Life-Cycle of Structures and Infrastructure Systems

Editors

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Reliable estimation of investment and life-cycle costs from road projects to single road assets

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ABSTRACT: The estimation of investment costs of road projects is a key task at every stage of planning and implementation. From the initial project idea to detailed planning and legal approval, the costs of transport infrastructures play a decisive role for investors, authorities, and the public. Although each project is different and some deviations between estimation and actual costs are to be expected, there is ample evidence from the literature on systematic underestimation and the main reasons for this effect. Beyond investment costs, reliable estimations of life cycle costs from single assets and projects up to entire road networks are of an increasing importance to determine budgeting needs, preserve asset value, and define contracts between stakeholders. In all cases, systematic methods and a large database on road projects and individual measures are needed to provide a sufficient basis for cost estimations and validation. This paper tries to fill this gap by providing unit costs both at the project and asset level for construction and rehabilitation measures with adjusted prices for the year 2022. Thereby, the cost estimates are based on extensive research and collected cost data from projects on regional roads and highways in Austria over the last two decades. In addition, the paper presents calibrated standardized live cycle costs for key road assets together with life cycle cost factors providing the means to estimate life cycle costs based on construction costs alone. Finally, the adjustment of prices for different regions and years of construction are highlighted, allowing for a validation of individual project appraisals.

1 INTRODUCTION

1.1 *Construction costs and construction prices*

The provision of transport infrastructure requires high initial investments as well as ongoing reinvestment with a long-term commitment of funds due to extensive service lives of these assets. Therefore, the estimation of investment costs of these projects is a key task at every stage of planning and implementation. From the initial project idea to detailed planning and legal approval, the costs of transport infrastructures play a decisive role for investors, authorities, and the public. Despite their importance in many cases, the provided information is based on rather rough estimations instead of a thorough statistical analysis. Furthermore, the information on the price basis, the reference year or which items are included or not included in the calculation are rather vague. In many cases it is therefore difficult to distinguish between price inflation, price increases due to unforeseen circumstances or regulatory requirements, and deliberate deception about actual costs.

Apart from individual circumstances of projects, it is important to understand the principal connection between costs factors and the development of construction costs and prices. According to EUROSTAT, the output prices of contractors depend on the development of the factor prices (e.g. material, labour, energy), the productivity, and a profit margin. The total costs for the client include additional costs (e.g. VAT, planner fee) and an additional profit. Apart from cost factors, there will be a final selling price on the market depending on

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the supply and demand. These final prices represent what was actually paid and what shall be analysed further in this paper (Figure 1).

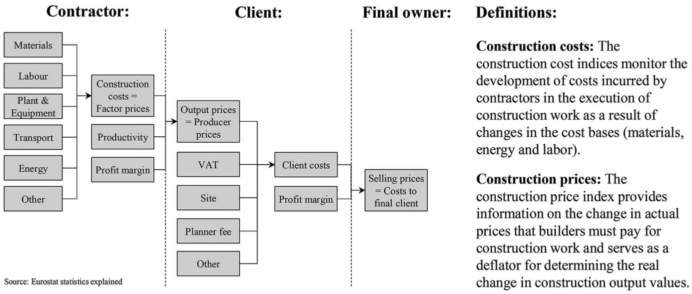

Figure 1. Input factors and difference between construction costs and prices explained.

1.2 *Regional cost factors and price indices*

Although every transport construction project is different, there are systematic similarities that have to be accounted for. In general, the prices for similar goods as well as construction works may differ both between regions and reference years due to differences and changes in the input factors as well as the market situation. Therefore, the national and international statistic bodies provide a systematic analysis on cost and price changes over time. The provided construction cost indices describe the monthly, quarterly, or yearly change of costs incurred by contractors based on the comparison of a weighted average of the prices of a basket of goods and services. The construction price indices describe the change of final market prices that builders must pay on a similar basket. Moreover, the construction costs and prices between different regions or countries can also be described in a similar way based on a representative basket. In this regard, Figure 2 provides the basis for the comparison of baskets as well as an example for adjusting projects costs for different years. In the second example project prices from one region are converted to those of another region based on purchasing power parities for civil works in Europe. As a rule for cost estimations and price comparisons, it should be mandatory to always provide information on the year and the region as well as adjusting for purchasing power and price changes over time. Furthermore, additional information on the project specifics and the sources of the price estimates should be provided to allow validation and updating.

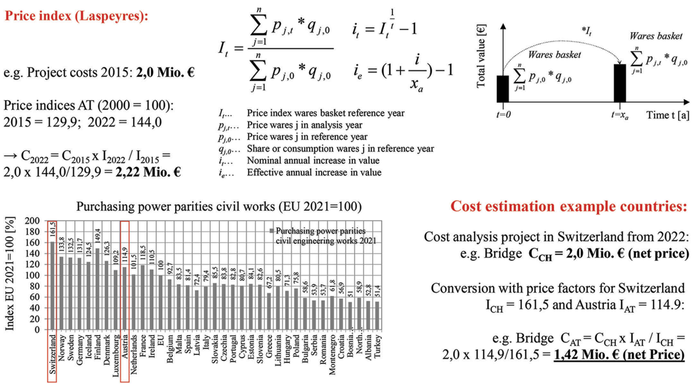

Figure 2. Price index from annual baskets of goods and purchasing power parities (PPP) with examples.

1.3 *Development of construction costs and prices in Austria*

Depending on the market situation, prices for goods and services may change over a comparative period. A general increase in prices in a sector is referred to as inflation, while falling prices are referred to as deflation. The consumer price index indicates how the prices of weighted representative goods and services of private household's change compared with a reference year. The consumer price index is therefore an important benchmark for wage negotiations and overall market development. The cost and price indices also play an important role in life cycle cost analysis. They are the basis for the adjustment and comparison of project costs from different years of construction for a reference year as well as a prerequisite for the determination of future costs and prices. In addition, prices in contracts can be negotiated as fixed or as variable prices from a given base year and adjusted accordingly with these indices According to the data from Statistics AUSTRIA, the consumer price index increased in average with +2,2% per year. The year 2022 was truly exceptional, as the consumer prices increased by +8,6%. The construction prices for civil engineering works, road works and bridges increased in average with +1,85%, +1,87%, and +1,55% per year in the analysis period. In contrast, the construction costs for roads and bridges increased in average by +3,66% and +3,49% per year. Comparing construction cost and price increases reveals a systematic annual gap of 1,79% and 1,94%.

Figure 3 shows an analysis of the development of construction costs and construction prices for roads and bridges from 1990 to 2022 with a simple forecast to 2030 based on linear regression. This systematic gap means that by doing nothing the profit margin of the civil construction sector in Austria would decrease by the same amount every year. However, as this is not an uncommon situation, there are a few ways out of this dilemma. The first possibility is to be more innovative and efficient, increasing the productivity every year. A second way would be to shrink market supply by reducing the number of companies and employees in the sector or by finding a cheaper work force. A third way are cartelization and price-fixing to ensure survival on a difficult market. A fourth possibility is reducing the quality of materials and civil works resulting in reduced functional quality, safety, and service life on the medium to long run. There is sufficient evidence in the construction sector showing the exploration of each of these possibilities with a varying degree of success. Beyond these systematic considerations, the price indices are used in this paper to adjust the provided unit prices to 2022 (Hoffmann 2019).

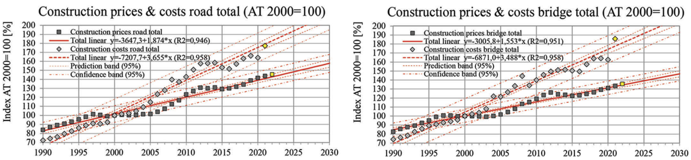

Figure 3. Construction cost and price indices development for road and bridge works in Austria.

2 ROAD CONSTRUCTION PRICES

2.1 *Unit prices of highways and regional roads*

The road construction costs are all final unit prices for the year 2022 per square meter or lane kilometer including 20% VAT. These unit prices include the entire range of construction works from pavements and civil structures in an unspecified amount (Figure 4). The construction prices of highways amount to an average of 1.522 €/m^2 and a median of 1.146 €/m^2 (n=26) resulting in an average of 9,0 Mio. €/lane.km and a median of 6,79 Mio. €/lane.km. The rehabilitation costs cover mainly small to medium size projects with average costs of 289 €/m^2 and a median of 226 €/m^2 (n=32) leading to 1,65 Mio. €/lane.km in average and a median of 1,41 Mio. €/lane.km. The adjusted unit prices for regional roads are significantly lower mainly due to lower share of civil structures (e.g. bridges and tunnels), lower traffic volumes, as well as lower legal requirements. The average unit prices for constructing regional roads amount to 713 €/m^2 and a median of 569 €/m^2 (n=90) resulting in an average of 2,82 Mio. €/lane.km and a median of 2,12 Mio. €/lane.km. As regional roads are comparatively older, the average costs of 205 €/m^2 with a median of 169 €/m^2 (n=80) translating into 0,71 Mio. €/lane.km in average and a median of 0,56 Mio. €/lane.km cover the entire range from small repairs to replacement. The distribution of the unit prices can be approximated by a normal or other distributions, with unit prices being right skewed with the mean being larger than the median due to a few projects with exceptionally high unit prices.

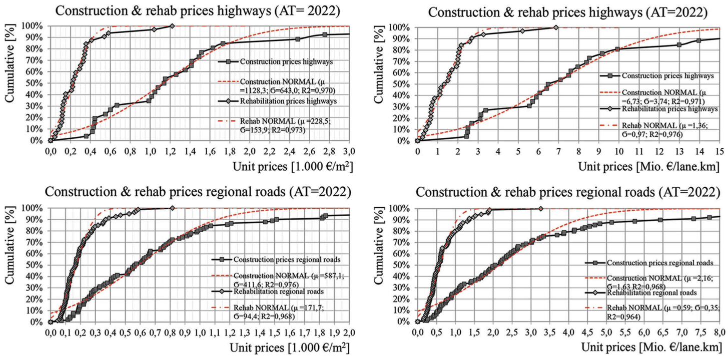

Figure 4. Unit prices highways and regional roads in Austria (prices 2022).

2.2 *Unit prices bridges and tunnels*

The analyzed unit prices for bridges and tunnels cover both projects on regional roads and highways of various size, materials and construction techniques in Austria. A deeper analysis on the contribution factors to the unit prices is feasible but beyond the scope of this paper. The unit prices of rehabilitation measures can be clustered depending on initial condition, type of M&R, and impact duration in small, medium and large measures (Hoffmann 2017, 2019, Hoffmann & Kammersberger 2012). As shown in Figure 5, the mean unit prices for road bridges in 2022 are 2.150 €/m^2 with a median of 1.896 €/m^2 (n=125) resulting in an average of 10,31 Mio. €/lane.km and a median of 9,00 Mio. €/lane.km. Very short bridges exhibit significantly higher average unit prices due to the foundation works being distributed over a limited bridge area. Bridges with a large span usually result in higher unit prices due to sophisticated statics and construction. The rehabilitation prices of bridges amount to 872 €/m^2 with a median of 717 €/m^2 (n=230) resulting in an average of 4,11 Mio. €/lane.km (median 3,59 Mio. €/lane.km).

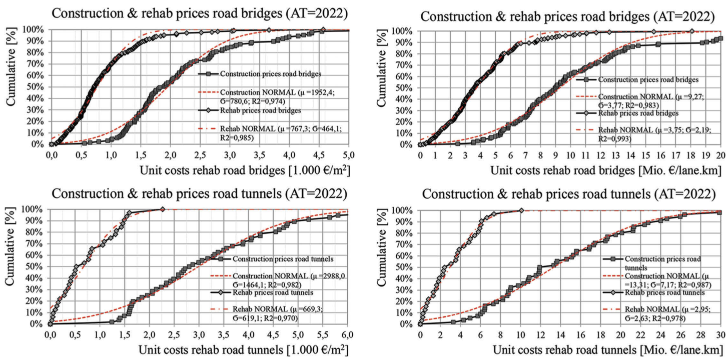

Figure 5. Unit prices bridge and tunnels construction and rehabilitation in Austria (prices 2022).

The mean unit prices for road tunnels are 3.229 €/m^2 with a median of 2.839 €/m^2 (n=56) resulting in 14,21 Mio. €/lane.km and a median of 12,62 Mio. €/lane.km. For rehabilitation, the mean unit prices are 753 €/m^2 with a median of 605 €/m^2 (n=32) resulting in 3,28 Mio. €/lane.km (median 2,73 Mio. €/lane.km). In contrast to road bridges covering the full range from small to large measures, the tunnel data on rehabilitation consist mainly of small to medium rehab due to a rather young asset stock in Austria. With extensive distress type and M&R measures on asset element level already available, the price database on road assets can be extended even further.

2.3 *Unit prices pavement works*

In this paper, the unit price analysis of asphalt pavement works covers structural measures which result in a sustained substantial improvement of the pavement condition and a corresponding extension of service life. The analyzed measures cover full-depth asphalt replacement including improvements in the unbound layers as well as partial-depth asphalt replacement (surface and binder layer). Furthermore, surface layer replacement and surface treatments/micro-surfacing are covered. The unit prices are analyzed both based on their cost distribution per square meter as well as the economies of scale unit costs and the total paved area. Together with service lives these economy of scale costs functions is the key to an advanced pavement management with optimal treatment selection, timing, and work-zone length (Donev & Hoffmann 2020, Hoffmann 2019). Typical full-depth asphalt replacements exhibit mean unit prices of 84 €/m^2 or 0,29 Mio. €/lane.km (n=95) with typical asphalt layer thickness from 12 to 18 cm. Treatments with surface & binder replacement show unit prices of 39 €/m^2 or 0,13 Mio. €/lane.km (n=166) and typical asphalt layer thickness of 9 to 12 cm. The replacement of surface layers with a thickness of 3 to 5 cm has mean unit prices of 23 €/m^2 or 0,074 Mio. €/lane.km (n=138). Surface treatments have a typical layer thickness of 1 cm exhibiting mean unit prices of 7 €/m^2 or 0,023 Mio. €/lane.km (n=40). The analysis in Figure 6 shows consistently declining unit costs with increased work-zone length or pavement area as the fixed costs are distributed and a higher efficiency is achieved.

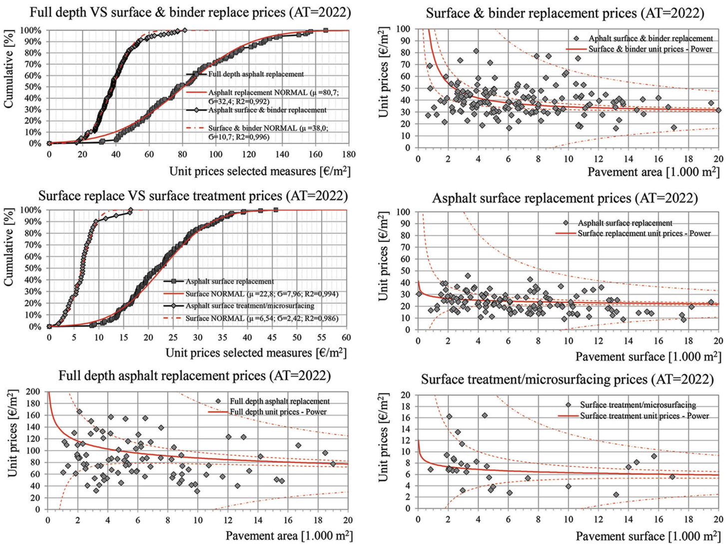

Figure 6. Unit prices pavement measures from full depth to surface treatment (prices 2022).

3 STANDARDIZED LIFE CYCLE COSTS

3.1 *Standardized deterministic life cycle*

In the fields of transport infrastructure cost-benefit analysis with aggregated condition grades and cost-benefit criteria are employed in Pavement Management (PMS) and Bridge Management Systems (BMS). Since 1970 these approaches have been extended towards considering economic impacts from "cradle to grave" with deterministic life cycle cost analysis (LCCA). Starting between 1990 to 2000 extensive research has been conducted into the integration of user and environmental aspects in decision making. Due to the stochastic nature of material parameters and loading a quantitative assessment of structural condition, reliability and risk are the main focus in current research on life cycle costing of transport infrastructure (Dhillon 2010, Hoffmann 2019).

With the focus on generalized investment and life cycle costs in this paper the stochastic nature of both construction costs and service lives will not be addressed here. Instead, the emphasis will be on a standardized framework for calculating deterministic life cycle costs of selected road assets based on an extensive costs database. Deterministic continuous models describe a functional relationship between determined input parameters x_i and precise outcomes y_i based on a deterministic function $f\ (x_i)$ without any variation. In such models, a hypothetical exact relationship between input parameters and outcomes without uncertainty or unknowns is assumed. Thus, a predicted cost or condition performance will always be the same for all assets or asset elements, resulting in identical service lives. In order to account for deviations in asset costs or performance, these deterministic models are commonly aligned (calibrated) to the actual development.

The presented standardized framework for a deterministic life cycle cost analysis in Figure 7 provides the necessary terms, parameters, and formulas to calculate total costs, present value, annual costs, condition performance, and residual asset value. The example shows a comparison of a simple replacement cycle with a rehabilitation prior to failure. In this case, the rehabilitation option yields lower annual costs being the economic solution. The condition performance in the framework is modelled using a power function. The residual asset value is calculated based on the remaining service life of the assets. In the example, the comparison of the investment alternatives shows that there are no sunk costs if assets are still needed and a rehabilitation is efficient. The results of such standardized deterministic life cycles can be used in early planning stages, cost estimations, and asset valuation as well as a validation of M&R recommendations. Furthermore, such standardized deterministic LCC can be extended to full stochastic LCC both at the project and the network level e.g. with a Monte Carlo Simulation (MCS).

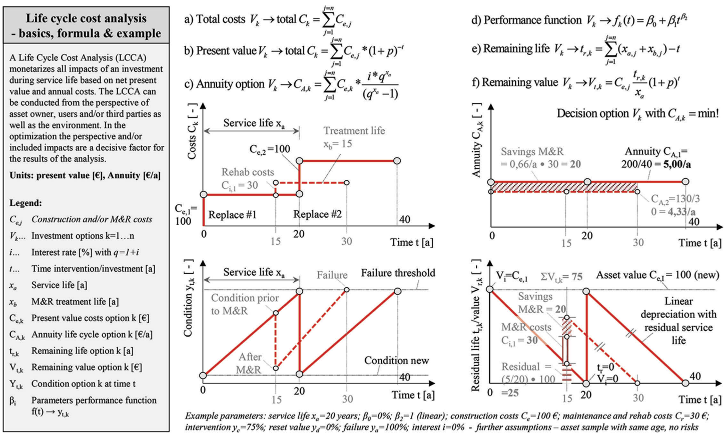

Figure 7. Standardized deterministic LCC with total costs, annual costs, condition, and residual value.

3.2 *Standardized deterministic LCC for pavement, bridges & tunnels*

The standardized deterministic life cycle costs for pavements, bridges and tunnels build on previous research (Hoffmann 2017, 2019, Hoffmann & Kammersberger 2012) with a largely extended database on costs of road projects from 2022. The standardized pavement life cycle covers planning, construction, crack sealing, surface replacement and a surface & binder replacement as well as operation and administration costs for 60 years (Figure 8). The resulting pavement life cycle costs on this basis amount to 190-200 €/m^2, a present value of 120-125 €/m^2 and average annual costs between 5-6 €/m^2. For a typical regional road with 7,5 m width this translates into total costs of 1,5 Mio. €/km, a PV of 0,9 Mio. €/km and annual costs of 40 k€/km.

The standardized life cycle costs for road bridges and road tunnels are calculated based on median construction prices, as the costs distributions are skewed due to a few projects with very high unit prices. In the case of bridges, land use, planning, construction as well as small, medium and large-scale rehabilitation until deconstruction are considered in an 80-year cycle. The total costs including operation and administration amount to 4.800-4.900 €/m^2, a PV of 2.700-2.800 €/m^2 and annual costs of 110-120 €/m^2. The total bridge costs for a typical width of 10 m are thus roughly between 47,5-50,0 Mio. €, a PV of 26-28 Mio. € and annual costs of 1,1 to 1,2 Mio. €/km.

The standardized life cycle costs for road tunnels include land use, planning, construction as well as small, medium and large-scale rehabilitation together with decommission in a 90-year cycle. The total costs including operation and administration amount to 7.500-7.700 €/m^2, a PV of 4.100-4.300 €/m^2 and annual costs of 160-180 €/m^2. The total tunnel costs for a typical width of 10 m can be estimated with 75-77 Mio. €, a PV of 41-43 Mio. € and annual costs of 1,6 to 1,8 Mio. €/km. Although the presented standardized life cycle costs of pavements bridges and tunnels consider construction costs on highway level as well, the provided estimates mainly address the regional road network. For highways the provided life cycle costs would be at least 10-20% higher mainly due to the safety and environmental standards as well as significantly higher operation and administration costs.

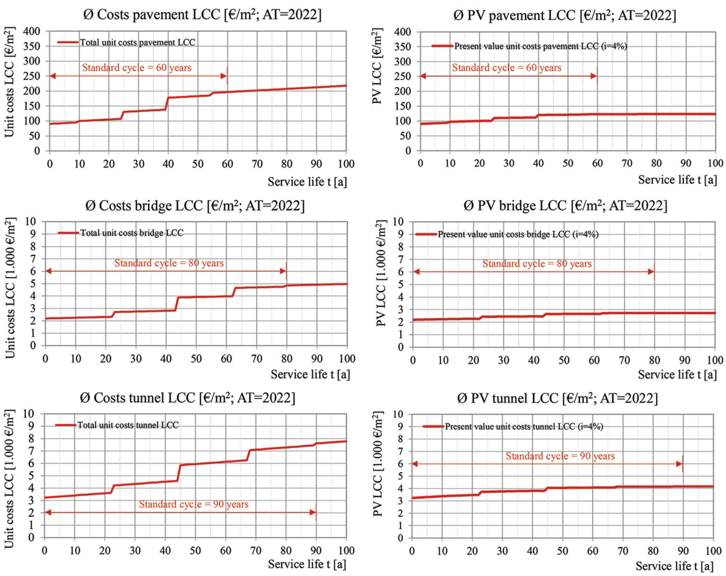

Figure 8. Standardized life cycle costs road pavements, bridges & tunnels in Austria (prices 2022).

4 CONCLUSIONS

The estimation of investment costs of road projects is a key task at every stage of planning and implementation. From the initial project idea to detailed planning and legal approval, the costs of transport infrastructures play a decisive role for investors, authorities, and the public. Despite their importance in many cases the provided information is based on rather rough estimation instead of a thorough statistical analysis. The presented research aims to close this gap providing the basis for a reliable estimation of investment costs from road projects to single assets. Furthermore, calculating LCC from single assets and projects up to entire networks is of increasing importance to determine budget needs, preserve asset value, and define contracts between stakeholders. In all cases, systematic methods and a large database on road projects and specific measures with unit prices and impact duration are needed to provide a sufficient basis for estimation and validation.

Apart from individual circumstances of projects it is important to understand the principal connection between costs factors and the development of construction costs and prices. Adjusted prices for different regions and years of construction are a crucial precondition for any cost estimation and validation. Based on extensive research and projects on regional roads and highways in Austria over the last two decades, the paper provides unit construction and rehabilitation prices for highways and regional roads for the reference year 2022. Furthermore, the unit prices on asset level for construction and rehabilitation works on road bridges and road tunnels are given. The analyzed pavement measures cover surface treatments, surface layer replacement as well as partial-depth and full-depth asphalt replacement with local improvements in the unbound layers.

Beyond construction prices, the paper shows a framework for calibrated standardized deterministic life cycle costs. The provided terms, parameters, and formulas allow a simple calculation of total costs, present value, annual costs, condition performance, and residual asset value. Drawing on previous research and an updated database on construction and M&R measure unit prices from 2022, the paper provides standardized life cycles for pavements, bridges and tunnels in Austria. The provided total costs, present value and annual costs are a sound basis for the validation of project cost estimates, asset valuation and investment decisions. As standardized distress catalogues and M&R measures for all main road assets have already been developed, the next step will be the extension and implementation in an asset management software.

ACKNOWLEDGEMENT

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