COMPETITIVE AND SUSTAINABLE GROWTH (GROWTH) PROGRAMME

UNITE

UNIfication of accounts and marginal costs for Transport Efficiency

Deliverable 10

Road econometrics – Case study motorways Switzerland

Version 2.2
20 March 2002

Authors:

Christoph Schreyer, Nicolas Schmidt, Markus Maibach, (Infras)
with contributions from Partners

Contract: 1999-AM.11157
Project Coordinator: ITS, University of Leeds

Funded by the European Commission
5th Framework – Transport RTD

UNITE Partner Organisations
ITS/UNIVLEEDS (UK), DIW (De), NEI (Nl), CES/KUL (Be), TIS.PT (Pt), IWW/UNIKARL (De), VTI (Se), IER/USTUTT (De), CERAS/ENPC (Fr), HERRY (Au), EIET/ULPGC (Es), ISIS (It), STRATEC (Be), SYSTEMA (Gr), JP-TRANSPLAN (Fi), VATT (Fi), ECOPLAN (Ch), INFRAS (Ch), EKONO (Fi), EKI (Se)

UNITE

1999-AM.11157
<u>UNIfication of accounts and marginal costs for Transport Efficiency</u>

Deliverable 10: **Road econometrics – Case study motorways Switzerland**

This document should be referenced as:
Schreyer C, Maibach M, Schmidt N (Infras) (UNIfication of accounts and marginal costs for Transport Efficiency) Deliverable …. Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, January 2002.

30 January 2002

Version 2.2

Authors: as above, with contributions from other UNITE partners

---

PROJECT INFORMATION

Contract no: 1999-AM.11157:
<u>UNIfication of accounts and marginal costs for Transport Efficiency</u>

Website: www.its.leeds.ac.uk/unite

Commissioned by: European Commission – DG TREN; Fifth Framework Programme

<u>Lead Partner</u>: Institute for Transport Studies, University of Leeds (UK)

<u>Partners</u>: ITS/UNIVLEEDS (UK), DIW (De), NEI (Nl), CES/KUL (Be), TIS.PT (Pt), IWW/UNIKARL (De), VTI (Se), IER/USTUTT (De), CERAS/ENPC (Fr), HERRY (Au), EIET/ULPGC (Es), ISIS (It), STRATEC (Be), SYSTEMA (Gr), JP-TRANSPLAN (Fi) VATT (Fi), ECOPLAN (Ch), INFRAS (Ch), EKONO (Fi), EKI (Se)

DOCUMENT CONTROL INFORMATION

Status: Version for Submission
Distribution:
Availability:
Filename:
Quality assurance: <QA reviewer, organisation, date>
Coordinator's review:
Signed: **Date:**

Table of Contents

Abbreviations

AFP	Factor used in national road account for allocation of weight independent costs
Aggression Factor	Factor used in national road account for allocation of weight dependent costs
ASTRA	Bundesamt für Strassen (Swiss Federal Roads Office)
BFS	Bundesamt für Statistik (Swiss Federal Statistical Office)
GDP	Gross domestic product
GVF	Dienst für Gesamtverkehrsfragen (Service for Transport Studies)
GVW	Gross vehicle weight
HGV	Heavy goods vehicles
LGV	Light goods vehicles
LAVOC	Laboratoire des voies de circulation (EPFL)
PPP	Purchasing power parity
TCS	Touring Club Switzerland
VAT	Value added tax

0 Summary

Aim and methological approach

This case study aims at estimating marginal infrastructure costs of operational maintenance, constructional maintenance and upgrade and renewal for Swiss main roads and highways. This has been done using an empirical approach looking at maintenance practice in relation of traffic levels and gross tons and axle loads respectively. It is the first time that such an approach has been applied. Initial studies for Switzerland were deriving specific percentages for HGV using an engineering approach, in order to allocate total costs to specific traffic categories.

Basically the results are based on two data sets and two approaches:

- **Time series analysis**: Operational maintenance costs, constructional maintenance costs and costs for upgrade and renewal for Swiss main roads and highways for 26 cantons and a time series 1985-1998. These variables were regressed with traffic volumes (differentiated according to vehicle categories) and a couple of dummy variables, like budgetary constraints and years of recession.
- **Cross section analysis**: Constructional maintenance costs for 127 highway section and four years differentiated according to cost categories (i.e. pavement, bridges and tunnel). This data set was regressed with specific traffic volumes. Several equations tried to find out specific correlations between cost categories and vehicle categories.

Both approaches were used to find cost function in order to derive marginal costs per vkm differentiated according to vehicle categories. For this purpose several functional forms have been applied.

General findings

It was easy to find a strong correlation between the cost level and traffic volumes with all data sets. More differentiated approaches however failed. Due to collinearity problems, it was not possible to find statistically significant differences between vehicle categories, especially for HGV.

The following table gives an overview on the resulting marginal costs of the time series analysis. There are several reasons for that. Firstly, the variance of HGV shares for different road sections is too small. Interesting sections like transalpine highways, were HGV shares are significantly higher, could not be considered due to specific events (like the flood problems in 1988, which disturbed ‘normal’ constructional maintenance). Secondly, one has to consider that the traffic data set is not strong enough to derive differentiated shares of HGV volumes. For example only there are only few WIM (weight in motion) installations to measure specific weight and number of axles available. Thirdly, based on several interviews with road maintenance agencies, one has to consider suboptimal maintenance practice due to budgetary reasons. Although it was not possible to find a statistically relevant correlation, it is obvious, that many necessary maintenance and upgrade projects had to be postponed due to budgetary reasons.

The most model fit was provided by rather simple equations using one or two influence factor. Complex multivariate equations were not appropriate. The best fit was provided by the variables ‘total traffic volume’ and ‘gross weight’.

With this output it was possible to derive so called mean marginal costs. In order to have more differentiated results we applied two additional methods:

- Statistical method: Based on the independent variable ‘gross weight tons’, it was possible to derive weight related marginal costs.

- Engineering method: Based on the results of available Swiss studies for different damage factors per standard axle (similar to the AASSHO-method), it was possible to differentiate marginal costs according to the main vehicle categories.

Marginal costs results
In general we conclude that the time series analysis present the best guess of marginal costs for different cost categories and different vehicle categories. The cross section analysis has been used for the plausibilisation of results. Due to the data availability for only four years, it was difficult to get comprehensive results since one has to consider that average maintenance cycles for constructive maintenance are around 12 years (according to the assumptions of the Swiss road account9.
The following table present the results:

Table S-1: Marginal infrastructure costs based on time series analysis

EUR/veh-km		**Cars**	**Trucks**	**Mean**
Operational maintenance costs	Statistical method	0.0027	0.0027	0.0027
Constructional maintenance costs	Statistical method	0.0019	0.0302	0.0037
	Engineering method	0.0014	0.0428	0.0039
Costs for upgrade and renewals	Statistical method	0.0004	0.0062	0.0008
	Engineering method	0.0001	0.0033	0.0003

It has to be considered that the marginal cost figures are decreasing with increasing traffic volumes.

The results of the road section analysis are comparable to those of the time series analysis. Marginal costs for passenger cars are slightly higher (0.3 Cents vs. 0.2 Cents per veh-km). Marginal costs for trucks are about the same as in the time series analysis.

Comparison with existing studies shows that conclusions of the new calculations are fairly consistent with already existing results. But it is not possible to compare them directly due to the different methodological approaches. In the existing studies it is also not very obvious which cost categories for the calculation of the marginal costs were included and which were not. The results of the existing case study for Heavy Goods vehicles (HGV) are more in the area of already existing studies for France and Germany. But they are substantially lower than those of the existing studies for Switzerland.

Conclusions and transferability of results
It was possible to find statistically relevant cost curves for Switzerland, although they could not be differentiated very much. In order to transfer the results to Switzerland as a whole and to Europe, one has to consider the following arguments:
- Due to the specific HGV-policy (esp. 20 ton limit), the road construction parameters and the traffic characteristics are different to other countries.
- The specific maintenance practice in Switzerland (small sections within cantons) are restricting optimal solutions per section. Thus the Swiss sample is too small to allow general conclusions for other countries.
- The situation in the alpine region is very specific and cannot be transferred to other countries. First of all the topographical parameters are very specific (tunnels, bridges), secondly the weather vulnerability is rather high which influences the level of constructive

maintenance. However – as the analysis has shown – these factors are very difficult to treat within an econometric approach.

Finally the exercise for Switzerland allows some conclusions of the transferability and the further development of the approach itself and its relative importance to an engineering based approach It was clear in advance that an econometric approach is not able to estimate optimal marginal infrastructure costs, due to many different real factors which deviate from optimal conditions, such as budgetary reasons, practical reasons, other exogenous influences such as weather conditions or accidents, which are different to isolate.
The exercise has shown as well that the data availability is a very critical factor. This is true for cost figures (maintenance, operation, construction) and the related traffic data incl. weight information. Even in Switzerland – which has rather a good data availability – the situation was insufficient. A more detailed approach would lead to very big expenses.
Data availability is a very crucial factor for this type of analysis. Most important is the availability of a rather high variance between HGV-shares on different roads, if a weight dependent relationship should result. This was not the case in Switzerland.
Thus we might conclude that the approach is valuable to show a strong relationship between traffic volume and road expenses. For the computation of optimal marginal infrastructure costs by category, an engineering (damage) based approach might be more appropriate.

1 Introduction

Marginal cost estimations for road infrastructure can be estimated either with an engineering (damage) based approach or with an empirical based approach. The latter is directly related to estimations of cost functions derived from actual road expenditures in relation to traffic data.

Since marginal infrastructure cost figures are – in contrast to other cost categories – related to real expenditures carried out and reported by specific entities, it is worthwhile to estimate marginal cost figures with different approaches. This is the result of the methodological review carried out within the intermediate report IR5.3.

This report describes the methodology, the procedure and the results of the econometric study of Switzerland. The methodology used is coordinated with those used in Germany and Austria. Initially it was foreseen to integrate data from other countries (in particular Spain) as well. Due to lack of data and problems with comparability, these attempts had to be stopped.

This study tries to estimate cost functions for investive and running maintenance costs. The influence of traffic volumes and HGV-related characteristics is estimated using different approaches (time series analysis and cross-sectional data, different functional forms). Out of a significant relationship between costs and traffic volume characteristics, the marginal costs for all means of road transport and for specific categories (i.e. passenger cars, HGV) are derived. In order to carry out that crucial step properly, additional methods have been applied.

This report summaries the Swiss econometric approach:

- Chapter 2 is giving a short description of the former Swiss attempts in order to estimate road infrastructure costs by category.
- Chapter 3 is presenting the data sets used within the two approaches applied.
- Chapter 4 is presenting the functional forms applied within the two approaches.
- Chapter 5 is presenting the results of the regression analysis for road transport as a whole and by category.
- Chapter 6 is presenting the results of marginal costs, and finally
- Chapter 7 and 8 are interpreting the results in a theoretical and practical manner.

2 State of the art review

There is no econometric approach available in Switzerland in order to estimate marginal costs up to now. Thus the present study carried out with Swiss cost and traffic data is unique.

The tradition of Swiss infrastructure cost estimations is based on an accounts approach. This approach estimates total costs by a perpetual inventory cost approach and allocates these costs to different vehicle categories. The approach is strictly top down using specific assumptions of weight dependent costs. These assumptions are based on engineering knowledge according to the principles of

- Cost causation of road investments: Switzerland allocates different percentages of specific investment costs (i.e. for bridges, road width, etc.) to big and heavy vehicle categories. The percentages are drawn from engineering studies estimating the additional costs for an increased road dimension.
- Damage causation of road maintenance: A part (45%) of investive maintenance costs is

assumed to be fully weight dependent. These costs are allocated to HGV using a redefined AASSHO-function considering the fact that Switzerland used to have a lower weight limit (28 instead of 40 tons). Thus the factor 4 was decreased to a factor 2.5.

Switzerland has recently published a study which aimed at reviewing the percentages used within this method. The percentages were slightly adjusted (i.e. increased for HGV) considering the recent increase of the weight limit stepwise from 28 to 34 tons (2001 to 2004) and to 40 tons gross weight.

Carrying out an econometric study for Switzerland, one has to consider the real life conditions of the practice of road construction and road maintenance. The following elements are most important:

- The construction and maintenance is carried out at cantonal level. Political and budgetary reasons (for the allocation of financial means) are a very decisive factor.
- Switzerland has a rather low HGV share on the main roads network, and a rather high share of rail traffic, due to the restrictions for road transport (night ban, 28 ton-limit). The weight limit has now (2001) been replaced by a new regime with a km, weight and emission dependent HGV-fee. However the new regime cannot be considered within the econometric analysis.
- The alpine transit axis (Gotthard, San Bernardino) have a considerably higher share of HGV than other highways. Within these areas however, special situations like the flood event within the canton of Uri (1988), which caused high repair costs for the road infrastructure and disturbed economically feasible maintenance cycles.
- In general one has to consider that the maintenance cycles are not optimal, since the real expenses are lagging behind engineering based maintenance cycles. This is due to budgetary reasons and to the fact that economies of scale might arise if several sections (i.e. for pavement renewal) are carried out at the same time, postponing several sections.

3 The data

3.1 Data sources and data treatment

Basically two datasets have been used for the regression analysis.

- For a 1985-1998 time series analysis, a cantonal dataset which is part of the national road account could be used. It contains cantonal new construction, upgrades and renewals and constructional maintenance costs as well as operational maintenance costs (cleaning, flow regulation, signalling, etc) of the motorway network. Mileage data for the respective vehicle categories has been taken from a traffic model which allows the allocation of the overall mileage to different road categories. However, this model is based on 1995. For the other years, vehicle category specific growth factors had to be applied to adjust mileage data.
- The second dataset is used for a cross section analysis of the motorway network. According to the classification of the Swiss Federal Roads Office (FRS), constructional maintenance costs for 127 sections of the motorway network for 4 different years (1997-2000) were collected and analysed. Mileage data of 4 different vehicle categories was derived from the so-called LVC-Stations (Long vehicle counter) which is continuously collecting traffic data all over Switzerland. But because LVC data is not available for every motorway section, the results of the automatic vehicle counter stations (AVZ: Automatische

Verkehrszählung) were used. These stations count only the absolute number of vehicles using a road and show no differentiation for the different vehicle categories.

The following cost differentiation is used in both data sets (whereas the cross sectional data set contains only data on constructional maintenance):

Table 3-1: Cost categories in the Swiss Road account.

Cost category	Description
Construction costs (of new motorways)	Costs for construction new motorway sections, its technical equipment, including planning, development/projecting, legal procedures, land acquisition, construction works
Costs for upgrading (of an existing motorway)	Costs for upgrading an existing motorway section: e.g. building of an additional lane and upgrading of the technical equipment
Upgrades and renewals costs	Costs for a complete restoration of a road section (replacement of surface and subgrade layers, replacement of parts of bridges, etc.)
Constructional maintenance costs	Repair costs for major damages and wear and tear of parts of a road and its technical equipment without a complete replacement of whole parts of a road section (e.g. restoration of joints, wearing course, etc.).
Operational maintenance costs	Costs for smaller repair works, cleaning costs, winter maintenance, etc.

3.1.1 Time series analysis

A pooled data set was used: Information for 23 cantons (the other 3 cantons do not have motorways) for the years 1985–1998 was available. Thus we finally had about 320 cases for the regression analysis. The cost category upgrade and renewals is only accounted for since 1994. The data of the different data sources (national road account and traffic model data) was merged into one dataset. The lists below contain the vehicle categories and all variables that were built in and that were used in the data analysis.

Table 3-2: List of variables.

Variables	Description	Source
Road length	Length of total motorway network for each canton	BFS 2000
Cost: Total	Sum of all cost categories	BFS 2000
Cost: Upgrade and renewals	Costs for upgrades and renewals of motorways	BFS 2000
Cost: Constructional maintenance	Costs for maintenance of more extensive damage (restoration of tracks, tunnels, bridges)	BFS 2000
Cost: Operational maintenance	Cost for maintenance of functionality of the motorways (cleaning, snow clearing…)	BFS 2000
Mileage • car • van • truck • bus • total	Mileage of vehicle category in vehicle-kilometre per year (number of vehicles * road length)	Ott, Seiler 1999

Variables	Description	Source
Gross tons • car • van • truck • bus • total	Gross tons of vehicle category (number of vehicles * mean weight)	Federal Roads Office (electronic data), provisional data set, not published
Axle load • car • van • truck • bus • total	Axle load of vehicle category (number of vehicle * mean axle load equivalent per category)	Federal Roads Office (electronic data), provisional data set, not published
Gross tons - km • car • van • truck • bus • total	Gross tons – km of vehicle category (vehicle-km * gross tons)	Calculated data
Axle load - km • car • van • truck • bus • total	Axle load - km of vehicle category (vehicle-km*axle load equivalent)	Calculated data

Other data was available, e.g data of purchase costs of land for road construction, costs for traffic regulation (among others traffic lights), administrational costs (salaries, insurances and others) and costs for new constructions. As there is no interdependence between these cost categories and the use of the roads (in weight or in mileage), we excluded these variables from the model.
The total cost category is the sum of all other cost categories inclusive purchase of land, traffic regulation and administration. Therefore it is not necessary to analyse the total costs as no new information could be gained.

3.1.2 Road section analysis

Cost data

The road section analysis contains cost data from 1997 till 2000 based on (sectionwise) detailed budget accounts of the Swiss Federal Roads Office (SFRO). Because of data availability and our basic assumption that constructional maintenance (replacement of surface overlays) varies considerably with traffic loads, we focus on constructional maintenance costs. The SFRO maintenance database includes a more detailed differentiation of the constructional maintenance costs in 5 subdivisions (overhead costs, general maintenance costs, costs for the restoration and replacement of surface overlays, maintenance costs of bridges and tunnels). These 5 subdivisions are the sum total of the overall constructional maintenance costs (Swiss road account).

Mileage data

Mileage data could be derived from automotive vehicle counting stations on the national road network. A distinction between 4 different vehicle categories based on vehicle length is possible. The table below shows the different vehicle categories.

Table 3-3: Vehicle categories.

Category	Length	Vehicles
1	- 2.7 m	Motorbikes
2	2.7 – 6 m	Cars, Vans
3	6 – 12.5 m	Vans with trailer, trucks, tractors
4	> 12.5 m	Trucks and trailer, tractors and semitrailers

The respective mileage data for each road section was computed by assignment of the nearest vehicle counting station. For some sections only so-called AVZ counting stations (without vehicle classification) were available. In those cases the vehicle split of nearby LVC stations was used.

Gross ton and Axle load equivalent data

To obtain data on total gross tons and the axle load equivalent per road section a detailed analysis of WIM (weigh-in-motion) measurements was made. In Switzerland altogether 5 WIM stations are actually in operation, unfortunately only one station provides data for the period 1997–2000 (station at the Gotthard alpine crossing). Data of this station has been analysed in depth. The database provides data on vehicle length, total weight, total number of axles, load of each axle as well as the respective distance between the axles. Based on a recent study on axle load equivalent (UVEK 2000), the axle load equivalent (number of standard axles) could be calculated, considering the axle configuration (single, double, tridem) of each vehicle and vehicle category. However, due to the fact that only data for the Gotthard axis is available, the explanatory value of gross tons and axle load equivalent for the regression is small (bearing in mind that trucks on the alpine crossings are considerably heavier than the national average).

The table below shows the most important variables used for the calculations:

Table 3-4: List of variables.

Variables	**Description**	**Source**
No. of lanes	No. of lanes (normally 2, 4 or 6 lanes): Some alpine national roads only have 2 lanes.	ASTRA 2000
Length of section (km)		ASTRA 2000
U0 Overhead (CHF million)	Different cost subcategories within the 'Constructional maintenance costs' category	Database (electronic) provided by Federal Roads Office (not published)
U1 General maintenance costs (CHF million)		
U2 Overlays (CHF million)		
U3 Bridges (CHF million)		
U4 Tunnels (CHF million)		
TOTAL COSTS (CHF million)		
VKM_LK1 (veh-km)	Mileage data of each road section, based on LVC and AVZ stations data	Federal Roads Office (electronic data).
VKM_LK2		
VKM_LK3		
VKM_LK4		
VKM_TOT		
VEH_LK1	Number of vehicles per road section, based on LVC and AVZ stations data	Federal Roads Office (electronic data).
VEH_LK2		
VEH_LK3		
VEH_LK4		
VEH_TOT		
GRTO_LK1	Gross-tons, calculated data (see above), based on WIM data of the Gotthard WIM station	Federal Roads Office (electronic data), provisional data set, not published
GRTO_LK2		
GRTO_LK3		
GRTO_LK4		
GRTO_TOT		
AXLE_LK1	Axle-load equivalent, calculated data (see above), based on WIM data of the Gotthard WIM station	Federal Roads Office (electronic data), provisional data set, not published, UVEK 2000
AXLE_LK2		
AXLE_LK3		
AXLE_LK4		
AXLE_TOT		
GTOKM_1	Calculated data: vehicle-km * gross-tons	
GTOKM_2		
GTOKM_3		
GTOKM_4		
GTOKM_TO		
AXKM_1	Calculated data: vehicle-km*axle-load equivalent	
AXKM_2		
AXKM_3		
AXKM_4		
AXKM_TOT		

The basic problem of the analysis is that due to an average of a 12 year renovation cycle for constructional maintenance, the probability of getting useful data out of the cost data per section of one year is very small (only around 10% of all sections should have any constructional maintenance in one year). To improve the probability to "observe" something on a section, we decided to use pooled data for a 4-year period (1997-2000) and also calculate with pooled data for 4 years.

3.2 Descriptive analysis of data (characterisation of data)

3.2.1 Time series analysis

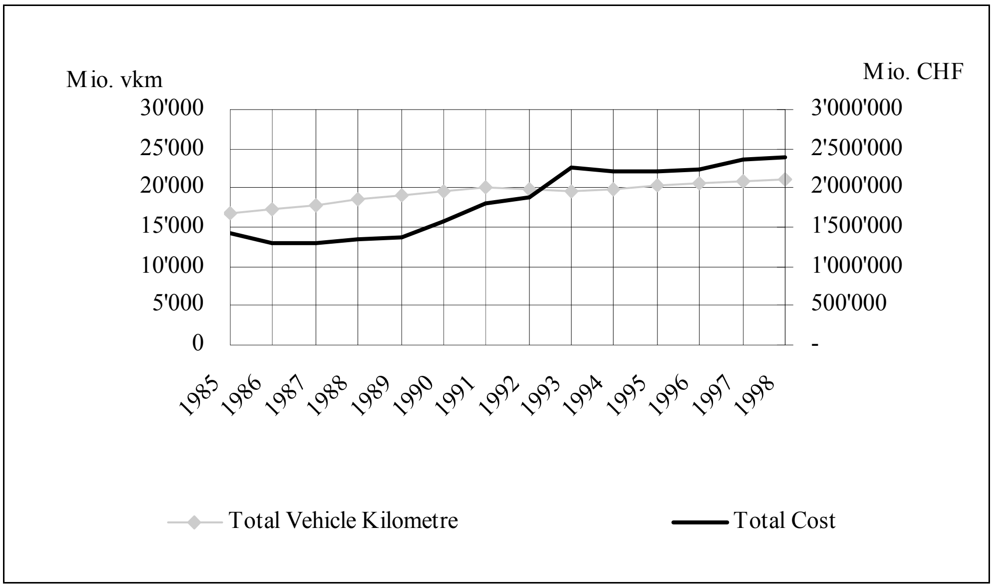
The following table describes the basic statistics of the time series analysis.

Table 3-5: Descriptive presentation of the most important variables.

Cantonal Summaries	N	Mean	Std. Deviation	Median	Minimum	Maximum
Length of Network (Km)	323	65.26	50.82	50.00	6.00	184.00
Total Cost (1000 Euro)	323	46'139	38'087	36'889	2'317	160'587
Upgrade and Renewal Cost (1000 Euro)	116	1'389	2'889	638	0	27'329
Cost for Constructional Maintenance (1000 Euro)	323	5'622	6'027	3'440	0	43'445
Cost for Operational Maintenance (1000 Euro)	323	3'117	2'540	2'208	0	10'900
Mileage Cars (Mil.Vkm)	323	748	724	439	4	2'623
Mileage Vans (Mil.Vkm)	323	42	44	23	0	189
Mileage Trucks (Mil.Vkm)	323	47	46	28	0	164
Mileage Buses (Mil.Vkm)	323	2	2	1	0	7
Total Mileage (Mil.Vkm)	323	839	815	492	4	2'983
Gross tons Cars (tons)	323	14'672'411	7'479'791	14'779'523	200'121	32'657'320
Gross tons Vans (tons)	323	1'555'685	876'628	1'506'450	1'811	4'021'335
Gross tons Trucks (tons)	323	14'364'130	7'355'116	14'445'522	158'578	31'390'974
Gross tons Buses (tons)	323	508'915	260'535	512'782	6'439	1'188'546
Total Gross tons (tons)	323	31'101'140	15'883'424	31'293'347	366'948	67'985'606
Axle load Cars (Equivalents)	323	1'129	575	1'137	15	2'512
Axle load Vans (Equivalents)	323	598	337	579	1	1'547
Axle load Trucks (Equivalents)	323	867'987	444'451	872'905	9'582	1'896'875
Axle load Buses (Equivalents)	323	125'638	64'320	126'593	1'590	293'422
Total Axle load (Equivalents)	323	995'352	509'296	1'001'349	11'188	2'183'404
Gross ton-km Cars (tons)	323	972'527'608	940'554'906	571'074'069	4'602'773	3'409'879'313
Gross ton-km Vans (tons-kilometre)	323	108'629'776	115'108'382	59'491'000	41'649	490'602'818
Gross ton-km Trucks (tons-kilometre)	323	959'765'611	939'395'650	574'677'674	3'647'300	3'389'424'140
Gross ton-km Buses (tons-kilometre)	323	33'703'011	32'580'179	20'091'599	148'090	115'919'649
Total Gross ton-km (tons-kilometre)	323	2'074'626'006	2'025'294'872	1'231'205'761	8'439'812	7'399'615'939
Axle load-km Cars (Equivalents-kilometre)	323	74'810	72'350	43'929	354	262'298
Axle load-km Vans (Equivalents-kilometre)	323	41'781	44'272	22'881	16	188'693
Axle load-km Trucks (Equivalents-kilometre)	323	57'996'148	56'765'244	34'726'282	220'397	204'814'116
Axle load-km Buses (Equivalents-kilometre)	323	8'320'431	8'043'232	4'960'114	36'560	28'617'663
Total Axle load-km (Equivalents-kilometre)	323	66'433'170	64'912'061	40'008'805	257'327	232'349'682

Description of data evolution

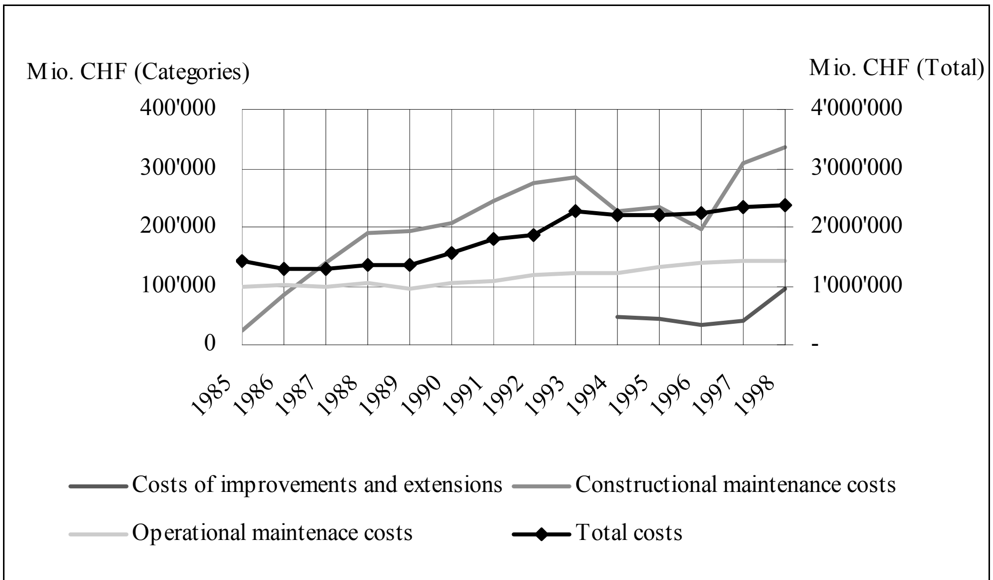
Figure 3-1: Comparison of total costs and total mileage for motorways.



The development of the total cost and the total mileage for motorways is similar. Between 1985 and 1998 the mileage rose constantly (+23%), the total costs even 67%. But in the late eighties and in the late nineties the evolution of the costs was almost constant (+5% between 1993-1998). The length of the total motorway network grew by 17.2%; and reached 1640 km in 1998.

The importance of screening a long time period is evident in the cost series. Between 1985 and 1989 the costs remain almost constant, then vary rapidly (+66% between 1989-93) and stagnate again from 1993 on. This figure indicates a possible behaviour pattern of the cantons: during the recessional phase of the late nineties the cantons tend to cut down expenses. In the next figure the same behaviour can be read more clearly.

Figure 3-2: Evolution of different cost categories.



The figure 3.2 depicts the evolution of the chosen cost categories in comparison to the total

costs. Interestingly enough, the operational maintenance costs rise with hardly any yearly variation. It is assumed that maintenance work like snow-cleaning is not compressible (+44% between 1985-98). This cost category varies with the length of the network.
The constructional maintenance cost (restoration of tracks, bridges, tunnels) increased more than 1300% between 1985 and 1998. But the collapse of expenses between 1993 and 1997 is of great interest. It could be linked to the economic recession. If this thesis proves right, it means that the cantons do not only decide on expenditures on the grounds of necessity (road quality) but also in relation to budgetary availability. This thesis will have to be checked.

The next figure shows the evolution of the constructional maintenance costs of a selection of cantons in comparison to the total of this cost category. The expenditures for constructional maintenance costs of different cantons vary significantly. While in some cantons (Zurich) the evolution develops parallel to the total cost in Switzerland, in other cantons the costs peak for one year (Schwyz 1993; St. Gallen 1989 and 1998). This augmentation seems not to be linked to the extension of the road network in these cantons, as for example in St.Gallen and Schwyz it is below average (7.7%, respectively 0%). This is further evidence for the time lag between rise of mileage and rise of costs (mainly constructional maintenance costs).

Figure 3-3: Comparison of the evolution of constructional maintenance costs for chosen cantons.

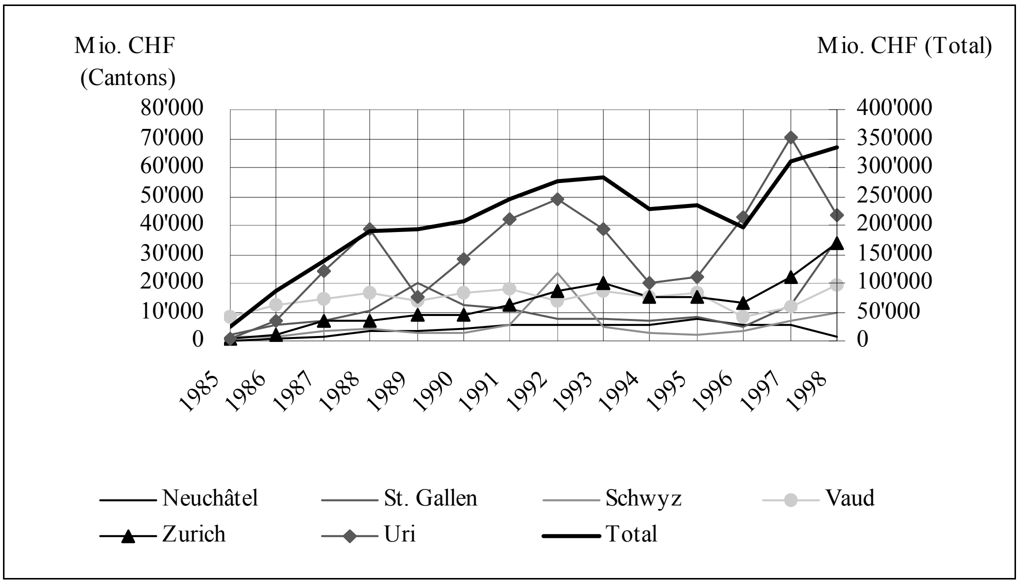
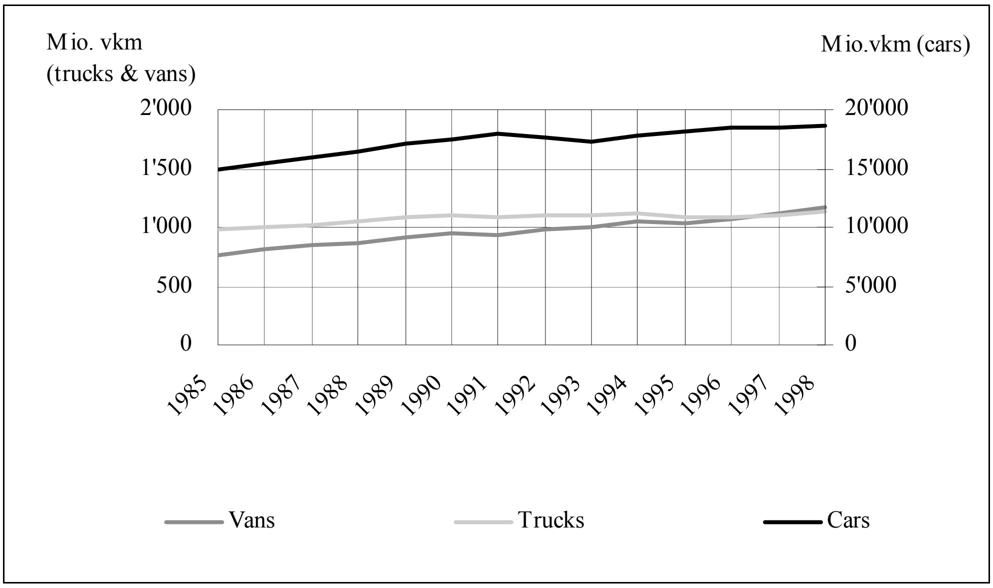


Figure 3-4: Evolution of the mileage of different vehicle categories.



The figure of the mileage of the different vehicle categories considered shows a similar rise for cars and trucks (1985-98: cars +22% and trucks +17%). Vans drive considerably more (1985-98: +52%).
The proportion of trucks on the total mileage remains almost stable through the years (highest 1984 5.9%; lowest 1996 5.3%). In the cross-section the proportion of trucks is also similarly stable (variation between cantons in 1998: 4.7-5.6%).
The uniformity of evolution of truck and car mileage, together with the fact that the proportion of cars and trucks on the motorways of all cantons is almost equal is a cause of serious problems in the data analysis. It will be difficult to differentiate the impacts of cars and trucks on the motorways and subsequently on the (constructional maintenance) costs.
The uniformity of proportion is partly due to a specific event. The Gotthardt axis (A" motorway) has in general a higher proportion of trucks, because this is the main alpine crossing for HGV. Actually, in 1987 a flood catastrophe in the Reuss Valley caused major destruction of the A2 motorway. Consequently, between 1988 and 1993 important constructions obstructed the Gotthardt axis and caused an augmentation of expenses.

Correlation:
The correlation between the independent variables is of major importance for the data analysis. The correlation results for the different categories (mileage, gross tons, and axle equivalent) do not significantly differ. The table gives only the values for mileage. The correlation values for gross tons and axle equivalent vary between 0.9-0.99.

Table 3-6: Correlations of independent variables.

		Mileage cars	Mileage vans	Mileage HGV	Mileage bus
Mileage cars	Pearson Correlation	1	.985	.998	.998
	Sig. (2-tailed)	.	.000	.000	.000
Mileage vans	Pearson Correlation	.985	1	.986	.981
	Sig. (2-tailed)	.000	.	.000	.000
Mileage HGV	Pearson Correlation	.998	.986	1	.998
	Sig. (2-tailed)	.000	.000	.	.000
Mileage bus	Pearson Correlation	.998	.981	.998	1
	Sig. (2-tailed)	.000	.000	.000	.

Table 3-7: Correlations of dependent and independent variables.

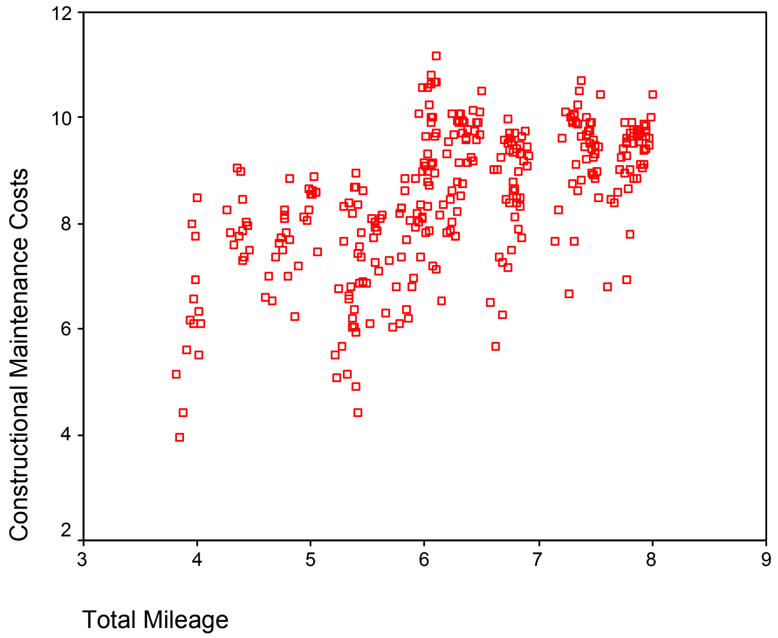
		Total mileage	Total gross tons	Total axle equivalents
Upgrade and renewal	Pearson Correlation	.179	.078	.067
	Sig. (2-tailed)	.001	.164	.231
Constructional maintenance	Pearson Correlation	.349	.061	.053
	Sig. (2-tailed)	.000	.271	.341
Operational maintenance	Pearson Correlation	.698	.036	.032
	Sig. (2-tailed)	.000	.524	.571

For the data analysis these high correlations mean serious complications:

- A high correlation within the categories of the same variable (mileage of cars, vans, trucks, buses) mean the regression analysis may not able to differentiate the effects of the categories, i.e. it probably won't be possible to answer questions of the different impacts of trucks or cars on the cost.

An illustration of the dependence between independent and dependent variables is given in the scatter plot below.

Figure 3-5: Scatter plot of Constructional maintenance costs and total mileage.



Remark: This figure represents a scatter plot of the total mileage versus constructional maintenance costs, both of them as logarithmic values. The vertical structure that seems to appear is due to the cantonal structure (i.e. total mileage of the cantons does hardly not vary, but the constructional maintenance costs vary)

3.2.2 Road section analysis

The following table describes the basic statistics of the road section analysis. In the later regression a pooled data set is used, where the sum over 4 years (1997-2000) is used for the estimation of the cost function.

Table 3-8: Descriptive road section analysis.

	N	Mean	Std. Deviation	Median	Minimum	Maximum
No. of lanes	424	3.75	1.12	4.00	2.00	6.00
Length of section (km)	424	15.24	11.81	12.40	0.60	52.40
U0 Overhead (CHF million)	424	0.02	0.09	0.00	0.00	0.68
U1 General maintenance costs (CHF million)	424	0.57	1.24	0.21	0.00	14.21
U2 Overlays (CHF million)	424	1.03	3.67	0.05	0.00	47.00
U3 Bridges (CHF million)	424	1.48	3.47	0.36	0.00	41.72
U4 Tunnels (CHF million)	424	0.49	1.55	0.00	0.00	15.79
TOTAL COSTS (CHF million)	424	3.59	6.58	1.61	0.01	60.15
VKM_LK1	424	1'129'827	2'469'900	71'878	347	16'238'846
VKM_LK2	424	143'151'504	158'705'298	81'366'583	1'013'794	841'112'248
VKM_LK3	424	8'472'740	9'882'234	4'983'301	84'426	58'487'440
VKM_LK4	424	7'191'229	10'040'990	3'540'079	143'196	65'870'080
VKM_TOT	424	159'945'301	177'609'300	89'284'736	1'249'848	967'528'818
VEH_LK1	424	73'937	127'985	4'505	41	722'155
VEH_LK2	424	9'515'023	6'332'183	8'514'624	363'668	28'411'017
VEH_LK3	424	564'438	387'947	485'667	32'465	1'881'127
VEH_LK4	424	486'417	422'684	323'906	27'954	1'775'407
VEH_TOT	424	10'639'814	7'020'380	9'471'934	448'934	31'959'340
GRTO_LK1	424	62'846	108'787	3'829	35	613'831
GRTO_LK2	424	12'369'530	8'231'838	11'069'011	472'768	36'934'322
GRTO_LK3	424	7'663'222	5'267'056	6'593'763	440'771	25'539'550
GRTO_LK4	424	11'593'126	10'074'129	7'719'892	666'241	42'314'571
GRTO_TOT	424	31'688'724	21'850'478	28'311'201	2'139'307	104'645'738
AXLE_LK1	424	4	6	0	0	36
AXLE_LK2	424	952	633	851	36	2'841
AXLE_LK3	424	747'865	514'020	643'495	43'016	2'492'443
AXLE_LK4	424	587'837	510'815	391'442	33'782	2'145'587
AXLE_TOT	424	1'336'657	993'509	1'055'022	105'144	4'640'860
GTOKM_1	424	960'373	2'099'406	61'096	295	13'803'019
GTOKM_2	424	186'291'213	207'031'973	102'791'203	1'317'932	1'093'445'922
GTOKM_3	424	115'134'409	134'768'374	67'656'929	1'146'233	794'068'107
GTOKM_4	424	171'541'729	240'623'788	84'373'311	3'412'902	1'569'930'091
GTOKM_TO	424	473'927'725	561'000'112	274'728'554	6'068'459	3'340'112'700
AXKM_1	424	56	123	4	0	812
AXKM_2	424	14'330	15'926	7'907	101	84'111
AXKM_3	424	11'236'140	13'152'248	6'602'741	111'863	77'494'299
AXKM_4	424	8'698'133	12'200'982	4'278'202	173'053	79'604'305
AXKM_TOT	424	19'948'659	24'974'438	10'835'324	294'704	152'101'693

As a consequence of the computation of the different variables, correlation between the different variables turned out to be a serious problem. The number of vehicles is highly correlated with gross tons and axle load equivalents respectively. As a result of a more or less stable share of HGV (vehicle categories 3 and 4) of total traffic, correlation of mileage data between the 4 different vehicle categories is significant (at 0.01 level)

The tables below show correlation coefficients of the different independent variables:

Table 3-9: Correlations vehicle-km of different vehicle categories.

	LNVKM_1	LNVKM_2	LNVKM_3	LNVKM_4
LNVKM_1	1.000			
LNVKM_2	.519**	1.000		
LNVKM_3	.519**	.975**	1.000	
LNVKM_4	.464**	.871**	.950**	1.000

Pearson Correlation
** Correlation is significant at the 0.01 level (2-tailed).

Since gross tons and axle load equivalent are both calculated based on the number of vehicles using a road section and the results of the WIM measurements of only one WIM station, both variables show highly significant correlations.

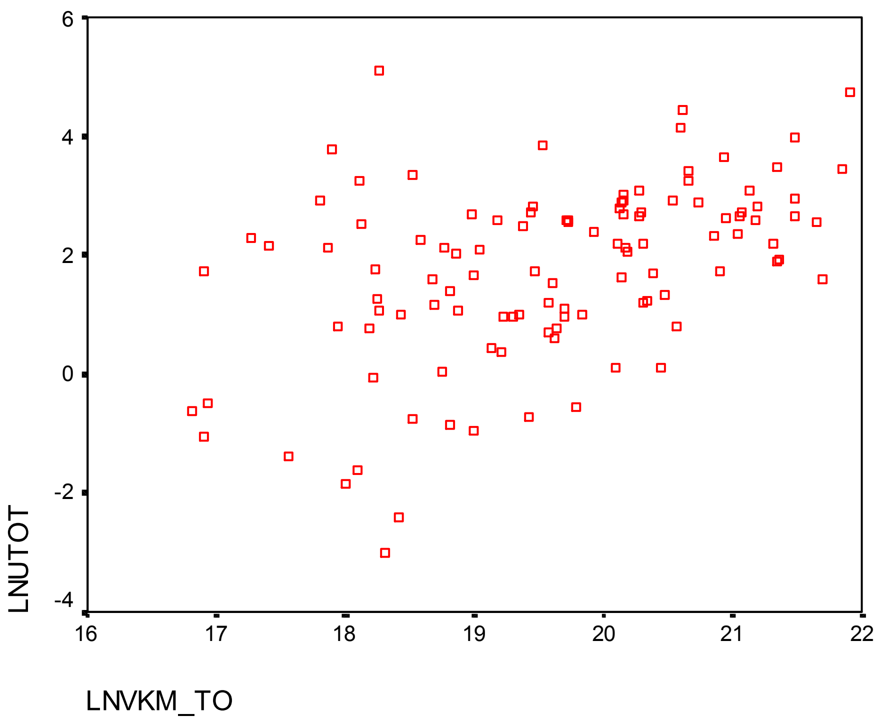
Table 3-10: Correlations gross tons and axle load equivalents respectively (4 different vehicle categories).

	LNGRTO_1	LNGRTO_2	LNGRTO_3	LNGRTO_4
LNGRTO_1	1.000			
LNGRTO_2	.270**	1.000		
LNGRTO_3	.266**	.942**	1.000	
LNGRTO_4	.204*	.739**	.906**	1.000

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The figure below shows total constructional maintenance costs vs. total mileage (log transformed values):

Figure 3-6: Scatter plot of dependent and independent variable



4 The model (functional form) applied

4.1 Time series analysis

4.1.1 Simple model

We expect an influence of the use on the cost for motorways. The general form of the equation that will be used for calculation is given below:

(1) $$Cost_{\text{specific castegory}} = f\left(Use_{\textit{mileage, axle load equivalent or grosstons}}\right)$$

Different variants of hypothesis have been tested. Only the models that proved bests are presented at this point. More information about the other variants will be given within the discussion of the results (chapter 6).

Operational maintenance costs:

The more traffic on a motorway, the higher the operational maintenance costs. We do not expect any influence of weight on operational maintenance costs.

(2) $$Cost_{\textit{operational maintenance costs}} = f\left(Mileage\right)$$

Constructional maintenance costs:
The more traffic on a motorway, the higher the constructional maintenance costs. We expect an influence of weight of the vehicles.

(3.1) $$Cost_{\textit{constructional maintenance costs}} = f\left(Gross\ ton - kilometre\right)$$

The variable gross ton kilometre is a combined variable of mileage times gross tons. We expect a better model fit using the gross ton kilometre variable than with gross tons only. The regression will also be calculated with mileage instead of gross ton-kilometres.

(3.2) $$Cost_{\textit{constructional maintenance costs}} = f\left(Mileage\right)$$

The cantons are believed to react to economic recession in their allocation of funds to the account of constructional maintenance costs. To check the correctness of this hypothesis, a next model has been elaborated including a dummy variable for the recession years. The period of economic recession has been established between 1994 and 1996.

(3.3) $$Cost_{\textit{constructional maintenance costs}} = f\left(Mileage, Dummy_{\textit{Recession}}\right)$$

Costs for upgrades and renewals:
The cantons may try to cut the expenses of maintenance with the construction of better motorways with less abrasion, but these will cost more. Therefore we expect the following: The more traffic on a motorway, the higher the costs for upgrades and renewals. This cost category depends on vehicle weight.

(4) $$Cost_{\textit{Upgrade and renewal}} = f\left(Gross\, ton - kilometre\right)$$

4.1.2 Multiple model

With multiple models we try to estimate the effects of different vehicle categories. We expect that the weight of vehicles has a significant impact on constructional maintenance costs (the higher the proportion of trucks, the higher the costs for constructional maintenance).

(5) $$Cost_{\text{constructional maintenance}} = f\left(mileage_{trucks}, mileage_{vans}, mileage_{bus}, mileage_{cars}\right)$$

4.2 Road section analysis

Basically, the same hypotheses were applied within the road section analysis with the restriction that only constructional maintenance costs are taken into account.

Interim report 5.3 (Marginal Cost Methodology for Infrastructure Costs) suggests a translog cost function as a theory-base, systematic and flexible approach. We tested the suggested functional form using all available variables. But even the simplest form including e.g. vehicle-kms and axle load equivalents of the 4 different vehicle categories show implausible results (negative coefficients for HGV) and non-significant coefficients.

Therefore we decided to apply very simple functional forms:

(6) $$Total\ Costs_{\text{constructional maintenance}} = f\left(mileage_{trucks}, mileage_{vans}, mileage_{bus}, mileage_{cars}\right)$$

and

(7) $$Total\,Cost_{\text{constructional maintenance}} = f\left(mileage_{total}\right)$$

Equation (7) was also used with gross ton-km and axle load equivalent-km as independent variable.

In several regression runs we also tested the influence of mileage data, gross tons and axle load equivalents on special cost subcategories of the overall constructional maintenance costs (costs for restoration of overlays, bridges and tunnels). Again, the regression shows no plausible results (non significant coefficients, negative coefficient for either one of the HGV vehicle categories).

Finally, 3 independent variables were used:

- total mileage
- total gross ton-km
- total axle load-equivalent-km

5 Model estimation and tests

5.1 Time series analysis

5.1.1 Simple Model

The models described in chapter 4.1.1 have been estimated with an OLS-regression[1]. The following table shows the best results. The interpretation of the results is given in chapter 6.

[1] OLS: Ordinary Least Square.

(2) $\ln(Cost_{\text{operational maintenance costs}}) = const. + b * \ln\left(Mileage_{\text{all vehicles}}\right)$

Model Summary

N	R	R Square	Adjusted R Square	Std. Error of the Estimate
322	.806	.650	.649	.55449

a Predictors: (Constant), ln(Mileage all vehicles)

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.315	.565		2.329	.020
ln(mileage total)	.686	.028	.806	24.385	.000

a Dependent Variable: ln(Operational maintenance)

(3.1) $\ln(Cost_{\text{constructional maintenance costs}}) = const. + b * \ln\left(Gross\ ton - kilometre\right)$

Model Summary

N	R	R Square	Adjusted R Square	Std. Error of the Estimate
316	.583	.340	.338	1.08881

a Predictors: (Constant), ln(Gross ton-kilometres)

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.618	1.163		.531	.596
ln(gross ton-kilometre)	.705	.055	.583	12.718	.000

a Dependent Variable: ln(Constructional maintenance)

(3.2) $\ln(Cost_{\text{constructional maintenance costs}}) = const. + b * \ln\left(Mileage\right)$

Model Summary

N	R	R Square	Adjusted R Square	Std. Error of the Estimate
316	.587	.345	.342	1.08505

a Predictors: (Constant), ln(Mileage)

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.065	1.117		.954	.341
ln(Mileage)	.715	.056	.587	12.718	.000

a Dependent Variable: ln(Constructional maintenance)

(3.3) $\ln(Cost_{\text{constructional maintenance costs}}) = const. + b * \ln\left(Gross\ ton - kilometre + Dummy_{Recession}\right)$

The dummy recessions has not been significant, thus the model (3.2) does not contain any new information. The model (3.1) has the best fit.

(4) $\ln(Cost_{\text{upgrade and renewal}}) = const. + b * \ln\left(Gross\ ton - kilometre_{\text{all vehicles}}\right)$

Model Summary

N	R	R Square	Adjusted R Square	Std. Error of the Estimate
98	.509	.259	.251	1.49951

a Predictors: (Constant), ln(Gross ton-kilometres)

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-3.620	3.007		-1.204	.232
ln(gross ton-kilometre)	.822	.142	.509	5.790	.000

a Dependent Variable: ln(Upgrade and Renewal)

5.1.2 Multiple Model

Due to statistical reasons none of the multiple regressions worked out. The model (5) testing the different impacts of the vehicle categories had to be abandoned because of serious problems of collinearity. As a conclusion we state that the variance between mileage of the different vehicle categories is too small to allow estimations. The hypothesis including more than one variable could neither be accepted nor rejected. Other multiple models, like Cobb-Douglas, have not been tested because of insufficient quality of data.

5.2 Road section analysis

Due to the already mentioned problems with the available database, the regression analysis showed serious problems. Small R^2 combined with non-significant coefficients reveal either insufficient data or an unsuitable cost function. As a consequence, we introduced a dummy variable for all those cases which show no or substandard expenditures for constructional maintenance. Regression analysis including the dummy variable led to improved R^2 together with significant coefficients (total mileage, gross ton-km, axle load-km respectively and dummy).

As in the time series analysis, collinearity between mileage data of different vehicle categories only allows estimations using overall mileage data (sum of mileage of all vehicle categories). And because overall gross tons, gross ton-km, axle load equivalent and axle load equivalent-km per road section are derived based on average values of one WIM stations using mileage data, collinearity also occurs between those independent variables.

As a consequence of these limitations, regressions with the simple model (see section 4.2, equation (7)) and total mileage, total gross ton-km and total axle load equivalent-km were carried out. While mileage data allows the calculation of marginal costs for the total mileage of all vehicle categories, calculations with gross ton-km and axle load equivalent-km allows basic cost allocation to different vehicle categories with the help of average gross tons and average axle load equivalents for each vehicle category.

The best regression using mileage date (sum of the mileage of all vehicle categories) and total constructional maintenance costs shows a R^2 value of 0.215. The coefficient is significant (T-Value of 5.58). All other regression calculations show implausible results (e.g. mileage of the 4 different vehicle categories as independent variables). In addition, severe collinearity problems occur, if variables for the 4 different vehicle categories are included in the regression.

The best regression results for the independent variables 'total mileage', 'total gross ton-km' and 'total axle load equivalent-km' are presented below:

5.2.1 Regression based on total mileage data

a) Independent variable: total mileage

The following model was used:

$$\ln(Cost_{Operational\,Maintenance}) = const. + b * \ln\left(Total\ Mileage_{all\,vehicle\,categories}\right)$$

The following tables present the results of the regression:

Model summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.472	0.222	0.215	1.340

Predictors: Constant, lnvkm_to
Dependent Variable: lnutot

Coefficients:

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-9.491	2.017		-4.705	0.000
LNVKM_TO	0.574	0.103	0.472	5.583	0.000

Dependent Variable: lnutot

The adjusted R^2 is fairly low with 0.22. This factor can be improved using a dummy variable for those sections where no or only little operational maintenance has been carried out in the analysed 4 years period.

The introduction of a dummy variable (dummy = 1, if constructional maintenance costs are below 50'000 CHF per year and km motorway) < 1) leads to a significant higher R^2 as the following tables depict:

b) Independent variable: total mileage and dummy for sections with low maintenance

Model summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.757	0.574	0.566	0.997

Predictors: Constant, lnvkm_to, dummy
Dependent Variable: lnutot

Coefficients:

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-8.558	1.504		-5.690	0.000
LNVKM_TO	0.550	0.077	0.452	7.191	0.000
DUMMY1	-2.168	0.230	-0.593	-9.430	0.000

The dummy variable introduced increases R^2 considerably. However, the definition of the dummy variable is somewhat arbitrary because there is no existing benchmark for above or below average constructional maintenance.

5.2.2 Regression based on total gross ton-km

a) Independent variable: total gross ton-km

The calculation with total gross ton-km shows a better result than total mileage data only.

Model summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.516	0.267	0.260	1.301

Predictors: (Constant), LNGTOKMT
Dependent Variable: LNUTOT

Coefficients:

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-11.315	2.079		-5.441	0.000
LNGTOKMT	0.632	0.100	0.516	6.293	0.000

Again, an additional dummy for sections with none or only small constructional maintenance improves R^2 of the regression.

b) Independent variable: total gross ton-km and dummy

Model summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.766	0.587	0.579	0.981

Predictors: (Constant), DUMMY1, LNGTOKMT
Dependent Variable: LNUTOT

Coefficients:

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-9.649	1.578		-6.114	0.000
LNGTOKMT	0.573	0.076	0.468	7.543	0.000
DUMMY1	-2.077	0.227	-0.568	-9.154	0.000

5.2.3 Regression based on total axle load equivalent-km

a) Independent variable: total axle load equivalent-km

The best regression fit for calculations with one independent variables shows the variable 'total axle load equivalent-km'.

Model summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.525	0.276	0.269	1.293

Predictors: (Constant), LNAXKM_T
Dependent Variable: LNUTOT

Coefficients:

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-9.334	1.725		-5.412	0.000
LNAXKM_T	0.634	0.098	0.525	6.442	0.000

The result of the regression could be improved using the above mentioned dummy variable.

b) Independent variable total axle load equivalent-km and dummy
Model summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.76	0.58	0.58	0.98

Predictors: (Constant), DUMMY1, LNAXKM_T
Dependent Variable: LNUTOT

Coefficients:

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-7.631	1.328		-5.746	0.000
LNAXKM_T	0.562	0.075	0.465	7.448	0.000
DUMMY1	-2.040	0.228	-0.558	-8.930	0.000

The regression with total axle load equivalent-km and a dummy variable shows the best model fit of all regression runs (R^2 = 0.58). In chapter 6

6 Results

The following section presents the overall results of the calculations with both data sets. Since the road section analysis dataset covers only a period of four years, the results of the time series analysis are more relevant. However, the results of the regression with road section data and the resulting marginal costs will be presented as additional information, always bearing in mind that most probably not all maintenance costs are included in the data base.

First of all the hypothesis of chapter 4 are tested which will lead to the most important influencing factors and finally to the cost functions. In the second part of this chapter, several approaches to derive marginal costs are presented. Due to the fact that multiple models did not work out with the available data set, only simple cost functions could be derived. As a consequence marginal costs for different vehicle categories (e.g. passenger cars and trucks) could not be derived directly. However, different approaches were made to calculate marginal costs of different vehicle categories based on additional assumptions.

The following table gives an overview on the different results:

Table 6-1: Results structure

	Time series analysis	Road section analysis
Operational maintenance costs	Marginal costs derived from : - total mileage data (no cost allocation to different vehicle categories due to the basic assumption, that operational maintenance is weight independent)	- (no cost data available)
Constructional maintenance costs	Marginal costs derived from: - total mileage data (cost allocation to different vehicle categories with the help of an engineering approach) - total gross ton-km (cost allocation to different vehicle categories with average gross ton data per vehicle category)	Indicative marginal costs derived from: - total mileage data (no cost allocation) - total gross ton-km (cost allocation to different vehicle categories with average gross ton data per vehicle category) - total axle load equivalent-km (cost allocation based on average axle-load equivalent per vehicle category)
Costs for upgrade and renewals	Marginal costs derived from: - total mileage data (cost allocation to different vehicle categories with the help of an engineering approach) - total gross ton-km (cost allocation to different vehicle categories with average gross ton data per vehicle category)	- (no cost data available)

6.1 Cost structure

6.1.1 Time series analysis

The regression results allow us to test most of our hypothesis. The R^2 values indicate that most of the models fit the data well (a value of 1 would be a 100% fit). The models were tested on collinearity problems and normality. The Durbin-Watson test revealed no problem of autocorrelation of the residuals. We will now discuss the detailed results of the hypothesis. The numbers are according to the hypothesis in chapter 4.

(2) Operational maintenance costs vary positively with the mileage of all vehicles.

(3) The constructional maintenance costs vary positively with the use of the roads.

(3.1) The best model fit can be found in the model with gross ton-kilometres of all vehicles. The model with axle load equivalent-kilometres is of similar quality.
(3.2) Neither axle load equivalent kilometres nor gross ton-kilometres have a significantly better model fit (R^2) than the model with mileage as independent variable, i.e. mileage is the dominant factor in both the variables gross ton kilometres and axle load kilometres.
The relation between gross ton kilometres and constructional maintenance costs is significant; the results are plausible. However, the R^2 value is rather low. The same is true for the relation between axle load equivalents and constructional maintenance costs.

(3.3) The hypothesis of an impact of the economic recession years on constructional maintenance cannot be accepted. The dummy variable for the recession period is insignificant. An explanation of this may be that a) the cantons do nevertheless react to recession (Figure 3.3 gives an evidence of this behaviour); but b) the recession is only one reason for delaying expenses, other reasons are also important (in general availability of budget). These different reasons interfere and even out the effect of the recession. Our conclusion is that the influence of recession cannot be proven or rejected.

(4) The more gross ton kilometres on a specific road section, the higher the cost for upgrade and renewal. This hypothesis can be accepted. Likewise, the hypothesis of impact of axle load equivalent-kilometres on costs for upgrades and renewal, can be adopted. The model fit is equal to the model with gross ton-kilometres.

Different forms of multiple models like (5) could not be tested with our dataset.

The model (2) for operational maintenance cost, (3.1) for constructional maintenance cost and (4) for cost of upgrade and renewals will be used to calculate the marginal costs.

6.1.2 Road section analysis

Based on regression results our hypothesis could be tested as follows:

(3) The constructional maintenance costs vary positively with the use of the roads.

(3.1) The best model fit can be found in the model with gross ton-kilometres and axle load equivalent-kilometre respectively. For both the model fit shows an R^2 value of 0.26 and 0.27 respectively. If only total mileage per section is taken into account as an independent variable, R^2 is only 0.22.
(3.2) Given the fact that section wise constructional maintenance cost data was only available for a period of 4 years, several sections in our dataset have none or very low constructional maintenance. The introduction of a dummy variable for these sections improved the regression considerably, R^2 values of 0.58 for the calculation with gross ton-km and axle load equivalent-km respectively as independent variable result and of 0.57 for total mileage as independent variable.

As in the time series analysis, multiple models could not be tested with the road section data set.

6.2 Marginal infrastructure costs

The marginal cost function can be deducted from the cost function. In chapter 6.1.1 we have chosen three cost functions that show the same mathematical structure.

(6.1) $\ln(Cost) = const. + b * \ln(Use)$

This equation has to be exponentiated:

(6.2) $Cost = e^{(const.+b*\ln(Use))} = e^{const.} * e^{b*\ln(use)} = e^{const.} * \left(e^{\ln(use)}\right)^b = e^{const.} * use^b$

And finally derivate:

(6.3) $(Cost)' = e^{const.} * b * use^{(b-1)}$

The equation 6.3 is the general form of the marginal cost function. The marginal cost functions in our case are exponential equations.

6.2.1 Results based on time series analysis

With our dataset we can calculate the level of the mean marginal costs. But, due to our data structure, it is not possible to properly estimate the marginal cost of different vehicle categories in detail. Nevertheless, to give an illustration of the marginal costs of the different categories, two indirect methods can be applied.

- Statistical approach: The estimation for gross ton-kilometre allows calculating a proxy for the marginal costs of each vehicle category.
- Engineering method: The cost split of the engineering method can be applied on the marginal costs level estimated thanks to the mean marginal costs function (details to the engineering approach can be found in the Annex).

a) Marginal costs of operational maintenance

The marginal costs for operational maintenance is in total 0.006 Euro per kilometre if altogether 1 million vehicle use a specific road section within a year have been driven. All vehicle categories have the same level since operational maintenance costs are assumed to be weight independent.

Table 6-2: Marginal costs of operational maintenance for every additional vehicle kilometre per kilometre motorway.

Vehicles p.a.	Mean Euro/km
1'000'000	0.006
2'000'000	0.004
5'000'000	0.003
10'000'000	0.003
15'000'000	0.002
20'000'000	0.002

[a] Total amount of vehicles (all vehicle categories) within a specific road section

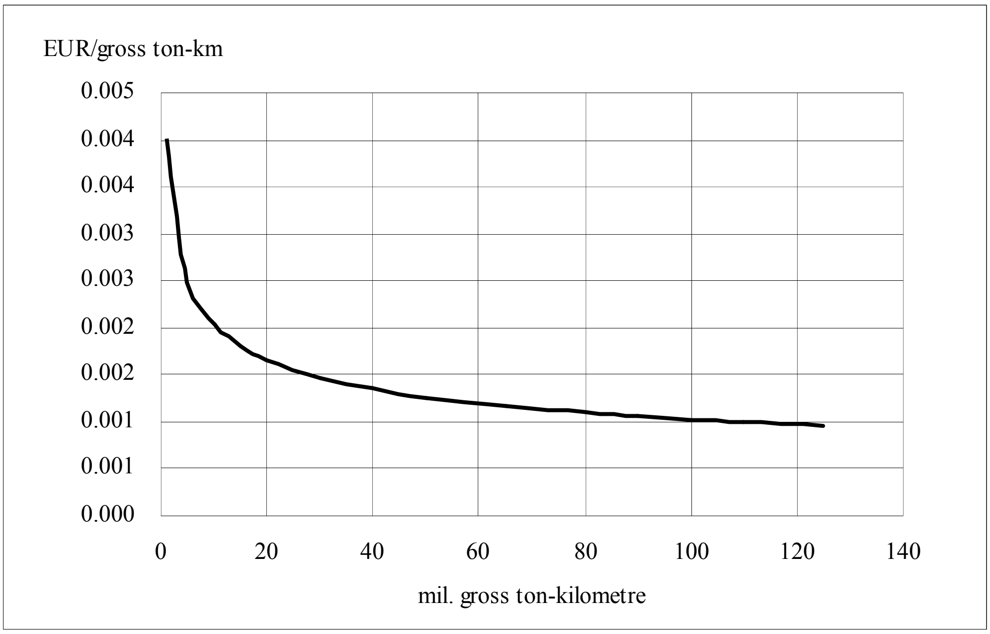
Figure 6-1: Marginal costs of operational maintenance per vehicle kilometre.

b) Marginal costs of constructional maintenance

The marginal cost of the different vehicle categories will be calculated with the two different approaches: the statistical approach and the engineering method.

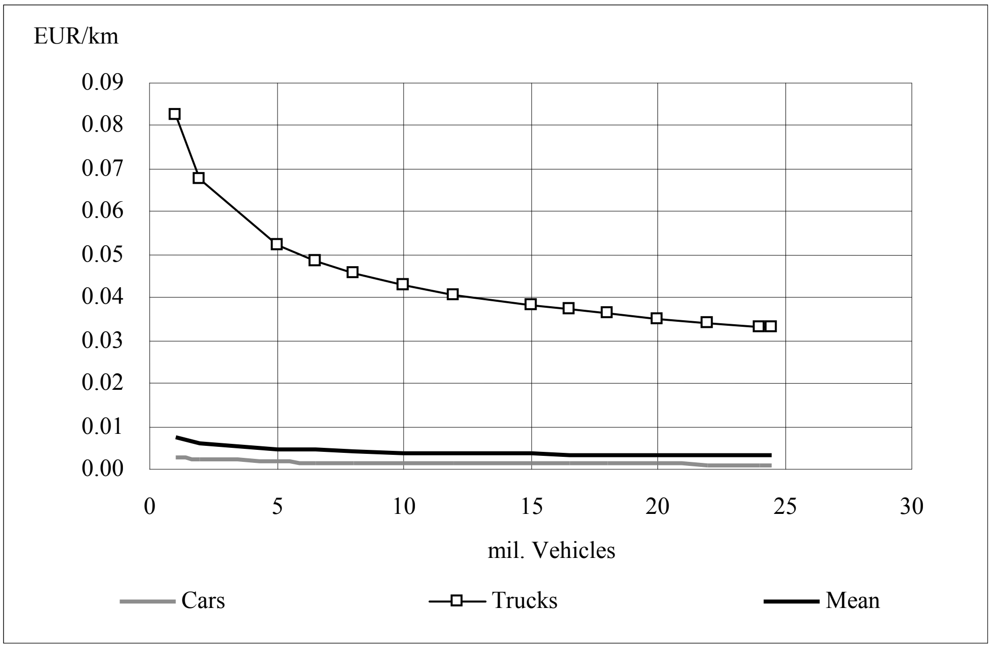
The **statistical approach** consists of the estimation of the marginal costs with an independent variable measuring the driven ton-kilometres (3.1).

Figure 6-2: Marginal costs of constructional maintenance (independent variable: total gross ton-kilometre of all vehicles categories).



The **engineering approach** is calculated on the basis of the regression with mileage as independent variable (3.2).

Figure 6-3: Marginal costs of constructional maintenance.



By taking the average weight of the vehicle categories, the marginal costs for every category can now be calculated on the basis of regression (3.1). Using the results of regression (3.2) the engineering method can be applied.

Table 6-3: Marginal costs of constructional maintenance per vehicle kilometre. Calculated for an average Swiss motorway, i.e. with 10 mil. vehicle kilometre or 30 mil. gross ton-kilometres.

Vehicle category	Average weight (gross tons)	Statistical approach Marginal costs (EUR/vkm)	Engineering method Marginal costs (EUR/vkm)
Cars	1.3	0.0019	0.0014
Vans	2.6	0.0038	0.0015
Trucks	20.6	0.0302	0.0428
Buses	16.0	0.0235	0.0860
Mean	**2.5**	**0.0037**	**0.0039**

The comparison of the results between the two methods shows a high level of consistency.

c) Marginal costs for upgrade and renewal

Like marginal costs of constructional maintenance, marginal cost for upgrade and renewal for the different vehicle categories will be calculated with the two different methods.

Figure 6-4: Marginal costs of upgrades and renewals.

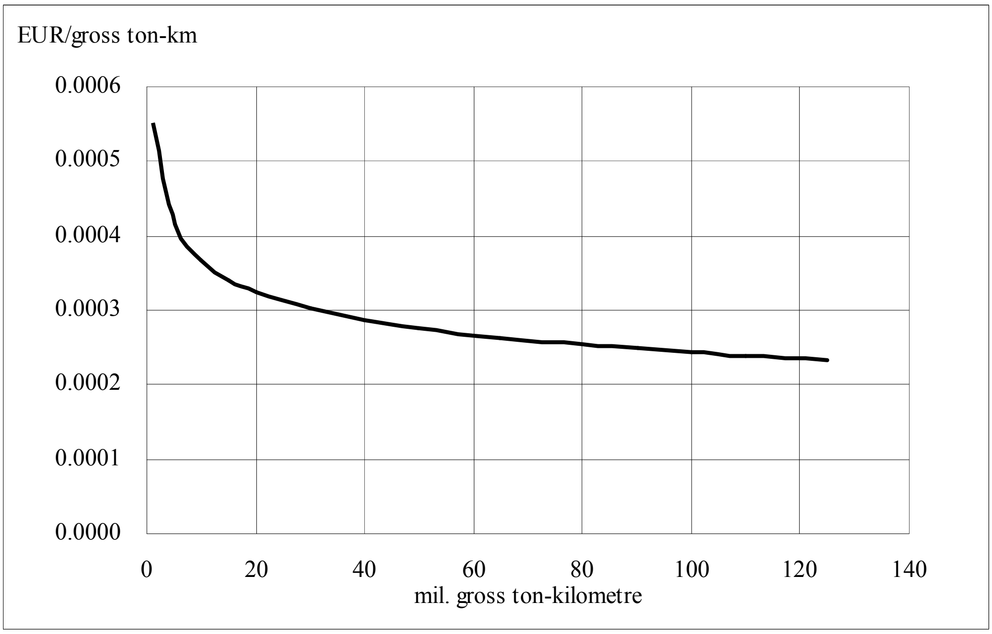


Table 6-4: Marginal costs of constructional maintenance per vehicle kilometre. Calculated for a motorway of Swiss average, i.e with 10 mil. vehicle kilometre or 30 mil. gross ton-kilometre).

Vehicle category	**Average weight (gross tons)**	**Statistical approach Marginal costs (EUR/vkm)**	**Engineering method Marginal costs (EUR/vkm)**
Cars	1.3	0.00039	0.00011
Vans	2.6	0.00078	0.00011
Trucks	20.6	0.00622	0.00327
Buses	16.0	0.00483	0.00658
Mean	**2.5**	**0.00075**	**0.00030**

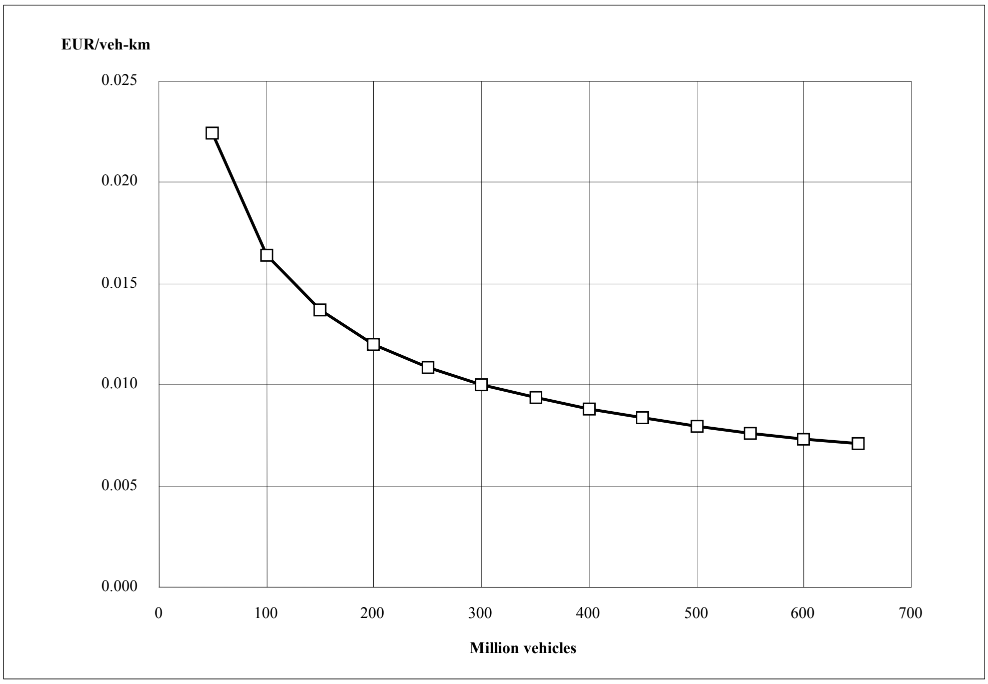
The statistical and the engineering method show similar results. A direct comparison of the two results is difficult, because the average reference points chosen (here 30 mil. gross ton-kilometre, respectively 10 mil. vkm) do not precisely correspond. This imprecision should nevertheless not have a strong effect on the results.

6.2.2 Road section analysis (additional calculations)

A calculation of marginal costs based on the model with total constructional maintenance costs as dependent variable and total mileage, total gross ton-km and total axle load equivalent-km of all vehicle categories respectively as independent variable was made. The shown results are based on the regression calculations with the inclusion of a dummy variable for the sections with substandard maintenance.

a) Results based on regression with total mileage data

Figure6-5: Marginal costs for constructional maintenance (independent variable: total mileage of all vehicle categories).

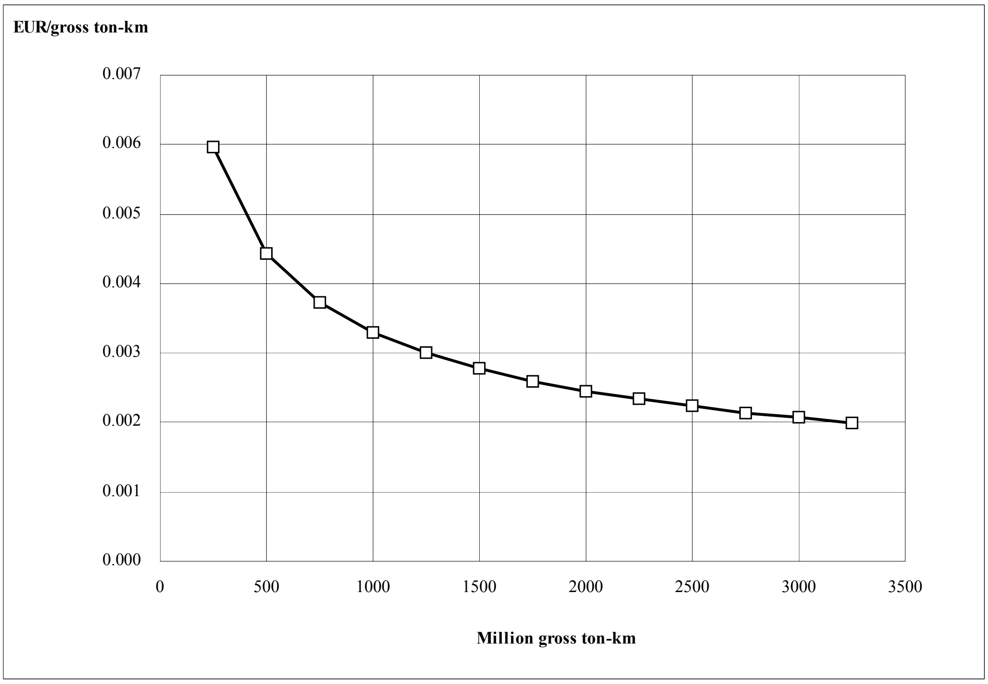


In the area of 500 million vehicles per year (mean of all considered sections), overall marginal costs of 0.8 cents per vehicle-km result.

b) Results based on regression with total gross ton-km

Using **gross ton-km** as independent variable, the following marginal cost curve results:

Figure 6-6: Marginal costs for constructional maintenance (independent variable: total gross ton-km of all vehicle categories).



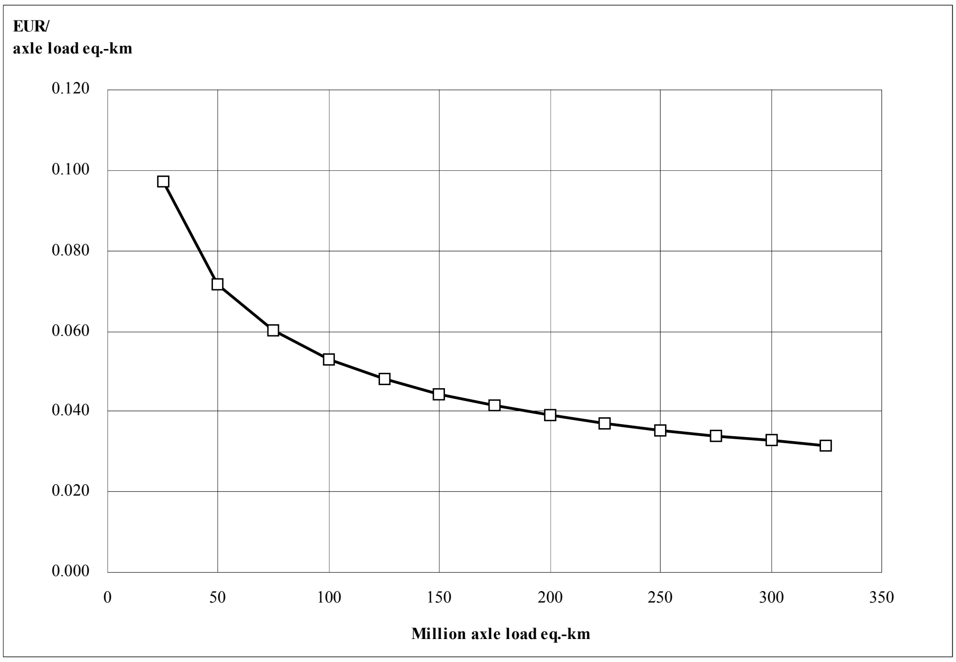
Considering the average weight of the 4 different vehicle categories, marginal costs per vehicle category and km can be derived (calculated with an average of 1'750 Mil. gross ton-km per section):

Table 6-5: Marginal costs for constructional maintenance based on gross ton-km calculations.

Vehicle category	**Vehicles**	**Average weight** (gross-tons)	**Marginal costs** (EUR/veh-km)
1	Motorbikes	0.70	0.002
2	Cars, Vans	1.30	0.003
3	Vans with trailer, trucks, tractors	15.00	0.039
4	Trucks and trailer, tractors and semi trailers	28.00	0.073

Finally, if total axle load equivalent-km are used as independent variable, the following marginal cost curve results:

Figure 6-7: Marginal costs for constructional maintenance (independent variable: total axle load equivalent-km of all vehicle categories).



Considering the average axle load equivalent (number of standard axles) of the 4 different vehicle categories, marginal costs per vehicle category and km can be derived (calculated with an average of 75 Mil. axle load equivalent-km per section):

Table 6-6: Marginal costs of constructional maintenance based on axle load equivalent-km calculations.

Vehicle category	**Vehicles**	**Average axle load equivalent** (no. of standard axles)	**Marginal costs** (EUR/veh-km)
1	Motorbikes	0.00005	0.000003
2	Cars, Vans	0.0001	0.000006
3	Vans with trailer, trucks, tractors	1.32	0.080
4	Trucks and trailer, tractors and semitrailers	1.21	0.073

The obtained results can be compared with average constructional maintenance costs. We hereby only considered sections where something happened, i.e. some constructional maintenance has been carried out during the 4 years period.

Table 6-7: Average constructional maintenance costs (calculated only for those section with constructional maintenance).

Lanes	**Average constructional maintenance costs** (EUR/veh-km)
2	0.092
4	0.042
6	0.049
Average	**0.049**

Average maintenance costs sum up to ca. 5 Cents per veh-km (total of all vehicle categories).

6.3 Summary

The following table gives an overview on the resulting marginal costs of the time series analysis.

Table 6-8: Results time series analysis (in EUR per vehicle-km)

EUR/veh-km		Cars	Trucks	Mean
Operational maintenance costs	Statistical method	0.0027	0.0027	0.0027
Constructional maintenance costs	Statistical method	0.0019	0.0302	0.0037
	Engineering method	0.0014	0.0428	0.0039
Costs for upgrade and renewals	Statistical method	0.0004	0.0062	0.0008
	Engineering method	0.0001	0.0033	0.0003

The results of the road section analysis are comparable to those of the time series analysis. Attention should be paid to the fact that the road section analysis includes only the costs of the constructional maintenance. This only enables the comparison with the constructional maintenance costs of the time series. Additional methodological discrepancy lies in the fact that in the road section analysis there is a differentiation between 2 different HGV classes. The reason for this originates in different sources of vehicle mileage.

The results o the road section analysis are presented according to the structure of Table 6-1. They include the results of the regressions when using a dummy variable for sections with substandard constructional maintenance during the observation period.

Table 6-9: Results road section analysis for constructional maintenance costs (in EUR per vehicle-km)

EUR/veh-km	Cars	Trucks	Trucks + Trailer/ Semitrailer	Mean
Calculation based on …				
total mileage (veh-km)	-[1)]	-[1)]	-[1)]	0.008
gross ton-km	0.003	0.039	0.073	-
axle load equivalent-km	0.0003	0.080	0.073	-

1) no cost allocation to different vehicle categories possible.

A comparison with the results of the time series analysis indicates the following:

- Marginal costs for passenger cars are slightly higher (0.3 Cents vs. 0.2 Cents per veh-km).
- Marginal costs for trucks are about the same as in the time series analysis.
- Only an indirect comparison with the category (trucks with trailers) from the road section analysis is possible, because the time series analysis consists of only one vehicle category of the HGV-category.
- The calculations of category-specific marginal costs are based on a regression with the independent variables gross ton-km resp. axle load equivalent-km ex post with mean values of the resp. vehicle categories (av. gross tons, av. axle load equivalent. This results in differences especially in the vehicle category 'trucks' (trucks with a length between 6 and

12.5 m). The vehicle category of HGV above 12.5 m (trucks with trailers/semitrailers) shows a higher number of axles which leads to lower axle loads and therefore to a lower number of standard axles. This is the reason why the marginal costs in the category 'trucks' (6-12.5m) are higher when calculated on a basis of axle load equivalents than those with the longer HGV's.

- This allows the conclusion that both approaches result in comparable figures. The problem of the sections with low constructional maintenance could be solved in an elegant way with the help of the dummy variable.

Comparison with existing studies shows that conclusions of the new calculations are fairly consistent with already existing results. But it is not possible to compare them directly due to the different methodological approaches. In the existing studies it is also not very obvious which cost categories for the calculation of the marginal costs were included and which were not.

Table 6-10: Comparison with Marginal Infrastructure Costs for Motorways 1994 from other Studies (Link, Maibach et al. 1999).

ECU 1994/veh-km	**Switzerland [1]**	**France [2]**	**Germany**
All vehicles [3]		0.011	0.0036
Passengers cars		0.007	-
Buses		0.016	0.057
Light goods vehicles [4]		0.009	0.000
Heavy goods vehicles [5]	0.173	0.033	0.021
Rigid goods vehicles	0.160	0.028	0.016
Lorries with trailers	0.191	0.026	0.026
Articulated vehicles	0.191	0.036	0.023

[1] Marginal costs: 60% of maintenance, 50% of running costs. At current prices.- [2] 1990 figures, at 1990 prices.- [3] Germany: including motorcycles, mopeds, special and agricultural vehicles.- [4] Goods vehicles < 3.5t max GVW.- [5] Goods vehicles > 3.5t max. GVW. Switzerland: >3t max. GVW.

The results of the existing case study for Heavy Goods vehicles (HGV) are more in the area of already existing studies for France and Germany. But they are substantially lower than those of the existing studies for Switzerland. Up to now comparable values for passenger cars were only obtainable from France. These values are 2.5-3.5 higher than the results presented here.

The following conclusions can be taken

- Due to the problems mentioned earlier, based on the existing data it was only possible to estimate very simple cost functions. All approaches for the estimation of theory-based cost functions failed due to problems of data availability and collinearity of independent variables (i.e. small variation between share of vehicle categories).
- Very simple marginal cost curves with a downward run are a direct consequence.
- The results of the time series analysis are based on a complete time series between 1985–1998 of the national road account. All costs are therefore contained, opposed to the road section analysis. Though methodically problematic with time series analysis is the fact that model based mileage data was only available for 1 year (1995) and has to be adjusted according to general growth factors per vehicle category.
- The most important problem of the road section analysis is the small database containing maintenance cost data per section for only four years. In connection with a lack of knowledge of preceding maintenance works, it was not possible to assess if the included maintenance costs have a tendency be too low. However, the introduction of a dummy variable

enabled an improvement of the results of the regression considerably. These results tend to be in the same area as those of the time series analysis.

- Many important influence factors like climate conditions, design speed, total number and length of bridges and tunnels could not be considered since no adequate differentiated data was available. This is true for both data sets and methods (time series and road section analysis).
- We also know that cost allocation between different types of maintenance works is made according to allocation rules set by the Swiss Federal Roads Office (SFRO). However, allocation might anyway be sometimes arbitrary and subject to budget policy decisions.
- In addition there was no data available concerning construction standards of the different motorway sections. Because the database contains different types of national roads (even roads with 2 lanes in alpine regions) it was impossible to make statements concerning the standard or substandard maintenance works.

7 Conclusions and transferability of results

In order to evaluate the quality and transferability of results, one has to consider different levels:

Generalisation of the results for Switzerland
The discussion of the results in the previous chapter has shown the difficulty of the approach. The time series analysis was able to provide sound results for the whole of Switzerland (motorways and main roads) on a general traffic level. The (average) marginal costs of all vehicles of operational maintenance, constructional maintenance and upgrade and renewal are helpful and provide new emphasis of marginal costs.
The marginal costs derived for specific vehicle categories (esp. trucks) however have to be seen on another quality level. Due to a very limited variety of HGV shares, there is no strong evidence for a weight dependent cost function. The collinearity is too strong between the variables. The approach has been weakened in addition due to special situations in the alpine area (where HGV shares would be higher) and due to rather limited availability of weight related traffic information.
Thus the vehicle specific values should be treated carefully. They are not a direct result of the econometric analysis. Moreover they should be seen as illustrative.

Generalisation of the results for Europe
The conclusions drawn above hold as well true for the European level. In addition one has to consider further arguments which lead to a rather limited generalisation possibility for Europe:

- Due to the specific HGV-policy (esp. 20 ton limit), the road construction parameters and the traffic characteristics are different to other countries.
- The specific maintenance practice in Switzerland (small sections within cantons) are restricting optimal solutions per section. Thus the Swiss sample is too small to allow general conclusions for other countries.
- The situation in the alpine region is very specific and cannot be transferred to other countries. First of all the topographical parameters are very specific (tunnels, bridges), secondly the weather vulnerability is rather high which influences the level of constructive maintenance. However – as the analysis has shown – these factors are very difficult to treat within an econometric approach.

Appropriateness of the approach

Finally the exercise for Switzerland allows some conclusions of the transferability and the further development of the approach itself and its relative importance to an engineering based approach.

It was clear in advance that an econometric approach is not able to estimate optimal marginal infrastructure costs, due to many different real factors which deviate from optimal conditions, such as budgetary reasons, practical reasons, other exogenous influences such as weather conditions or accidents, which are different to isolate.

The exercise has shown as well that the data availability is a very critical factor. This is true for cost figures (maintenance, operation, construction) and the related traffic data incl. weight information. Even in Switzerland – which has rather a good data availability – the situation was insufficient. A more detailed approach would lead to very big expenses.

Most important is the availability of a rather high variance between HGV-shares on different roads, if a weight dependent relationship should result. This was not the case in Switzerland. Thus we might conclude that the approach is valuable to show a strong relationship between traffic volume and road expenses. For the computation of optimal marginal infrastructure costs by category, an engineering (damage) based approach might be more appropriate.

Annex: Details vehicle differentiation

Calculation of marginal cost allocation using the cost split of the engineering method.

The allocation of costs will be made after the new methodology of LAVOC 2000. The LAVOC is a laboratory of the Federal Institute of Technology (ETH), which has renewed the Swiss cost allocation method thanks to new experimental results.

First step: Split total cost into weight dependent and independent costs
- Cost for upgrade and renewal: 6.91% of these cost are weight dependant,
- Constructional Maintenance: 63.8% of cost of motorways are weight dependant,
- Operational Maintenance: 100% of these costs are weight independent.

Second step: Allocation of weight independent costs
- The weight independent costs are distributed in proportion to the mileage of the vehicle categories

Fourth step: Allocation of weight dependent costs
- Constructional Maintenance: the weight dependent costs are allocated using LAVOC's Aggression factors.
- Upgrade and Renewal: the weight dependent costs are allocated using LAVOC's AFP-factors.

Fifth step: Summing up and calculation of marginal costs
- The weight dependent and independent costs of the different vehicle categories are summed up together. It results in a cost function for each vehicle category.
- Finally, these cost functions are derivated to get the marginal cost functions.

As an example the marginal cost function for cars is stated:

$$(Cost_{cars})' = Allocation_{cars} * e^{const.} * (1/Mileage_{cars})^{b} * b(x * Mileage_{cars})^{b-1}$$

Allocation is the proportion of costs that can be attributed to a certain vehicle category. Mileage is the proportion of driven kilometre of a category to the total mileage of all categories. The table shows the proportions of cost allocations for the different vehicle and cost categories. The value for operational maintenance costs corresponds to the percentage of mileage of a category on total mileage. The values for constructional maintenance and for upgrade and renewal correspond to the percentage of costs allocated to a categories on total costs.

Table 0-1: Cost allocation according to LAVOC methodology (LAVOC 2000).

Cost category	**Cars**	**Vans**	**Trucks**	**Buses**
Operational maintenance	89.2%	5.0%	5.6%	0.3%
Constructional maintenance	32.4%	1.9%	60.3%	5.5%
Upgrade and renewal	83.1%	4.6%	11.8%	0.5%

References

ASTRA 2000: Schweizerische Nationalstrassen, Abschnittsverzeichnis für Unterhalt und Betrieb, Stand 01.01.2000, Federal Roads Office, Bern 2000.

BFS 2000: Statistisches Jahrbuch der Schweiz, Bern

LAVOC 2000: Compte routier: Vérification des coefficients de répartition des coûts, Lausanne 2000

Link, H, Lindberg, G (2000) Marginal Cost methodology for Infrastructure Costs. UNITE (Unification of accounts and marginal costs for Transport Efficiency), Interim Report 5.3, Funded by 5th Framework RTD Programme, ITS, University of Leeds, September 2000

Link, Maibach et al. 1999: The Cost of Road Infrastructure and Congestion in Europe, Physica-Verlag, Heidelberg

Ott, Seiler et al. 1999:Externe Kosten im Verkehr: Regionale Verteilungswirkungen, National Research Programme 41, Bern, 1999

UVEK 2000: Anzahl Äquivalenter Einheitsachslasten verschiedener Fahrzeugtypen, Eidgenössische Technische Hochschule Zürich ETH, Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau IVT, Horat M. et al., Forschungsauftrag 11/00 auf Antrag der Vereinigung Schweizerischer Strassenfachleute (VSS), Zurich, December 2000

Federal Roads Office (electronic data), provisional data set, not published