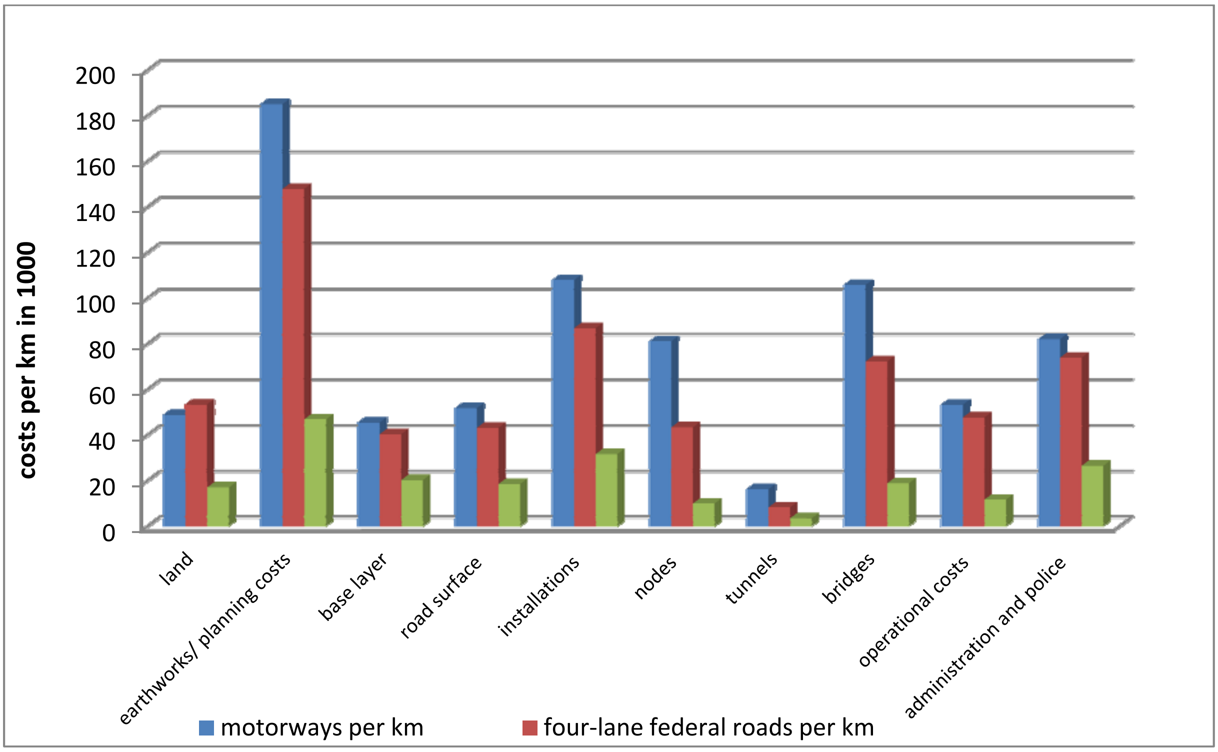
Figure 4 Network of four lane federal roads, motorways and other federal roads 2010



Source: ProgTrans/IWW (2011)

In comparison the infrastructure costs per kilometer of motorways are about 30% (803.426€/km) higher than costs of four-line federal roads (618.197€/km) and four times more than other federal roads (204.987€/km). Especially nodes, tunnels and bridges of motorways and four-lane federal roads are more expensive than other federal roads. These extra costs result on the one hand from more lanes per kilometer on motorways. On the other hand this is due to a larger dimensioning of these road sections, which results in higher assets and capital costs. In comparison to motorways the land costs per kilometer on four-line federal roads are about 9% higher. This results from a relatively high proportion of four lane federal roads in agglomeration areas, where land is more expensive. (ProgTrans/IWW (2011)).

Figure 5: Comparison of costs per km for selected infrastructure elements on motorways, four-lane federal roads and other federal roads

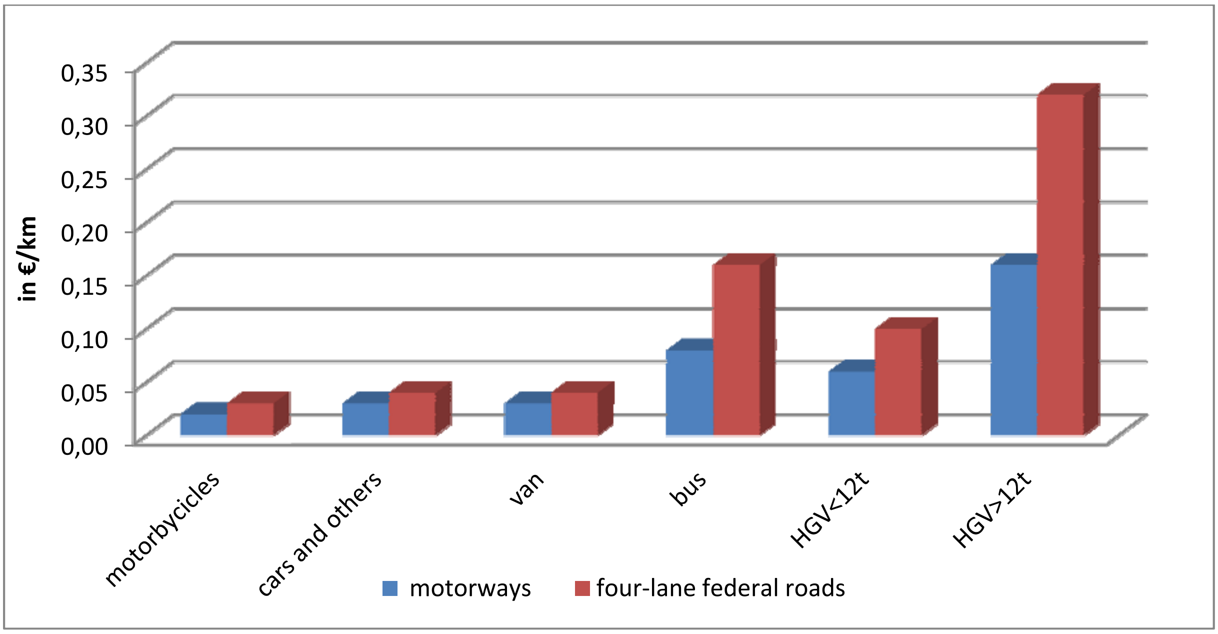


Source: ProgTrans/IWW (2011)

For allocating infrastructure costs to several vehicle categories information on vehicle mileages of the respective category is necessary. For this purpose information is adapted, which has already been used for the infrastructure cost model in the year 2007. This information is mainly based on an intern data set of the Federal Highway Research Institute (BASt) revealing for instance, information about lane numbers, average daily traffic volume and length of road sections. This data set served to reconstruct the average daily traffic volume for four lane federal roads and other federal roads has been reconstructed for the six vehicle classes.

As already explained in chapter 2.2 the infrastructure costs of four-lane federal roads have been allocated to six different vehicle groups. Figure 6 shows the average toll rate on selected four-lane federal roads and motorways by vehicle categories. The average toll rate on four-lane federal roads for HGVs>12t and busses is twice as high (0,32€/km) as the average toll rate on motorways (0,16€/km). Cars and motorcycles have to pay in average 33% more on four-lane federal roads than on motorways. This consideration can be explained by comparatively small mileages of busses and HGV>12t (0,5% of total mileages) and at the same time high costs of infrastructure dimensioning (30,3% of total costs) allocated to these categories. The major part of the infrastructure costs of four-lane federal roads is allocated to cars (62%), which use these four-lane federal roads with a share of 86% of total mileage. (ProgTrans/IWW (2011))

Figure 6: Average toll rate for selected four-lane federal roads and motorways by vehicle category 2010



Source: ProgTrans/IWW (2011)

The differentiated calculations for HGV>12t via toxicity factors as well as via external costs entail similar results. Corresponding to the allocation results also the differentiation calculation shows considerable higher specific toll rates of different euro classes on four-lane federal roads compared to motorways.

4. Conclusion

The ProgTrans/IWW model is a fair and activity-based infrastructure cost model. In contrast to other infrastructure cost models this model uses a future-oriented approach by applying the economic depreciation. In this way changes in prices and quality affecting the net asset, can be taken into account without failing the success neutrality.

It could be shown, that this model can be applied for a differentiated infrastructure costs analysis. Because of a decision o the German parliament road user charges will not only be taken on motorway but also on four-line federal roads, which are directly connected to motorways. When comparing the infrastructure costs of these road sections it could be shown that infrastructure costs on four-line federal roads and motorways are considerable higher than on other federal roads. When allocating these costs especially HGV>12t have to bear high average costs per vehicle due to low mileages.

5. References

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