INTRODUCTION OF LIFE CYCLE COSTING FACTORS OF ROAD INFRASTRUCTURES FOR THE OPTIMIZATION OF BUDGETING AND INVESTMENT DECISIONS

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ABSTRACT: With budget restrictions and cost control, life cycle costing analysis and asset management have gained importance for road authorities. However, in most cases common life cycle costing analysis only targets specific cases or investment decisions. The presented framework instead aims at the definition of a standardized framework for life cycle costing of all road infrastructures. The framework consists of a set of conditions and standardized maintenance and rehabilitation measures on different levels. It can be scaled "top down" from standardized costs per average kilometer of road and "bottom up" at position or asset element level for all assets (pavements, bridges and tunnels). With this framework, it is possible to determine the budgeting needs for the entire road network and all its assets at every necessary level of detail. Based on standardized life cycles for typical road assets, a life cycle costing factor can be calculated as a magnitude of the initial construction costs. This life cycle costing factor allows a fast forward accounting of all further budgeting needs or proposed alternatives and is already implemented in the new regulations for cost-benefit analysis in Austria (RVS 02.01.22).

KEY WORDS: ROADS, BUDGETING, INVESTMENT, MANAGEMENT, LIFE CYCLE

1. ASSET MANAGEMENT LEVELS ROAD INFRASTRUCTURE

Asset management in modern road authorities represents a comprehensive and structured approach to long-term management of all road assets with the goal to provide the best possible service for both road users and tax payers. In order to achieve that goal the needs of construction, operation maintenance and rehabilitation until deconstruction have to be considered already at the planning stage. With the concept in Fig.1, a continuous analysis and optimization during the life cycle is possible.

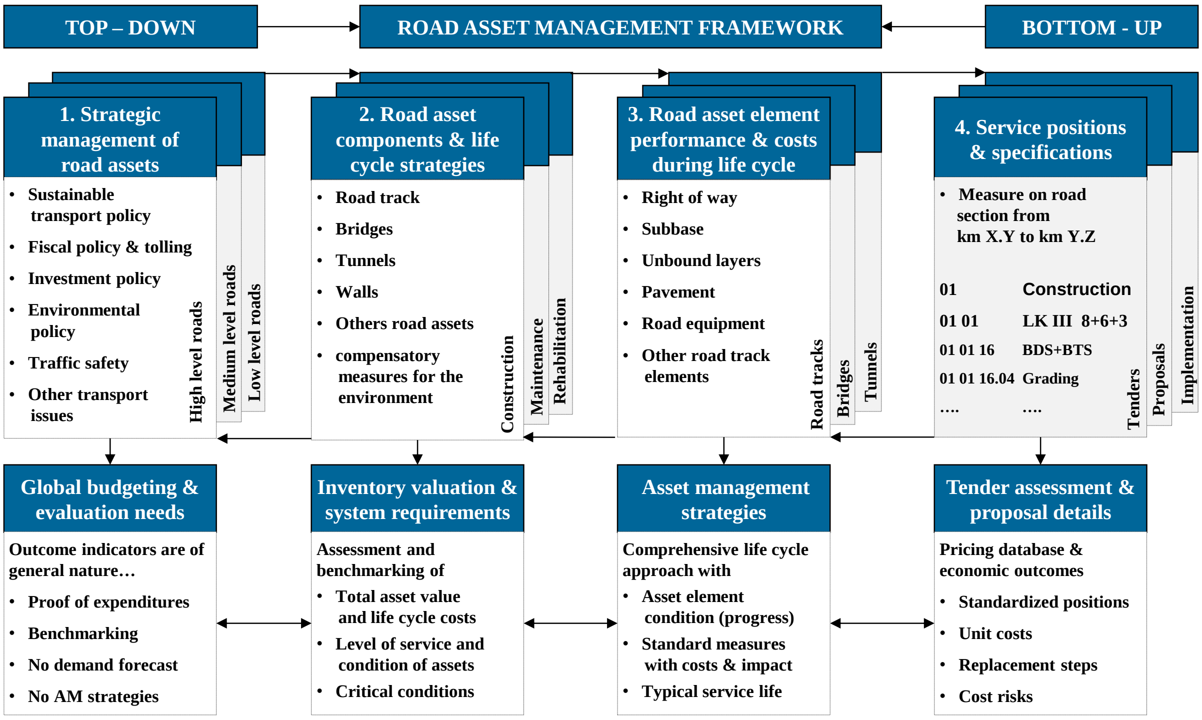

Fig.1: Asset management levels for road infrastructures „top down" & „bottom up"

With the “top down” approach existing budgets and expenditures per unit can be compared between road authorities. Furthermore investment and fiscal policy as well as tolling and other operational benchmarks can be assessed. Demand forecasting or asset management strategies are not feasible at this level, because actual expenditures do not necessarily have a connection to the actual budgeting needs. If individual assets (e.g. road tracks, bridges, tunnels) and the necessary expenditures at each phase during the life cycle are linked with their condition the total asset value and budgeting needs can be estimated. A detailed planning of rehabilitation measures or an optimization of the life cycle however is only feasible at a more detailed level for each asset element. At project level the individual specifications and positions have to be considered and may be systematically assessed and compiled “bottom up”.

2. THE LIFE CYCLE APPROACH IN ROAD ASSET MANAGEMENT

To determine the actual financial needs and the sustainable use of scarce public resources a consideration of the entire life cycle with its impacts from the perspective of the operator, user and third parties as well as the environment is required. Such a life cycle begins with planning and construction, followed by periodic maintenance and rehabilitation intervals during the service life until deconstruction (Fig.2 above). The assessment of life cycle costs of construction projects, route alternatives or repair strategies is usually addressed by comparing the average annual costs. Parallel to the investment cycle the benefits and revenues usually grow with increasing traffic towards the end of the service life (Fig.2 below). This is especially true for highways and motorways or agglomerations in Austria. On the other hand low volume roads and peripheral regions are not expected to have a significant increase in traffic in the future [HOFFMANN 2010]. This has to be considered if revenues of the investments are a deciding factor. The benefits of road investments for road operators follow directly from tolls and for users with time savings. The benefits of the economy (e.g. locational advantages and productivity gains) from infrastructure investments have to be distinguished between redistribution and additionally generated benefits.

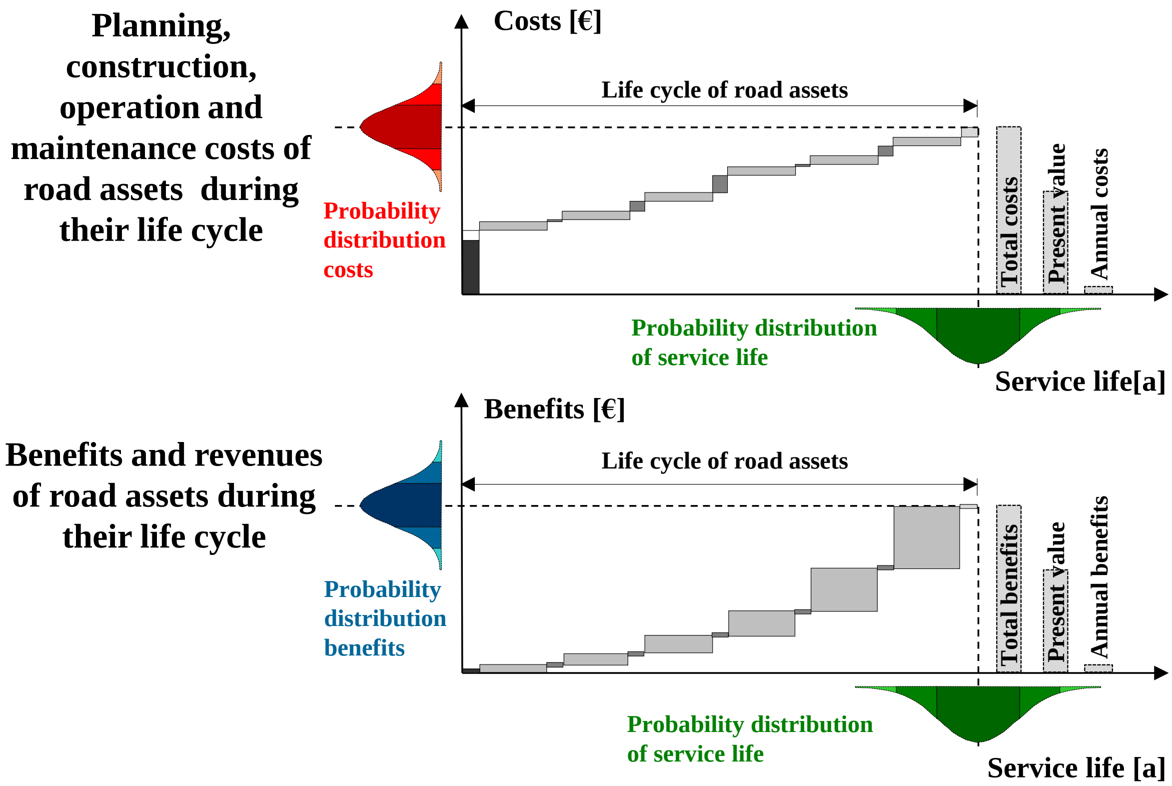

Fig.2: Schematic representation of accumulating costs and benefits of road assets during their service life with their respective stochastic distributions [HOFFMANN 2010]

3. INVESTMENT COSTS FOR INITIAL CONSTRUCTION OF ROAD ASSETS

If realized projects or assets are compared "top down" the distribution of the unit costs can be analysed. This cost distributions include all realized cost risks of the analysed projects and are therefore an ideal basis for testing the plausibility of detailed calculations "bottom up" of individual projects. In Fig.3, the distributions of the construction costs of new projects for regional roads (median = 402 €/m^2), highways and motorways (median = 1.130 €/m^2) are presented. These unit costs include engineering works (without taxes) of entire road sections in Austria. Furthermore the construction cost distributions of bridges (median = 1.594 €/m^2) and tunnels (median = 2.364 €/m^2) are given. The probability distributions of the unit costs are modelled based on a log-normal distribution. Together with the distribution of the service lives and standard cycles for typical road assets a probabilistic model based on Monte Carlo method can be compiled. Based on this method and such standard cycles the financial needs on project level as well as network level can be estimated.

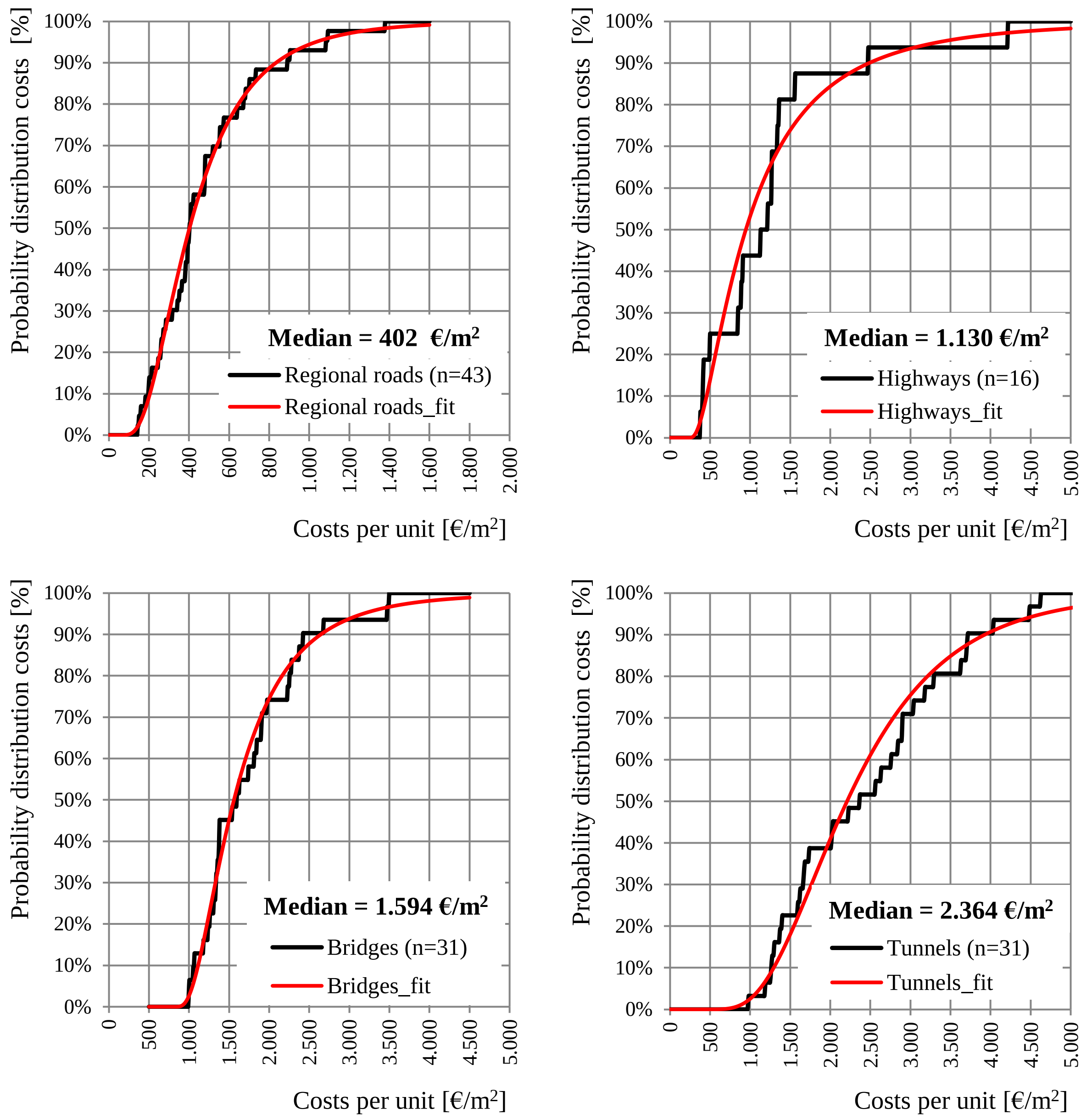

Fig.3: Cost distribution of the adjusted unit costs of road construction projects with all structures as well as individual assets (e.g. bridges and tunnels) with prices as of 2010 (without taxes)

4. STANDARDIZED LIFE CYCLE OF ROAD SUPERSTRUCTURES

Based on the typical pavement performance, failure types and service lives of road surface rehabilitation measures and intervals can be identified. The presented standardized measures and service lives are based on extensive research [HOFFMANN 2006b] and statistical evaluations. For regional roads the typical rehabilitation measures, depending on their condition and affected element/layer are presented:

- Type II-I: Small rehabilitation with crack filling and a replacement of the top layer by thin cold overlay (DDK) or hot overlay (DDH)
  Service life: from 10 to 15 years; costs: from 5 to 7 €/m²
- Type III-I: Medium rehabilitation with replacement of asphalt layers depending on observed failures from condition assessment and FWD - measures
  Service life: from 15 to 20 years; costs: from 15 to 20 €/m²
- Type IV-I: Major rehabilitation of all bound and unbound layers from top to the bottom of the superstructure
  Service life: from 35 to 40 years; costs: from 35 to 45 €/m²
- Type V-I: Construction of the superstructure without artificial structures or major earth movements on the open field.
  Service life: Entire life cycle from 60 to 100 years; costs: from 80 to 100 €/m²

Naturally, costs and timing of intervention and service life may differ in individual cases and has to be adapted to the respective projects. Fluctuations in unit costs and service life become less significant in later stages of the service life if interest rates are accounted for (Fig. 4). If the amount of tracks with a condition corresponding to the presented standardized measures is combined, the budgeting needs can be estimated by entering the standardized life cycle at that specific measure. The same principle applies for individual projects if the annual costs of rehabilitation or new construction are compared to each other.

LCC - modell superstructures		**Cycle [a]**	**80**		**Interest [%]**	**3%**
Pos.	*Description of positions*	*Unit costs [€/m²]*	*Cycle [a]*	*Timing [a]*	*Present value [€/m²]*	*Annual costs [€/m² *a]*
A	**Right of way**					
1	Costs of land use	20,0	infinite	0	20,0	0,6
B	**Construction + Reinvestments**					
1	Planning	6,0	**80**	0	6,0	0,2
2	Type V-I: New construction	90,0	**80**	0	90,0	3,0
3	Type II-I: Small rehabilitation 1	5,5	**80**	15	3,5	0,1
4	Type III-I: Medium rehabilitation 1	17,5	**80**	25	8,4	0,3
5	Type IV-I: Major rehabilitation	40,0	**80**	40	12,3	0,4
6	Type II-I: Small rehabilitation 2	5,5	**80**	55	1,1	0,0
7	Type III-I: Medium rehabilitation 2	17,5	**80**	65	2,6	0,1
C	**Running costs**					
1	Maintenance	1,5	**80**	0	45,3	1,5
2	Administration	1,0	**80**	0	30,2	1,0

Total costs (prices 2010) in €/m²	**402,0**
Present value (prices 2010) in €/m²	**219,3**
Annual costs during entire life cycle [€/m²*a]	**7,20**
Life cycle costing factor (rehabilitation only)	**1,38**
Life cycle costing factor (rehabilitation+maintenance)	**2,21**
Life cycle costing factor (rehabilitation+maintenance+right of way)	**2,44**

Cost estimation	**Lenght [m]**	**1000**	**Width [m]**	**6**
	Present value (prices 2010) in €			**1.315.782**
	Annual costs during entire life cycle [€/a]			**43.194**

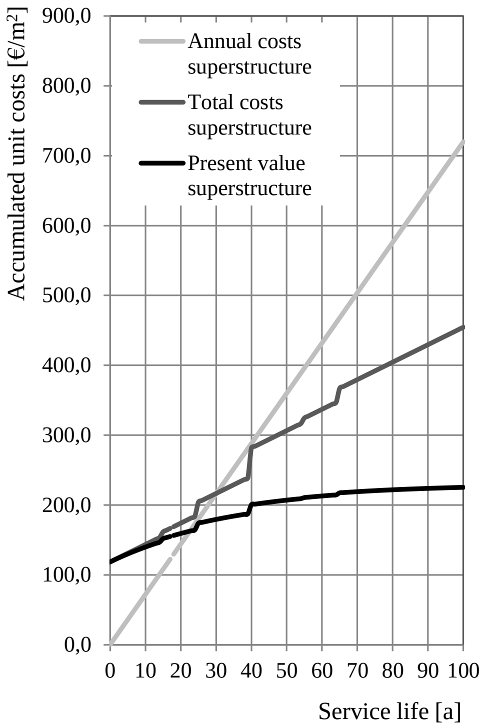

Fig.4: Simplified life cycle costing model for the entire superstructure without major earth movements or artificial structures for regional roads with prices as of 2010 (without taxes)

5. STANDARDIZED LIFE CYCLE OF ROAD BRIDGES

The simplified life cycle costing- model (LCC) for regional road bridges is based on the analysis of the bridge database of Styria. The standardized rehabilitation measures are a result of typical frequent co-occurrence of the repair work on individual bridge elements [HOFFMANN 2005; 2006b]:

- Type II-I: Small rehabilitation with lining repair, joint replacement, drainage, dilatation joints, isolation and small concrete repairs
  Service life: from 20 to 25 years; costs: from 300 to 400 €/m²
- Type III-I: Medium rehabilitation with lining repair, joint replacement, drainage and isolation repair, replacement of edge beams, concrete repairs, abutment reconstruction and ensuring accessibility according to the regulations in Austria
  Service life: from 30 to 35 years; costs: from 600 to 700 €/m²
- Type IV-I: Major rehabilitation as above but with additional replacement of bridge bearing and bearing structure or widening and strengthening of the bearing structure
  Service life: from 35 to 40 years; costs: from 700 to 1.000 €/m²
- Type V-I: New construction of road bridges with adaptation to specific (traffic) requirements and state of the art.
  Service life: Entire life cycle from 50 to 90 years;
  Costs: for length < 35 m from 1.750 to 2.250 €/m²
  Costs: for length > 35 m from 1.500 to 2.000 €/m²

The variety of bridge types, construction methods, materials and damage patterns can be represented with this generalized approach at the network level with sufficient accuracy. For individual project assessment a comparison between new construction and rehabilitation based on annual costs is also feasible. A more sophisticated individual assessment on project level requires a more detailed analysis. Such a standardized and detailed system on element level for road tracks, bridges and tunnels has to deal with the individual failure types and measures and their connections.

LCC - modell road bridges		**Cycle [a]**	**80**		**Interest [%]**	**3%**
Pos.	*Description of positions*	*Unit costs [€/m²]*	*Cycle [a]*	*Timing [a]*	*Present value [€/m²]*	*Annual costs [€/m² *a]*
A	**Right of way**					
1	Costs of land use	20,0	infinite	0	20,0	0,6
B	**Construction + Reinvestments**					
1	Planning (7% of V-I)	122,5	**80**	0	122,5	4,1
2	Type V-I: New construction	1750,0	**80**	0	1750,0	57,9
3	Type II-I: Small rehabilitation	350,0	**80**	25	167,2	5,5
4	Type IV-I: Major rehabilitation	850,0	**80**	45	224,8	7,4
5	Type III-I: Medium rehabilitation	650,0	**80**	65	95,2	3,2
6	Demolition of bridges (10% of V-I)	175,0	**80**	80	16,4	0,5
C	**Running costs**					
1	Maintenance	3,5	**80**	0	105,7	3,5
2	Administration	1,0	**80**	0	30,2	1,0

Total costs (prices 2010) in €/m²	**4.277,5**
Present value (prices 2010) in €/m²	**2.532,0**
Annual costs during entire life cycle [€/m²*a]	**83,78**
Life cycle costing factor (rehabilitation only)	**1,36**
Life cycle costing factor (rehabilitation+maintenance)	**1,44**
Life cycle costing factor (rehabilitation+maintenance+right of way)	**1,45**

Cost estimation bridge	**Lenght [m]**	**30**	**Width [m]**	**10**
			Present value (prices 2010) in €	**759.586**
			Annual costs during entire life cycle [€/a]	**25.133**

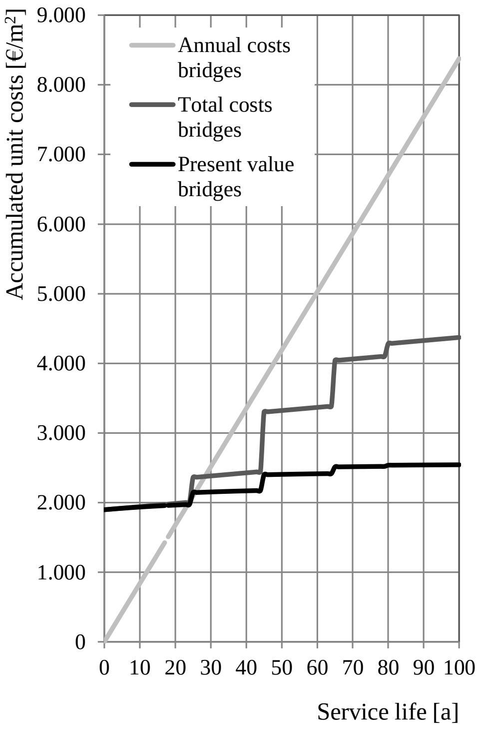

Fig.5: Simplified life cycle costing model for road bridges based on typical jointly conducted rehabilitation measures on bridge elements with prices as of 2010 (without taxes)

6. STANDARDIZED LIFE CYCLE OF ROAD TUNNELS

The simplified LCC - model for road tunnels is based on the condition assessment and evaluation of the tunnels on regional roads in Styria. The resulting rehabilitation plans and conducted measures were also considered. Based on actual service lives of tunnel elements and their necessary replacement or rehabilitation typical aggregated rehabilitation types with unit costs and service lives can be derived [HOFFMANN 2005; 2006a]:

- Type II-I: Small rehabilitation with crack filling and other concrete repairs, rehabilitation of pavement, drainage repairs, renewal of technical equipment and tunnel painting
  Service life: from 20 to 25 years; costs: from 400 to 500 €/m²
- Type III-I: Medium rehabilitation with crack filling and other concrete repairs, replacement of pavement, drainage repairs, renewal of technical equipment and tunnel painting as well as a tunnel safety package
  Service life: from 30 to 35 years; costs: from 500 to 700 €/m²
- Type IV-I: Major rehabilitation with replacement of tunnel lining, replacement of pavement, drainage renewal, renewal of technical equipment and tunnel painting, safety package, control units and safety crosscuts
  Service life: from 35 to 40 years; costs: from 700 to 1.000 €/m²
- Type V-I: New construction of road tunnels with adaptation to specific (traffic) requirements and state of the art.
  Service life: Entire life cycle from 70 to 100 years; costs: from 1.500 to 3.500 €/m²

The unit costs of this aggregated rehabilitation types are derived from the total expenses per square meter of the tunnel floor. The development of the present value of the life cycle costs proves the dominance of the initial construction costs of tunnels (Fig. 6).

LCC - modell road tunnels		**Cycle [a]**	**80**		**Interest [%]**	**3%**
Pos.	*Description of positions*	*Unit costs [€/m²]*	*Cycle [a]*	*Timing [a]*	*Present value [€/m²]*	*Annual costs [€/m² *a]*
A	**Right of way**					
1	Costs of land use	20,0	infinite	0	20,0	0,6
B	**Construction + Reinvestments**					
1	Planning (10% of V-I)	175,0	**80**	0	175,0	5,8
2	Type V-I: New construction	2500,0	**80**	0	2500,0	82,8
3	Type II-I: Small rehabilitation	450,0	**80**	20	249,2	8,2
4	Type IV-I: Major rehabilitation	1250,0	**80**	40	383,2	12,7
5	Type III-I: Medium rehabilitation	800,0	**80**	60	135,8	4,5
6	Demolition of Tunnels (5% of V-I)	125,0	**80**	80	11,7	0,4
C	**Running costs**					
1	Maintenance	5,0	**80**	0	151,0	5,0
2	Administration	1,0	**80**	0	30,2	1,0

Total costs (prices 2010) in €/m²	**5.800,0**
Present value (prices 2010) in €/m²	**3.656,1**
Annual costs during entire life cycle [€/m²*a]	**121,00**
Life cycle costing factor (rehabilitation only)	**1,38**
Life cycle costing factor (rehabilitation+maintenance)	**1,45**
Life cycle costing factor (rehabilitation+maintenance+right of way)	**1,46**

Cost estimation bridge	**Lenght [m]**	**200**	**Width [m]**	**10**

Present value (prices 2010) in €	**7.312.177**
Annual costs during entire life cycle [€/a]	**241.994**

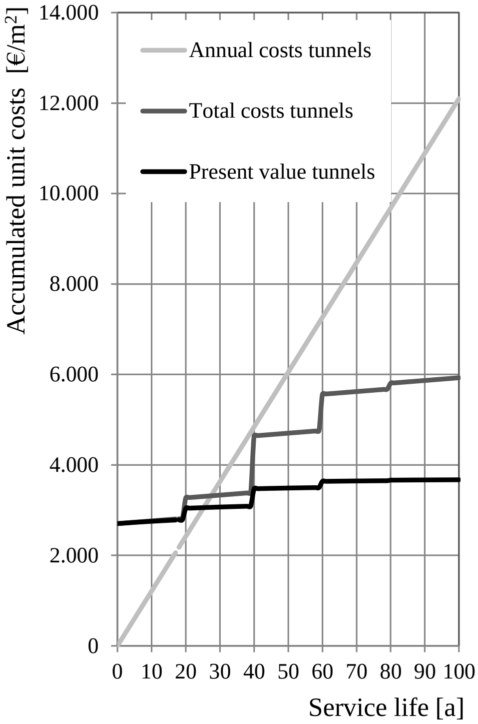

Fig.6: Simplified life cycle costing model for road tunnels based on typical jointly conducted rehabilitation measures on tunnel elements with prices as of 2010 (without taxes)

7. STANDARDIZED LIFE CYCLE COSTING FACTORS

With the standardization of life cycles for different road assets an assessment of road projects and a comparison of route alternatives or construction alternatives becomes feasible [M. HOFFMANN 2010]. For example it is possible to determine the impact of a different speed and the resulting amount of civil engineering structures based on their life cycle costs already at the planning phase.

A simple way to take into account the costs of infrastructure investments based on the initial construction costs was added to the new regulations for cost-benefit analysis of roads (RVS 02.01.22 October 2010 page 17-21). The life cycle factor represents the ratio of the net present value during the service life (including initial investment, repair work, demolition and capital costs) and the amount of the initial construction investment itself ($F_{lzk} \geq 1$). This factor also allows an easy estimation of the life cycle costs based on the cost estimate for the initial construction. The same method can be applied for the comparison of project alternatives.

The annual cost factor derived from the life cycle costing factor allows an estimation of the average annual investment needs. To determine the current financial requirements for an existing road network condition and age this method is not suitable. For this task the amount of sections in a specific condition linked with the standardized life cycles have to be considered. The influence of subsequent reinvestments, and the resulting life cycle costing factors as well as the annual cost factors are essentially interest rate-dependent. For road authorities at state level or communal level in Austria the usual inflation-adjusted interest rate can be set between 2% to 4% [KOMMUNALKREDIT p. 21-22]. In general the medium to long term interest rate oscillates somewhere around the inflation adjusted annual growth rate of the gross domestic product and the interest rate of government bonds.

Typical road assets (e.g. interest rate = 3%)	*Typical service life (full cycle)*	*annual cost faktor af (construction)*	*Life cycle costing factor** rehab F_{lzk}*	*Annual cost factor (F_{lzk}) (with rehab)*
Non-depreciable services:				
Right of way	∞	0,0300	1	0,0300
Costs of land use	∞	0,0300	1	0,0300
Depreciable services/assets:				
Planning and construction management	cycle*			
Base, foundation, dams and walls	70	0,0343	1,2	0,0412
Compensatory measures (eg. for environment)	60	0,0361	1,05	0,0379
Drainage	60	0,0361	1,1	0,0397
Unbound layers (z.B. anti-freeze course)	40	0,0433	1,3	0,0562
Flexible base layer, binder layer and surface layer	20	0,0672	1,1	0,0739
Rigid layers	30	0,0510	1,1	0,0561
Cobble layers	50	0,0389	1,1	0,0428
Bridges	80	0,0331	1,1	0,0364
- Base, foundation	90	0,0323	1,1	0,0355
- Structure	70	0,0343	1,2	0,0412
- Equipment	20	0,0672	1,1	0,0739
Retaining walls and slope stabilization	80	0,0331	1,1	0,0364
Tunnel in mining construction (excavation and support)	100	0,0316	1,05	0,0332
Cover tunnels and galleries (Excavation)	80	0,0331	1,05	0,0348
- Tunnel lining	80	0,0331	1,2	0,0397
- Tunnel equipment and safety systems	15	0,0838	1,1	0,0921
Road equipment	20	0,0672	1,2	0,0807
Noise protection walls and windows	20	0,0672	1,1	0,0739
Associated buildings (e.g. road maintenance, tunnel control)	60	0,0361	1,4	0,0506

* This are the typical service lifes of road assets. If only elements of road assets are replaces their average service life has to be taken into account

** The life cycle costing factor according to RVS 02.01.22 includes only rehabilitation investments (no maintenance, right of way…)

Fig.7: Service lives, annuities and life cycle costing factors of typical road assets

8. SUMMARY AND OUTLOOK

The aim of cost-benefit analysis should be to identify and realize only those projects with high benefits and revenues compared to the arising costs during their service life. Any other investment strategy results in a reduction of the scarce available resources, reduces the chances of implementation of better projects and is therefore not consistent with the public interest [B. Flyvbjerg et. al. 2003]. The challenge for the road and traffic planning in Austria will be primarily focused on ensuring a high availability of the existing well developed road network. For new road projects, however, those projects are to be preferably realized, that are of essential importance (eg. bottlenecks). Furthermore these projects should be optimized regarding their life cycle costs. Essential tools for such decisions are an asset management system and economic feasibility studies based on a life cycle approach. In summary, it can be concluded:

- The challenge regarding limited resources is to operate more efficiently and to identify the projects with the highest return on investment for the economy compared to their life cycle costs. *Result: Life cycle costing is mandatory*
- With a road asset management concept and typical life cycles the resulting questions regarding budgeting, optimization of investments and life cycle costs may be answered. *Result: Optimization of road assets*
- The presented standardized life cycles for road assets allow a fast forward estimation of required budgets and a comparison of investment alternatives. *Results: Simple and straightforward cost-benefit analysis*
- A majority of the costs of road assets arise with the initial construction, while benefits and revenues will come later and are diminished by discounting. *Result: Benefits must be high and should be created as early as possible*
- Where resources are scarce and the road network is already well-developed the road authorities should focus on maintenance and rehabilitation as the dominant strategy. *Results: Preservation of existing assets in such cases is a priority*

REFERENCES:

FLYVBJERG B.; BRUZELIUS, N.; ROTHENGATTER, W.: *Megaprojects and Risk*; Cambridge Press ISBN 0521009464 S; Cambridge, 2003

HOFFMANN M.; *Rehabilitation investment needs of the state roads in Styria*; German; study on investment needs in road investments (track, bridges, tunnels, etc.) on behalf of the Office of the Styrian state government; Graz; 2005

HOFFMANN M.; *Condition survey and risk assessment of all tunnels on state roads in Styria*, German, study and implementation on behalf of the Office of the Styrian state government; Graz; 2006a

HOFFMANN M., *Rehabilitation of roads*, German; PhD - thesis, Technical University Graz, 2006b

HOFFMANN M., *Efficient planning of roads – stochastic decision parameters for optimized planning of roads;* German, Presentation and Paper at the summer university „Road planning in transition" Technical University Graz; 2010

KOMMUNALKREDIT; *Community financial report 2010*; German; Vienna; 2010