Life cycle cost analysis of road Infrastructures using LCC AM/QM software

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Abstract

The use of life cycle cost analysis as a supporting tool for asset management has grown exponentially over the years, in several sectors. For the construction sector, particularly, it has been verified that the use of this analysis promotes significant optimization in the financial planning of engineering enterprises.

The present dissertation introduces a methodology proposal for life cycle cost analysis of infrastructures, based on european and international standards. This proposal intends to demonstrate the implementation of this type of analysis in the construction sector, using a case study from the road sector. The case study concerns the construction and exploration of a highway in South America, by a concessionary company.

Additionally, this study uses a specialized commercial software as a calculation tool to support life cycle cost analysis. This software is named LCC AM/QM - Life cycle cost asset management/quantitative methods – and it was developed by S&G Asset Management, a company based in Holland.

The results obtained from the application of this methodology and from the analysis performed with the LCC AM/QM software revealed the importance of studying the whole life cycle of the highway. With the use of the software it was possible to perform several types of analysis, which shows how useful this software can be when it comes to studying maintenance activities and performing simulations for several different possible scenarios.

Key-words: asset management, life cycle cost analysis, software LCC AM/QM, road infrastructure

1. Introduction

The use of life cycle cost analysis (LCCA) has been growing exponentially, over the last years. However, there is still a long way to go regarding the use and optimization of this management tool in the construction sector.

European and international standards have been published about this theme, aiming at increasing the development of this type of analysis and demonstrating its impact on asset management, particularly in engineering infrastructures.

This study focuses on the employment of life cycle cost analysis in road infrastructures, by exploring the potential of using this methodology in monitoring and forecasting costs throughout their life cycle, in order to optimize their use in terms of costs.

The main goal of this investigation is to identify the importance and influence that LCCA has on decision support regarding road infrastructures, and also to explore the benefits of cost modelling through the different stages of the infrastructure's life cycle.

For this purpose, we intend to develop a methodology proposal for LCCA, by testing it on a case study, using a specialized commercial software as a calculation tool to support LCCA. This software is named LCC AM/QM – Life cycle cost asset management/quantitative methods – and it was developed by S&G Asset Management, a company based in Holland.

2. Literature review

A brief explanation of the asset management concept is required in order to provide a clear understanding of this study. Asset management enables an organization to realize value from assets in the achievement of its organization objectives. The value from each asset will depend on these objectives, the nature and purpose of the organization, and the needs and expectation of its stakeholders. Asset management supports the realization of value while balancing financial, environmental and social costs, risk, quality of services and performance related to assets (ISO 55000, 2014)

Life cycle cost is a technique used to predict and assess the cost performance of constructed assets (ISO 15686-5, 2008).

Life cycle cost analysis is the process of evaluating the economic performance of an infrastructure over its entire life. LCCA balances initial investment with the long-term costs of owning and operating infrastructures. This analysis can explore alternative scenarios and can determinate the time required for the different alternatives to achieve its payback. Maintenance, operation and use costs play an essential role in the total life cycle cost, representing a value almost the same order of its initial investment (Stanford University, 2005).

In general, the main purpose of this type of analysis is to maximize profits and reduce costs. Therefore, it is important to emphasize that decisions taken at all stages of the infrastructure's life cycle have economic consequences (Langdon, 2007).

The life cycle cost of an item is the sum of all funds expected in support of the item from its conception and fabrication through its operational to the end of its useful life (White and Ostwald, 1976).

3. Methodology for LCCA

The methodology proposal for life cycle cost analysis is essentially based on the ISO 15686-5 and EN 16627 standards and Langdon's (2007a) methodology. It should be noted that there is not one single methodology for this calculation, due to the great variety of assets existent. However, we propose a common and consistent methodology for the employment of LCCA, which will be adapted to the particular case study: road infrastructure.

The methodology is made up of twelve steps, referred by the EN 16627 standard and Langdon's (2007a) methodology, and it is also based on norms and requirements described in ISO 15686-5. The aforementioned steps, regarding risk and sensitivity analysis and processes of verification of the obtained results are not addressed throughout this study.

A summary of this methodology is presented in table 1. It is divided in twelve steps, and each step is divided by objectives, following a logical line of thought that allows the reader to have a better understanding of the methodology. Additionally, the table presents the standards and/or methodologies used for the definition of each objective of each step.

This table also defines the applicability of the steps to the case study, described in section 5. The steps 3, 5, 7 and 12 are excluded from the analysis because these steps are not part of this papers scope or simply because there wasn't enough data.

Table 1 – LCCA Methodology: steps, objectives, sources and application

Steps		Objectives	EN 16627	Langdon 2007a	ISO 15686-5	
1	Purpose	Purpose of the analysis	6.1	1.2 e 1.4	4.1 e 4.4.1	✓
		Type of application/analysis	-	1.2 e 1.3		
2	Scope	Scale of application	6.1	2.2	4.4.2	✓
		Activities from the analysis		2.3 e 2.4	4.2.1 e 4.3	
		Relevant aspects and parameters		2.5	4.2.2, 4.4.2 e 5.4	
		Reporting format and required outputs		2.6	9.1	
3	Relationship between sustainability assessment and LCC	Sustainability assessment	6	3.2	6.5	
		Measures employed on sustainability assessment		3.3		
		Relationship between sustainability and LCC		3.4 e 3.5		
4	Period of analysis and methods of economic evaluations	Period of analysis	7.3	4.2 e 4.3	5.2 e 5.3	✓
		Methods of economic evaluations	7.5 e 11	4.5 e 4.6	7 e Annex B	
5	Risk and sensitivity analysis	Risk analysis	10	5.2 a 5.6	8.1 e 8.2	
		Sensitivity analysis		5.6, 5.7.1	8.4 e Annex C	
6	Project and asset requirements	Identify the key features and key parameters of the asset	8	6.2 e 6.3	-	✓
		Qualitative requirements		6.6		
		Project constraints		6.7		
		Confirming the scope, budget, timescale and program		6.5, 6.8 e 6.9		
7	Analysis options	Elements to include	9	7.2	4.4.3, 4.4.4 Annex D	
		Options for each element		7.2 e 7.3		
8	Database – costs and timescales	Identify and classify costs	7.4, 9.3 e 9.4	8.2 a 8.4	4.2.2. e 5.4	✓
		Time related data for each cost		8.5 e 8.6		
		Database	10.4	8.7	4.5 e 4.6	
9	Verify values of financial parameters and period of analysis	Verify the period of analysis	10	9.2	-	✓
		Verify the financial parameters and the method of economic evaluation		9.3 a 9.5	-	
10	Perform the economic evaluation	Computerize costs and time data	11	11.2 e 11.3	Annex A	✓
		Perform the LCCA		11.4		
11	Interpret and present initial results	Review and interpret the results	12	14.3	-	✓
		Present the results using the appropriate formats		14.2 e 14.4	-	
		Identify the need of further LCCA iterations		14.6	-	
12	Present final results	Final report	12	15.2 a 15.4	9.1	
		Documents required for audit trail		15.5	9.3	
		Testing the validity of LCC	13	15.6	4.9	

4. LCC AM/QM

The commercial software used for the modelling of the life cycle cost analysis of the engineering infrastructure of this case study, was developed by S&G Asset Management, a software development company, founded in 1985, which focuses on analytical techniques to be used as supporting tools in tactical and strategic decision making.

The goal of LCC AM/QM is to optimize the performance of its assets from an economical and technical standpoint.

Based on the risk evaluations and the asset conditions, multiple previsions of costs and revenues can be carried out (in this case study, only data concerning costs will be used).

It is possible to estimate the development of several different scenarios in the future, customized by the client, from data that is presently available, in order to find an optimal operation and maintenance solution (http://www.sg-assetmanagement.nl/eng/products-2/lcc-amqm/)

5. Application of the methodology for LCCA to the case study using LCC AM/QM

The case study used to test the applicability of the methodology and the LCC AM/QM software, refers to a 43.4 km-long highway, which is going to be built in South America. It is predicted to be constructed between 2016 and 2020, and its use stage is predicted to start in 2021, having a 34 years duration period. Therefore, the total period of the life cycle cost analysis is 39 years.

Data regarding the construction and use stages was collected, therefore, these were the life cycle stages that were studied. Table 3, was developed in step 8 of the methodology and presents the distribution of costs between the modules referring to each stage of the life cycle. After its execution, based on the standards and the methodology mentioned in section 1 and 3, the costs included in this analysis are identified.

Even though the A0.2 module concerning expropriations is included in the pre-construction stage, according to the consulted standards, for the purpose of the present case study, this occurs during the construction phase. For this reason, a decision was made to include the value of the costs associated with expropriations (A0.2) in the construction stage (A4-5).

Analyzing only the construction and use phases of this infrastructure, information was found regarding 11 of the 23 modules proposed throughout these stages, representing a total of 47.8% of the modules.

Initially, it is necessary to organize all the available data. For that purpose, table 4 was composed, presenting the identified costs concerning the modules of the proposed methodology, as well as its distribution between the costs activities, according to the original data made available by the company. Each of these costs is associated with percent values referring to the total cost of the construction and use of this road infrastructure.

Following, the data is entered in the software. This is an extremely important step for the implementation of the analysis. Initially, according to the software's manual, it is necessary to build a cost hierarchy, as shown in figure 1. This data structure enables an easy understanding and efficacious performance of LCCA in this software.

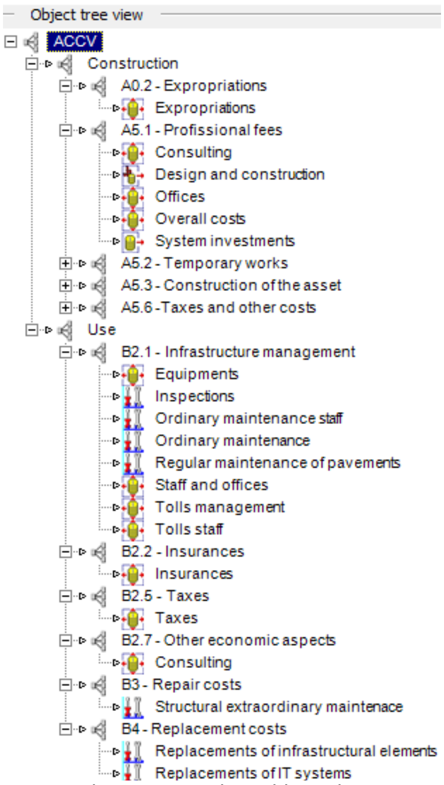


Figure 1 –Database hierarchy

Each of these costs must be characterized when they are inserted into the software, regarding its type, classification, time period, periodicity, and annual costs values (Table 2).

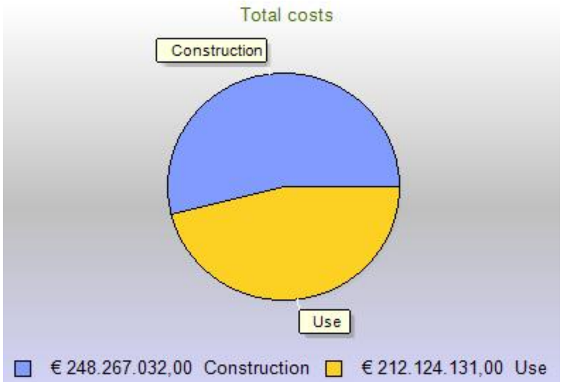
Table 2 – Type and classification costs (S&G Asset Management, 2016)

Type of costs	**Costs classification**
Production costs	-
Investment costs	-
Miscellaneous costs	Revenues Others Operational Overall Environmental Energy Risk
Maintenance costs	Inspective Preventive Corrective Adaptative Other

This software enables the user to perform several types of analysis, but for that purpose it is necessary to define the desired analysis parameters, in terms of the periods of occurrence and the data base to which they resort.

Analyses were made concerning the construction, use, and the whole life cycle of the highway. The results are presented in an annual and also global aspect. Only the analyses which include the total life cycle of the road infrastructure will be presented.

The main conclusion to be taken from this analysis concerns the importance that the use stage has on the total life cycle of the highway. The costs contracted in this stage account for 46% of the total costs, which shows why it is important to perform life cycle cost analysis in the initial stages of the decision making process of the project, which can economically compromise future activities. This is one of the main reasons why the use of this type of analysis is growing exponentially, and its full potential has not been explored yet (Graphic 1).



Graphic 1 – Total LCC – construction and use stage

Graph 2 is a bar graph that represents the annual costs divided by the modules defined on the methodology developed, along the entire life cycle of the highway.

This graph can clearly differentiate between the two stages of the life cycle cost analysis. In the first five years, the construction stage results are shown. We clearly identify a cost peak in 2020 mainly because of the module A5.3 related to the construction of the asset – this module represents 36% of the total costs of the infrastructure, as it is presented on table 4. It is also possible to identify the reasonably high costs from module A0.2 related to the expropriations costs - this module represents 8.33% of the total costs of the infrastructure, as it is presented on table 4.There are the two main modules that most contribute to the construction costs, and consequently for the total costs of the road.

The second part of Graphic 2 is related to the use stage that embraces a period from 2021 to 2054. Through this period it is easily identifiable the two costs peaks that are shown in 2032 and 2042. This happens because of the high amount of money expected to spend on the replacement of IT systems (RIT) that represents almost 5% of the total LCC of this project. We can also identify that module B2.1 related to the infrastructural management represent a high portion of the total costs – almost 30% (Table 4). Though Graphic 2 it's possible to identify the regular periodicity and approximate costs of this category. Between 2032 to 2034 and 2042 to 2044, we can recognize a slight increase of the B2.1 costs, mainly because of regular maintenance of pavements activities (RMP).

Analyzing the total period of Graphic 2, it's possible to describe that the construction stage has higher annual costs but it is also important to understate that this stage runs a period that covers only 5 years of the total 39 years of the analysis, comparing to the 34 years of the use stage.

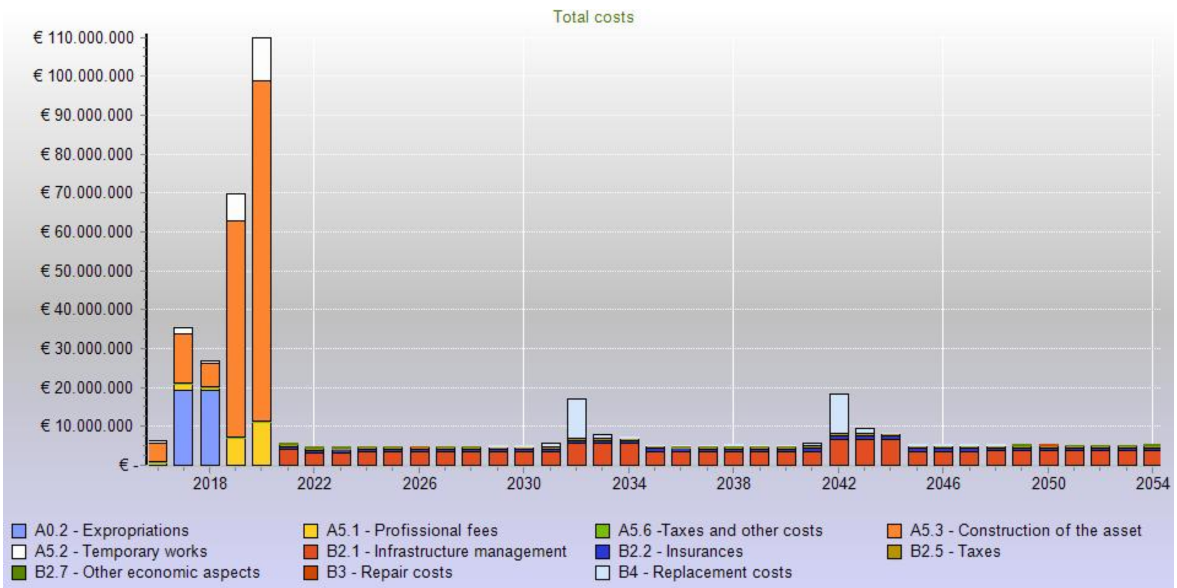
After the obtained results we are able to identify the aspects that could be optimized in terms of financial performance. It was developed a serial simulations exploring different scenarios of the analysis. This paper, only include one simulation related to the standardization of use costs, where the costs peaks were reduced and distributed in a more effective way. This simulation is represented on Graphic 3 and it was done using LCC AM/QM software. The costs related to RIP and RMP are the two main costs responsible for the high expenditures over the use stage. Therefore, the same method was adopted for this two groups of costs: anticipate their begging and extend their operation for 4 years on each cycle (instead of the 3 years) and apportion on an equitable way the costs for each of the 4 years. Thus, the major cost occurred previously in 2043 was reduced almost 44% and the available capital of the concessionary company was standardize.

Table 3 - Identification of costs applicable to the case study

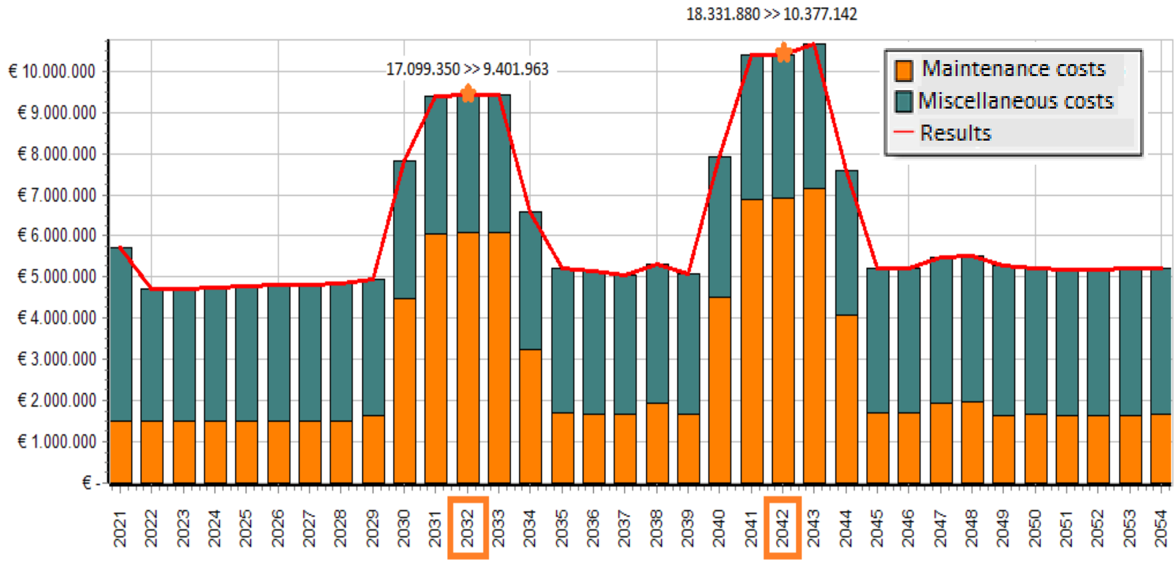
Pré - construction	**A0 – Site costs**	
	A0.1 – Site costs: purchase or rental costs	
	A0.2 – Expropriation	✓
	A0.3 – Taxes	
Product stage	**A1 – A3 – Costs incurred on product stage**: raw-material, transport and manufacturing operation...	
Construction stage	**A4 – Transport costs incurred on construction stage**	
	A5 – Construction costs	
	A5.1 – Professional fees: engineering and architecture design, construction e geotechnics, resource management and administration…	✓
	A5.2 – Temporary works: activities to prepare the site for construction and to provide infrastructure and services (gas, electricity and water)	✓
	A5.3 – Construction of the asset: all aspects of the procurement and construction of the infrastructure, including directly associated parking within the immediate site	✓
	A5.4 – Fit out: Adaptation or fit out of asset	
	A5.5 – Landscaping: landscaping, external Works on curtilage	
	A5.6 – Taxes and other costs related to the permition to build	✓
	A5.7 – Subsidies and incentives: incomes related to renewable energy, and efficiency measures installed on the infrastructure	
Use stage	**B2 – Operation and maintenance costs**	
	B2.1 – Infrastructure management: Costs for regular and routine activities such as inspections, caretaking, management of planned services contract, products or materials used for mentioned activities; professional service	✓
	B2.2 – Insurance	✓
	B2.3 – Leases and rental payable to third parties: leases and rents, excluding land rental (ground rent)	
	B2.4 – Cyclical regulatory costs: fire, access inspections declarations relating to energy performance...	
	B2.5 – Taxes: rates, local charges, environmental taxes	✓
	B2.6 – Subsidies and incentives: incomes related to renewable energy, emissions, energy efficiency measures on the infrastructure	
	B2.7 – Other economic aspects	✓
	B2.8 – Cleaning : regular or cyclical cleaning and periodic specific cleaning of the infrastructure	
	B2.9 – End of lease	
	B3 – Repair costs: repairs and replacements of minor components	✓
	B4 – Replacement costs: replacement of major systems and components	✓
	B5 – Refurbishment costs: planned adaptation or planned refurbishment of asset in use	
	B6 – Energy costs	
	B7 – Water related costs	
End of life stage	**C1 – Deconstruction costs**	
	C1.1 – End of life inspections,	
	C1.2 – Deconstruction, dismantling, demolition	
	C1.3 – Reinstatement of site to meet contractual requirements	
	C1.4 – Site cleanup	
	C1.5 – Taxes: taxes on goods and services; landfill and other disposal costs	
	C2 – Waste transport costs	
	C3 – Waste processing costs: costs from re-use, recycling and energy recovery at end of life	
	C4 – Disposal costs	
After life stage	**D – Benefits and loads beyond the system boundary**: revenue from disposal of interest in land, revenue from recycling...	

Table 4 – Total costs and percentages of the LCCA

	Activities	€	%	Module	€	%	€	%	€
Construction stage	Expropriations	38.338.580	8,33	A0.2 – Expropriation	38.338.580	8,33	248.267.035	54	460.391.174
	Design and Construction	182.647.495	39,67	A5.1 – Professional fees	20.760.848	4,51			
	System investment	15.961.069	3,47	A5.2 – Temporary works	20.760.848	4,51			
	Overall costs	5.198.656	1,13						
	Offices	805.143	0,17	A5.3 – Construction of the asset	166.086.786	36,08			
	Consulting	2.996.120	0,65						
	Insurances	260.783	0,06	A5.6 – Taxes and other costs related to the permition to build	2319973	0,50			
	Taxes	2.059.189	0,45						
Use stage	Ordinary maintenance	28.112.832	6,11	B2.1 – Infrastructure management	136.391.171	29,63	212.124.139	46	
	Ordinary maintenance staff	18.717.586	4,07						
	Inspections	6.504.781	1,41						
	Tolls staff	17.204.042	3,74						
	Tolls management	10.062.235	2,19						
	Staff and offices	39.348.350	8,55						
	Equipment	630.327	0,14						
	Regular maintenance of pavements	15.811.018	3,43						
	Insurances	23.578.096	5,12	**B2.2 – Insurances**	23.578.096	5,12			
	Taxes	21.003.729	4,56	**B2.5 – Taxes**	21.003.729	4,56			
	Consulting	5.302.412	1,15	**B2.7 – Other economic aspects**	5.302.412	1,15			
	Structural extraordinary maintenance	127.992	0,03	**B3 – Repair costs**	127.992	0,03			
	Replacement of infrastructural elements	2.939.682	0,64	**B4 – Replacement costs**	25.720.739	5,59			
	Replacement of IT systems	22.781.057	4,95						



Graphic 2 – Annual LCC (including the construction and use stage)



Graphic 3 – Simulation of the LCCA over the use stage

6. Conclusions and further research

The implementation of the methodology by defining steps resulted in a huge facility to set the project in question, clearly identifying the objectives, assumptions and data analysis.

Pursuant to the case study, it can be concluded that the methodology developed based on the previously mentioned standards, is globally applicable, even not being applied to the entire highway life cycle. However, if a greater coverage of the database was required, in terms of the road life cycle, this methodology would be perfectly able to be applied.

In this case analysis, it was only been used values related to costs. If revenues had been available, additional type of analyses could be explored by the software, like funding and financial statements analysis, among other types of unexploited analysis due to this limitation.

It was found a limitation during the use of LCC AM/QM related to use of the budget functionality. This type of analysis is only used to investment costs activities. But after an exchange of ideas with the software suppliers, it was concluded that the budget functionality would be created next year, in order to be applied to dynamic maintenance activities.

The results obtained from the application of this methodology and from the analysis performed with the LCC AM/QM software revealed the importance of studying the whole life cycle of the highway. With the use of the software it was possible to perform several types of analysis, which shows how useful this calculation tool can be when it comes to studying maintenance activities and performing simulations for several different possible scenarios.

However, as it happens in most commercial softwares, the calculation algorithms were not available for the software user, therefore it is considered necessary to validate the results obtained from the analysis made.

The choice of this software resulted in a major challenge and innovation due to its limited use and information in Portugal, but after a deep understanding of this software functionality, it proved to be an extremely effective tool for the type of analysis carried out by this study. It was required a strong support on the LCC AM/QM manual, allowing the learning features of this software.

This type of analysis should be complemented in the future with the inclusion of risk and sensitivity analysis in order to increase the level of reliability and confidence of the estimates made. However, it should be noted that, due to the high number of future estimated cost forecast taken over this paper, it can be said that there is in fact a level of uncertainty associated with this study.

The work focused on road infrastructure, but may be reproduced in the future for other types of infrastructure and also for buildings.

In the future, it is intended to compare the analysis results made with the actual values occurring at the end of the life cycle of this highway.

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