Infrastructure Cost Calculation and Charging for Heavy Goods Vehicles on German motorways

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Abstract

In 2002 a consortium consisting of ProgTrans (Basel) and the Institute for Economic Policy Research (IWW) at the Universität Karlsruhe (TH) developed a method for infrastructure cost calculation and charging which has been updated in 2007. The results of the two studies serve as the basis for the road user charges for HGVs on German motorways. The present paper describes the basic principles of the approach which is based on fairness and efficiency criteria. The calculation algorithm uses a disaggregated approach contrary to most of the traditional cost calculation schemes which are described shortly in this paper. Afterwards, the implementation of the approach and its results are presented. Finally, first experiences with the adaptation of the approach to other network industries are given.

Keywords: Life-Cycle Cost, Infrastructure Cost Calculation, Cost Allocation, User Charges

1. Introduction

In 2001 the German federal cabinet decided to introduce a distance-based toll-system for the German motorways. The toll system is applied to Heavy Goods Vehicles (HGV) and detaches the existing Eurovignette which has been in operation since 1995. According to the EC-Directive 1999/62/EC and its succession directives, charges should meet the expenses for construction, operation and maintenance of the trunk road network. Therefore, an approach is needed which fulfils these requirements.

In 2002 a consortium consisting of ProgTrans (Basel) and the Institute for Economic Policy Research (IWW) at the Universität Karlsruhe (TH) developed a method for infrastructure cost calculation and charging. The results served as the basis to determine the road charges for HGV on German motorways. In 2007 an update of the study was carried out. This update should integrate up-to-date data on infrastructure development, cost and mileage. In addition there was an amendment of Directive 1999/62/EC and incentives for reducing air pollution should given by a price differentiation. The present paper compares different European approaches briefly, describes the developed methodology of ProgTrans/IWW and especially the modifications and analyses its results. Finally, the conclusion demonstrates the applicability and usefulness of the cost calculation method in other network industries.

2. Comparison between European approaches for Infrastructure Cost Calculation

Especially in Central and Northern Europe comprehensive cost calculation schemes have been developed over the last decades (Doll, 2004). The traditional approach bases on the principles of a “public administration” business model. One example of such a traditional approach is the Perpetual Inventory Method (**PIM**) of the German Institute for Economic Research (DIW) which was developed by the Enquête Commission of the German Parliament in 1969 (Enquête Commission, 1969). This cost calculation method applies an aggregated approach by activating real and planned expenses grouped by four clusters of structures (DIW, 2000): earthworks, pavement, tunnel/bridges and equipment. PIM capitalizes time series of annual investment expenditures by cumulating the annual investments and by subtracting the values of those assets which exceeded their life-expectancy (Ecorys, 2005). Total cost is allocated to the infrastructure users by using three types of allocation keys: ASSHO factors, capacity demand factors for fixed cost and unweighted allocation keys.

The objective of the German government to implement a charging system on motorways where charges are based on an infrastructure cost calculation method, leads to the challenge that a future-oriented decision-making approach is needed.

Price cap regulation is applied in **Italy** where franchisees build, operate and manage their network under the framework of a concession. Charges are calculated to payback the initial investment as well as management and maintenance costs. The idea behind the approach is to give incentives to the natural monopolists to become more efficient. Historical tariffs are adapted on the base of the national inflation rate, parameter for cost recovery (including benefit mark-up) and a quality parameter of the road infrastructure. Despite the objective of setting incentives, the Italian tariffs increased monotonously over time and users did not benefit from efficiency gains. On the other hand financial results of all franchisees have been outstanding and much above average Italian enterprises (Gallo, 2007).

Contrary to the Italian price cap regulation is the **Austrian** full-cost calculation method. Based on average investment expenses per kilometre, the total value of the gross assets is calculated. Running expenses and capital costs are allocated using the approach of general allocation keys. Regression analyses between capital costs/running expenses and the three parameters vehicle-kilometres, axle-load weighted kilometres and gross-weight weighted kilometres are applied to identify allocation keys for every user group. The user tariffs are then derived from the two parameters total cost and allocation key. Methodological challenges of the Austrian approach are the phenomenon of fallacious regression, various possibilities for colinearity (km, tkm) and the existence of a basic cost independent of the vehicle-load (“fixed-cost”). Some of these problems have been handled by assuming linear regressions through the origin and by separating regressions for each of the three explaining variables.

Further approaches for cost calculation and charging are found in several countries around the world. Most of these approaches are not suitable with the European Directive 1999/62/EC which postulates a fair charging mechanism, the encouragement of less-polluting vehicles through toll differentiation, a non-discriminatory system, user-charges based on duration of the use and in relation to the costs by the road vehicle. The following method bases on the requirements of the European Commission and has originally been developed for the German trunk road network.

3. German methodology for Infrastructure Cost Calculation

The cost calculation method is based on fairness and efficiency criteria and assumes a theoretical business model of a public enterprise. **Fairness principles** include usage-based fairness, causative fairness and intergenerational fairness. Usage-based fairness means that the deterioration of construction elements which is caused by one user category should be attributed to that category. Causative fairness means that user categories which are responsible for the dimensioning or provision of certain elements should bear the associated costs. This is especially true if the user group in question causes very little of deterioration and thus only a minimal share of the usage-based cost is allocated to this group. Intergenerational fairness means that a given generation of users should only bear the share of the cost that corresponds to the use of infrastructure by that generation of users. The present generation of users should not gain an advantage by postponing financial burdens until a future date, nor should future generations have the advantage of using infrastructure for free that was paid for by earlier generations of road users.

Efficiency is defined in a dynamic way meaning that the payments of the users ensure that the road network can be extended according to demand and that necessary maintenance works can be conducted at the economically indicated times.

The calculation algorithm is inspired by an engineering thinking. It uses a highly disaggregated approach. Each single constructive element is considered individually where data has been available. Roads are considered complex objects consisting of a huge set of (independent) sub-elements, such as bridges, road layers, tunnels etc. Each sub-element (e.g. bridges) is treated individually and thereby its specific attributes can be incorporated into the approach. The authors find that this disaggregated approach has the following advantages

- The potential error rate of the model is reduced by the definition of a standardised object category: in the mathematical model, all point-based cost elements are dealt with according to the same pattern.

- A differentiated inventory of existing physical capital is needed to justify the age distribution of the capital in regard to the specifications of the infrastructure cost Directive of the European Commission.
- The main reason, however - from an economic point of view - is the improved allocation of the infrastructure cost to the user categories in sections.

The applied infrastructure cost calculation method is based on the principles of Life Cycle Cost Calculation (LCC). In each period, the decisions on future investments are based on demand expectations for this specific road section. Each decision is accomplished against the background of minimizing life-cycle costs. The chosen approach calibrates the total investments with the German Federal Transport Investment Plan (BVWP 2003) to be in-line with the expected developments of the infrastructure (maintenance, upgrading, and extension).

The **gross stock of fixed assets** is calculated using replacement prices which were identified from the asset data (length, width and/or capacity of structures) and using detailed **unit prices**. Differentiated data on structural assets were composed from the BMVBS and the BASt, as well as investigations made by the consortium, where these were deemed necessary. The calculation approach distinguishes between the following asset categories:

- Land acquisition,
- Earthworks,
- Road layers (base layer, binder and road surface),
- Nodes (motorway junctions and turnoffs),
- Equipment,
- Bridges,
- Tunnels,
- Motorway service areas (with or without service) and
- Maintenance depots (motorway, highway or otherwise).

In a second step, equity that has already been used up from the gross stock of fixed assets must be eliminated. The **net stock of fixed assets** is derived from the elimination. The method used by the authors evaluates the net stock of fixed assets based again on individual components. Age, quality and expected strain on a component determine the remaining service life or, alternately, the residual output. In cases in which the economic service life of a component is independent of the load, the net assets are determined by the relation between the projected remaining service life and the expected total service life. In cases in which the service life is mainly dependent on the load, the net assets are determined by the relation between the projected residual output and the expected total output. Just like the total and residual output, the expected load is expressed in the number of transits of equivalent 10-tonne axles.

The application of LCC together with the assumption of a public enterprise business model requires economic **depreciation** in the cost calculation approach. In dynamic markets with accelerated depreciations and reinvestments, the economic depreciation distributes the financial burden between different user generations fairly (inter-generational and intra-generational fairness). Furthermore, economic depreciation satisfies the requirement that the sum of depreciations over time for each individual element (e.g. single bridge) is equal to its investment expense.

A future-oriented cost calculation approach needs to **predict the development** of unit prices of replacement and the development of standardized net assets (including depreciation and reinvestments). Replacement values are predicted using indexes of construction prices that are assigned nominal increase of 1% p.a. for the future to take technological advances into account.

Three different methods were used to predict the standardized net assets in accordance with the deterioration characteristics and the corresponding depreciation options, namely stochastic depreciation with cyclical reinvestment with time- and load-based variations, deterministic depreciation without cyclical reinvestment and the “50% hypothesis “[1].

The total cost (capital costs including depreciation and interest plus maintenance and running expenses) for each user generation is allocated to different user categories (e.g. HGV, passenger cars, etc.) accord-

[1] Further information on the approach can be found at ProgTrans/IWW, 2007.

ing to the principle of usage-based fairness (allocation calculation). The costs of the individual components are attributed to the following **allocation principles** using distribution keys:

- Costs attributed proportionally (linearly by distance driven),
- System-specific cost caused by cars,
- System-specific cost caused by light commercial vehicles (3.5 to 12 t GVW),
- System-specific cost caused by HGVs (12 t or more GVW),
- Capacity-dependent costs and
- Weight-based costs.

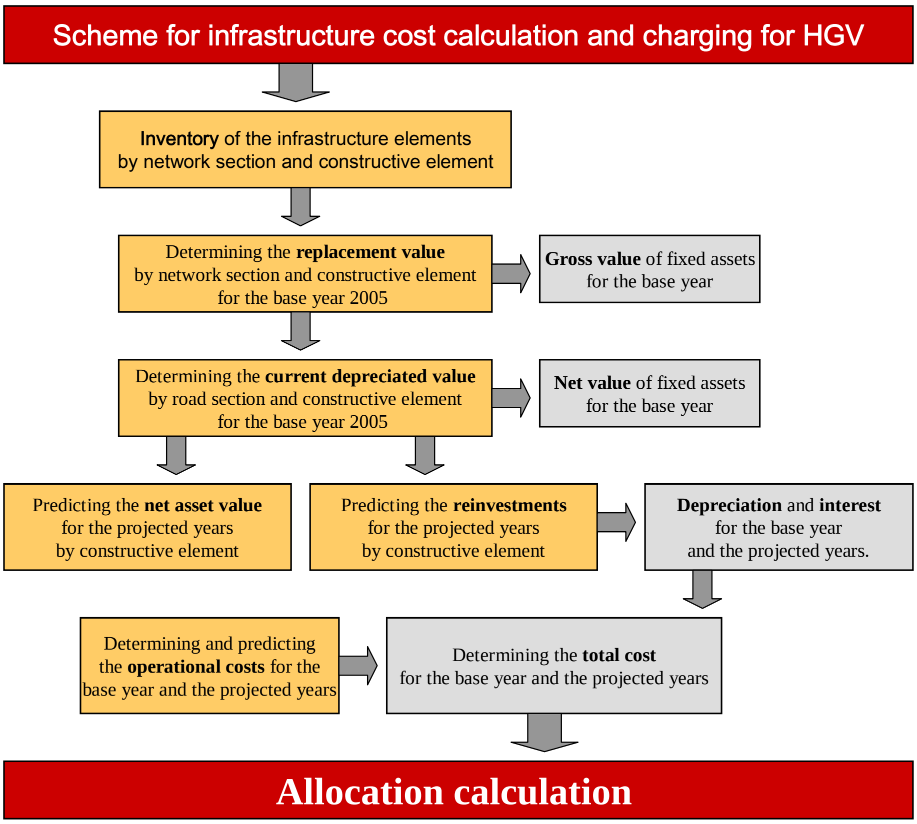

Figure 1: Structure of the infrastructure cost calculation and charging for goods vehicles

Source: ProgTrans/IWW

4. Implementation and Results

The study object is the **trunk road network** of the German Federal Transport Investment Plan (BVWP 2003). The provided data on the network was encoded geographically by a geographical information system. Information on the type of the road, the number of lanes, the existence of a hard shoulder, the age and location of the section have been available. This enables a detailed regional allocation of the individual road segments. Special attention was given on the hilliness classification of each road section as the geography of the surrounding area heavily influence the total cost of construction works. The hilliness of terrain has been calculated as the standard deviation of the altitude of fictitious nodes nearby the infrastructure node or section under consideration. Figure 2 shows the results of the determination of hilliness for the network of German trunk roads.

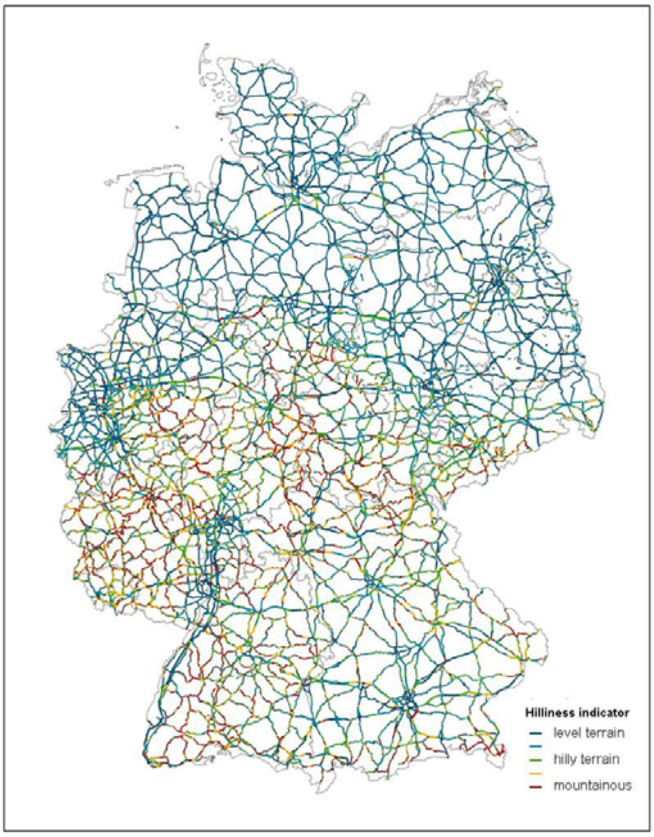

Figure 2: Hilliness of terrain along the network of German trunk roads

Source: ProgTrans/IWW

Based on the road network information, infrastructure costs for land works, earthworks, base layers, road surface and equipment/installations (road signs, noise barriers, traffic control system, guard rails, etc.) are calculated.

Point-based objects, such as bridges, tunnels, nodes, maintenance depots and service areas/lay-bys are geographically allocated to the network and treated individually. Inventory data was supplied among others by the German Federal Highway Research Institute (BASt). For instance data on bridges included the parameters geographical location, width, length, age and class of material (see Figure 3).

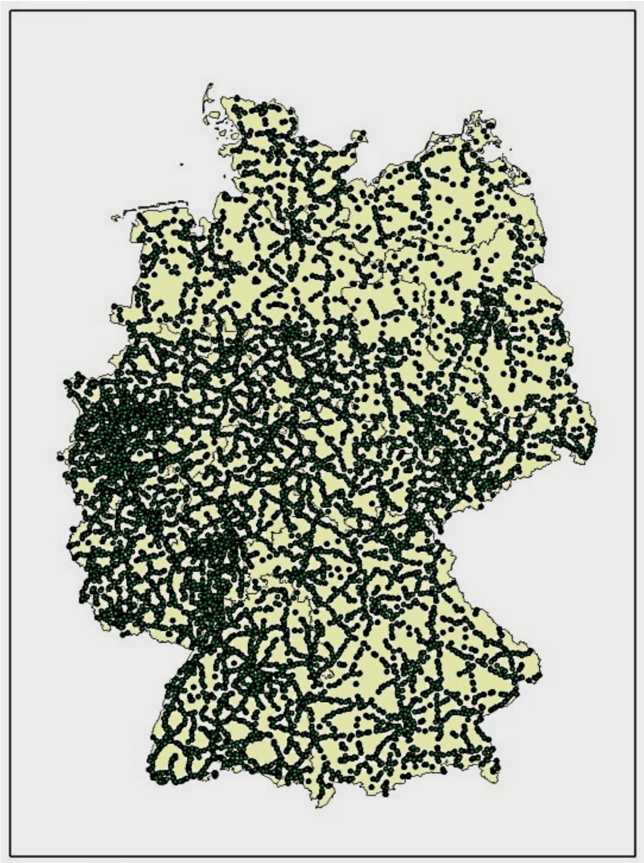

Figure 3: Bridges in the network of federal trunk roads[2]

Source: ProgTrans/IWW

This infrastructure cost calculation methods include the cost of infrastructure planning. The existence of planning cost is out of question. But it is difficult to estimate its value as different planning stages at different governmental levels are involved in the planning process. Therefore, the former study on infrastructure cost calculation (ProgTrans/IWW, 2002) used the official number of 3% which corresponds to

[2] The map contains the current inventory of bridges, including all bridges which will be completed by 2009 (current status).

the subvention from the federal government to the federal states for realised infrastructure investments (including construction management and construction supervision). Recent studies on estimating the value of planning have been carried out which justified well-grounded assumptions on planning costs far-beyond the official 3%. Studies of the Federal Accounting Office of Baden-Wuerttemberg (18-21%, 2003), of the Federal state of Schleswig-Holstein (10-12%, 2002), of the economic advisors of the CDU (56%, 2005) and of the DEGES, the German Unity motorway planning and construction company (15%, 2008) prove a higher share of planning costs. The authors apply a total share of 18% on the total investment costs dedicated to the whole planning process.

In the base year, 2005, the gross stock of fixed assets for the federal motorways amounted to 164.04 billion Euro. The largest cost categories are the cost of earthworks including planning costs (45.60 billion Euro), bridges (30.8 billion Euro), and nodes (18.58 billion Euro). The net stock of fixed assets for the year 2005 is about 111.52 billion Euro; this corresponds to 68% of the gross stock of fixed assets. Compared to the previous infrastructure cost calculation of 2002, which predicts a share of 61% for the year 2005, the average age distribution of German trunk roads has improved significantly. For the most part, this is due to a reassessment of the value of road surfaces and a stronger emphasis on the cost category "land acquisition", which does not depreciate over time. Finally, the total infrastructure costs are calculated at 9.53 billion Euro of which 4.08 billion Euro are allocated to HGV of 12 tonnes and more (43% of total costs).

The infrastructure cost projections for 2007, 2008, 2010 and 2012 show that only a slight increase in the total cost of the federal motorways is expected. The rise between the base year 2005 and the projection 2012 is predicted to be approximately 4% per year. The age distribution coefficient for federal motorways is predicted to decrease from 68% to 65%

Comparing the results with existing infrastructure cost calculation approaches of Austria, France and the PIM-approach it can be observed that

- a lower percentage of costs is allocated to HGV and
- higher charges are calculated for younger user generations (intergenerational fairness).

Both observations are in-line with the recommendations of the European Commission which postulates a fair charging mechanism between generations and within each generation and that charges are appointed in relation to the costs each vehicle category either causes (wear and tear of the roads) or induces (design of the roads).

5. Conclusions

The present paper describes the approach for infrastructure cost calculation and cost allocation which has been used for the German motorway network. The results are the basis for road charges on German motorways but only HGV are charged so far. Total infrastructure costs amount to 9.53 billion Euro of which 4.08 billion Euro is allocated to HGVs in 2005. For the coming years a slight increase in costs and fixed assets can be expected.

The results of the infrastructure cost approach are compatible with the economic assessment methodology of a Cost-Benefit Analysis, the principles of engineering decision making (dimensioning of the road layers) and the International Accounting Standards (economic depreciation). The approach supports the economically viable long-term development of infrastructures and it is a point of reference for cost calculation in other network industries (e.g. energy, telecommunication, etc.). It is suited for various kinds of business models – public, semi-public and private corporations.

In contrast to the aggregate and past-oriented PIM method, the developed approach always considers the actual state of the infrastructure. This is important since construction technology has further been developed in the past decades and the expectations on service life times of structures have changed significantly. The high degree of detail in the presented approach enables studying infrastructure cost of individual road sections or road sub-systems. This gives decision support when attracting private capital in form of partnership models, when remodelling the business model of the road operator and finally for price regulation.

First experiences with the adaptation of the developed approach to other transport modes showed its multisided applicability. Ott (2006) applied the approach to railway infrastructure and calculated the private infrastructure costs of a railway company. On behalf of the Deutsche Bahn AG, the Institute for

Economic Policy Research (IWW) estimated the infrastructure costs on selected corridors of the German railway network (IWW, 2002). The calculation shows that railways are able to cover their full infrastructure cost on their core network. Finally, Deutsche Lufthansa AG mandated IWW to estimate the infrastructure costs and their degree of cost coverage at German airports (IWW, 2005).

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