Railway Bridges Life Cycle Cost Modeling

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ABSTRACT: The utilization of Life Cycle Cost (LCC), as an asset management tool has gained importance, not only in a business context but also in the public sector. These dissertation is intended to promote the application of this tool in the railway infrastructure management, either in business or public context. The dissertation development is made in partnership with REFER, which is the Portuguese public company in charge of Portuguese railway infrastructure management.
The dissertation includes a broad bibliographic research, having as main focus the LCC concept and its application in what respects to railway sector and other related infrastructure engineering fields.
The document presents a model for the capture and aquisition of railway infrastrucutre related cost, created with the purpose of gathering costs associated with REFER´s railway bridge management.
By applying the developped model to REFER´s railway bridges, a set o life cycle analysis were performed, in order to compare the results achieved with the predictions made in REFER´s Plan of Asset Management. The results obtained in the analysis were accomplished taking into account a representative sample of the Portuguese Railway Bridges under the management of REFER. The results achieved are coherent with the information gathered during the research, namely about the major importance of Life Cycle's (LC) utilization phase of an asset related to the railway sector. Moreover, the obtained results evidence that steel and reinforced concrete bridges are the ones that play the most relevant part in REFER´s railway bridges LCC.
The most relevant contribution of this study to REFER´s asset management is related to the study of the impact of some major cost categories that aren´t currently taken into account in the preparation of REFER´s Asset Management Plan (AMP).

KEYWORDS: Asset Management, Life Cycle Cost, Life Cycle Cost Analysis, Railway Bridges..

1 INTRODUCTION

Scope and purpose

The LCC concept has gained importance and faced a major development as an asset management tool in the last years. That results not only in the publishment of works signed by renewed organizations of this area (like the Institute of Asset Management, the International Organization for Standardization), but also by institutes related to infrastructure management, namely, the New York State Department of Transportation and other sources.

This development promoted LCC as a practice in the railway sector, mainly by projects like Mainline and Innotrack, which associate railway companies (Prorail, NetworkRail, et al) in LCC research.

Framed in this paradigm, and based on the best asset management practices, the present work has the purpose of modeling and implementing a Life Cycle Cost Analysis (LCCA) in REFER's railway bridges.

2 KNOWLEDGE REVISING

Asset management

According to the ISO 55000 standard,the practice of Asset Management (AM) relates to implement as many processes as needed to fulfill pre-established operation requirements. The ISO 55001 standard defines the requirements that should be fulfilled by the organizations in order to implement a proper AM system. The definition of these requirements/objectives lead, according to the ISO 55002 standard, to each organization asset management policy, defined by its top management. The processes needed to achieve the objectives are stated in Strategic Asset Management Plans, which includes, besides the processes, tools to enable the monitoring and revising processes during the application of the plan. LCC is part of this chain, as a decision enabling tool, according to guide of the Institute of Asset Management "*Asset management – an anatomy*". The ISO 55002 standard states that the asset management policy translates itself into the asset management practice through many processes, as shown in the figure 1.

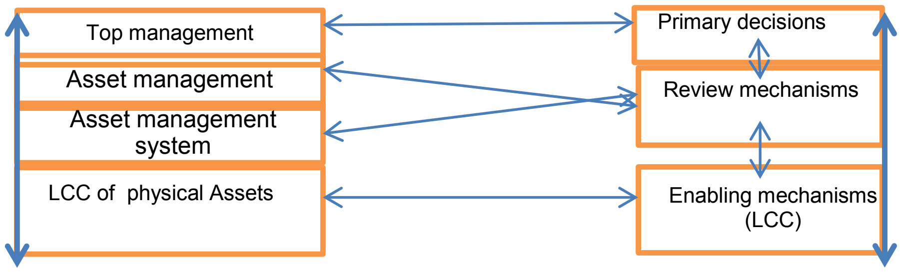


Figure 1 - Relation between the asset management policy and its implementation (adapted form ISO 55002).

Life Cycle Cost of built physical assets

According to the ISO 15686-5 standard, LCC is defined as "…*cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements…".*Typically, the Life Cycle (LC) of an asset is divided in different phases, within are grouped the costs that relate to each phase. The definition of the LC phases is not consensual in the terminology field. According to the ISO 15686-5 standard, the phases to consider are, construction, operation, maintenance and end of life; if the reference is the IEC 60300-3-3, the division would be concept and definition, design and development, manufacturing, installation, operation and maintenance, and disposal. Besides the differences in the terminology and division of the phases considered in the examples given, both of them, and all the other references included in the research, agree in the global scope of the costs to include in the LCC. The division of the LCC phases is also applied as primary cost categorization. The table 1 presents all the categorizations in relevant sources and the terminology adopted to describe the different LCC phases.

Table 1 - Terminology adopted for LCC phases.

Adopted terminology	IEC 60300-3-3	ISO 15686-5	rEN 16627	2014/25/UE Diretive	Davis Langdon
Construction	Conception and Definition; Design and development; Manufacture and instalation;	Construction	Process of construction	Aquisition	Investment planning and pre-construction; Design and construction;
Utilization	Operation and maintenance	Operation Maintenance	Utilization phase	Operation Maintenance	Operation and maintenance
End of lifespan	Alienation	End of lifespan	End of lifespan phase	End of lifespan	End of life/Alienation

The impact of decisions taken during the LC have a different influence in the LCC. According to UIC (2010), Innotrack (2006), and the ISO 15686-5 standard, the most relevant decisions for LCC are taken in the project phase.

According to ISO 15686-5, IEC 60300-3-3, Innotrack (2006), Mainline (2013) *et al,* the utilization of a Cost Breakdown Structure (CBS) is the most adequate way to organize the LCC. The firs level of the CBS is defined by the phases of the LCC. According to the ISO 15686-5 standard, further levels should respect a systemic level, and a detail level. The IEC 60300-3-3 standard recommends a tri-dimensional organization, so there can be an easy access to all the costs involved in LCC (this kind of organization requires not only certain regularity in the detail of the different phases, but also in the designation of the different cost categories, as long as it's possible).

Life Cycle Cost Analysis

According to the ISO 15686-5 standard, Life Cycle Cost Analysis (LCCA), is the "..*methodology for systematic economic evaluation of life-cycle costs over a period of analysis, as defined in the agreed scope..",* and it establishes that LCCA can be taken to predict the costs associated to a constructed asset in the rest of its life cycle, or to evaluate the costs related to different stages (construction, utilization, end of lifespan) in a project to develop in the future. In the year of 2007 the European Commission has sponsored the first step to create an a-sectorial methodology for LCCA. This methodology, created by Davis Langdon Consulting (nowadays known as AECOM Europe), has the purpose of delivering a methodology which allows LCCA application at several stages of the LC, namely to the evaluation of different projects, evaluation of different strategies for a project, and evaluation of different options to concept detailed systems of a project.

The methodology created defines certain core processes in the process of life cycle costing; although the IEC 60300-3-3 standard doesn´t have the same detail as the methodology, it also defines core processes for life cycle costing. The correspondence between the two sources, as well as the terminology used for the core processes it's shown in table 1.

Table 2 - Core processes of LCCA.

Adopted processes	**IEC 60300-3-3**	**Davis Langdon Metodology**	**Execution details**
Life Cycle Costing Plan	Life Cycle Costing Plan	Define the objective of the proposed LCC analysis	Definition of objectives, scope, period of analysis, operational environment, analysis boundaries, alternatives in study, needed resources;
LCC model selection or development	LCC model selection or development	Collection of cost and performance information; Implementation of the analysis, iteratively when needed	Selection of LCC model based on: availability of data, capability of performing analysis of the alternatives in study, obtain outputs that suit the objectives, allow the analysis to occur in adequate temporal horizon.
LCC model application and performance of economic analysis	LCC model application		Data collection and scenario evaluation, choosing the most valuable scenarios and most cost influent elements; Quantification of differences in the performances of different alternatives that are not perceptible on the results; Perform sensitivity analysis, explaining the factors that show major influence.
Interpretation and Documentation of results	Documentation of the LCCA and revision of its results	Expound and report of results	
Analysis Update	LCCA update	-	Relevant when the LCC model is kept during the lifespan of the asset and it seems possible to increase the robustness of the model with the introduction of new data

According to the ISO 15686-5 standard there are key parameters in LCCA that should be agreed and defined with the client before the LCCA. These parameters are the period of analysis, the organization and detail of the model, if the client requires a sensitivity analysis to be performed, the financial analysis method (namely the method to take in account the money value variation along the time), and the client requirements related to the results presentation.

Due to its relevance, the period of analysis should be defined taking in account the client requirements. According to the ISO 15686-5 standard, the period of analysis should try to equal the life cycle of the asset, expressing at the same time a maximum period of analysis for a realistic analysis of 100 years. The Davis Langdon methodology recommends a 60 year period of analysis for comparisons between new projects. For evaluating assets that are already operating, and which the LCCA require more detail, the recommended period of analysis is 30 years.

About the method to perform the financial analysis and the method to take in account the money value variation along the time, the standards ISO 15686-5 and IEC 60300-3-3 present the Internal Rate of Return (IRR) and Net Present Value (NPV) as the most adequate indicators to evaluate projects. Both of the indicators resort to a discount tax to take into account the money value fluctuation. The referred discount taxes depend on various macroeconomic indicators, which make it, in pair with the period of analysis as one of the most suitable factors to perform sensitivity analysis, according to Railways (2010). Besides the uncertainty related to the discount tax, there is also uncertainty associated with the data on which the model is based on; due to that, ISO 15686-5, IEC 60300-3-3 and others, recommend the application of perceptual deviations (establishment of different scenarios), or, in cases that require previsions with low uncertainity.

According to the IEC 60300-3-3 there is always the need of improving the LCCA estimates. That improvement can be done by reviewing some key points such as the framing of the results in the scope and goals defined for the LCCA, the correct application of the model and the veracity of the hypothesis assumed for the LCCA.

3 RAILWAY BRIDGES LCC MANAGEMENT

LCC in the railway sector

According to Rocha (2015) the description of LCC as a capacitation mechanism can be found not only in general asset management standards, but also in reports related to the railway sector such as UIC (2010a) and NetworkRail (2011), referring to LCC as an useful tool in railway sector asset management.

LCCA of railway bridges

According to Innotrack (2006) and Mainline (2013b) the key parameters of an LCCA are the period of analysis, life cycle phases division, identification of which costs are to be included in the analysis, the CBS construction and the financial analysis method.

According to Bonstedt (2009) the most usual life cycle duration considered for bridges is 100 years. Frangopol (2007) describes that bridges are important linking asset, it’s important to guarantee the correct functioning of them in all the scenarios, which requires a detailed and sometimes costly scheme of maintenance. About the level of detail of the LCCA, namely the CBS and its organization the ISO 15686-5 standard recommends it to be consistent with the detail level of the model, and the detail level required by the client in the key stages of the project. That vision is different, but not antagonist of the one previously told about the relationship between the period and the detail of analysis written in Langdon (2007).

According to Almeida (2013) and NHCRP (2013), there is not much sense in using TIR as financial indicator, since there aren’t expected any financial incomes on an investment such as a bridge; on the other hand, the use of NPV makes much more sense, because it shows the value of the asset at the end of the period of analysis. According to the ISO 15686-5, the NPV is calculated according to expression 1.

$$\sum_{n=1}^{P} \frac{Cfn}{(1+d)^n} \qquad (1)$$

Cfn - cash-flow at year n;
d –discount tax;

According to Almeida (2013), higher discount taxes suit smaller periods of analysis, and smaller taxes suit longer periods of analysis. The Innotrack Deliverable 6.2.4 recommends for public investments a discount rate of 4%; that value is similar to the one placed in Ordinance no. 13208/2003 published in Series II of the Official Journal of the Portuguese Republic, which is the normative reference for the discount rate to use in evaluation of public-private partnerships. In cases in wich the asset doesn’t have any expected income, the NPV turns into Net Present Cost (NPC).

3 Proposal of LCCA methodoly for REFER’s Railway Bridges

The proposed methodology is based on the case study of REFER. The first to step to develop the model was the definition of the codification and organization of the cost categories. The choices made are directed to the construction of a normalized model within the best actual practices in the LCC paradigm.

The methodology is composed by thirteen steps, and developed having by guide Langdon (2007) and the ISO 15686-5 standard. Is important to refer that, due to its specificity, the eighth step was developed consulting the NHCRP (2003) guide for purposes of cost to include, the ISO 15686-5 standard for purposes of framing those costs into the LCC, and encoded with the guidance of the prEN 16627. The methodology proposes the construction of a parametric cost model, so that any change in the data input has an immediate effect on the results. All the methodology steps are placed and briefly described at table 3.

Table 3 - Proposal of LCCA methodology for railway bridges.

Step	Description
1 – Purpose of LCCA	Definition of LCCA purpose and expected results of it
2 – Identify the Scope of LCCA	Definition of range, analysis limits, activities in each LC phase and the results format
3 – Relationship between LCC and Life Cycle Assessment	Evaluate the social and environmental impacts. (out of scope of LCC, encompassed at Whole Life Cycle Cost)
4 – Identify the period of analysis and the financial analysis tecniques	Definition of the period of analysis and the financial analysis techniques to apply
5 – Evaluate the need of sensitivity and risk analysis	Definition of need to include methods to reduce the uncertainty associated to the data available
6 – Identify the project's requirements and key parameters	Definition of the project's requirements (in operation), the key parameters and intended utilization of data
7 – Identify options to include in the LCCA	Definition of how many scenarios will be tested
8 – Gatherer LCCA relevant costs and its periodicity	Definition of which costs are included in the LCCA and associate with its period of occurrence; Definition of the CBS
9 – Verify the financial parameters and the period of analysis	Verify if there was any relevant change in frame of the analysis that affects the financial parameters and the period of analysis
10 - Perform the economic analysis	Introduction of all the inputs into the CBS and performance of the economical analysis
11 – Perform sensibility analysis	Performance of sensitivity analysis (in case of previous definition of its parameters at step 5)
12 – Interpret obtained results and present it suitable format	Review the obtained results, validate them, and in case of validation, present it in adequate format;
13 - Present results in suitable format	Final presentation of results

5 –METHODOLOGY APPLICATION TO CASE STUDY

The methodology developed was applied to the case study of the Portuguese Public company responsible for all the railway infrastructures management, REFER. REFER is responsible for managing nearly 2400 bridges (850 in stone masonry, 848 in reinforced concrete, 324 in steal structure, and 47 in steal-concrete composite structure). The described company has nowadays an AMP, effectual until 2034. The main objective of this work is to contribute for its improve, by providing the LCCA results as basis of comparison with this document.

Step 1 – Purpose of LCCA

The purpose of the LCCA is, by applying the proposed cost model, obtain data about the REFER's railways bridges(its part of LCC framed within the defined period of analysis), for comparison with REFER's AMP. Due to that, the analysis can be classified as an absolute one.

Step 2 – Identify the scope of LCCA

Most of REFER's bridges were included in the LCCA, exception made to steal-concrete composite bridges, which, due to lack of data and reduced weight in the global bridge park, were excluded. The LCCA considered all of the remaining bridges, with a regular level of detail, regardless the LCC phase the bridges are framed in.

There are different schemes of maintenance associated to the bridges in study. The table 4 presents those different schemes, according to terminology in EN 13306 – Maintenance – Maintenance terminology.

Table 4 - Maintenance activities according to EN 13306.

Type of maintenance	Periodicity (years)	Description
Preventive Systematic Maintenance	1	Regular, small size maintenance works
Long Periodicity Preventive Maintenance	Variable according to the different structural materials; stone masonry bridges are excluded	Works like reinforcement of foundations, replacement of damaged parts
Immediate Corrective Maintenance	Undefined	Reactive intervention to re-establish safety conditions caused by accidents
Routine Inspection	1	Visual inspection of bridges
Main Inspection	4	Underwater inspection, foundation assessment

Step 3 – Relationship between LCC and Life Cycle Assessment

The third step is out of defined scope for this work.

Step 4 – Identify the period of analysis and the financial analysis techniques

Since REFER´s AMP is calculated until 2034 the chosen period of analysis is form 2014 until 2034.As described before, the most adequate technique for financial analysis in assets which only generate costs is the CPC. To be coherent with the AMP, all the costs included in the LCCA are real costs, not being applied any discount tax to this costs.

Step 5 – Evaluate the need of sensitivity and risk analysis
The fifth step is out of defined scope for this work.

Step 6 – Identify the project's requirements and key parameters
The projects requirements are related to the objective of assuring the necessary safety and availability conditions in all of the REFER's railway bridges.
To perform de LCCA, there were defined 4 key parameters, presented in table 5. Due to lack of data and difficulty in classifying the surrounding environment, the LCCA presented covered only 3 of the 4 parameters, excluding the surrounding environmental parameter.

Table 5 - Key parameters of LCCA.

Key parameters	Influence in LCC
Bridge Material	The costs associated with each LC phase of railway bridges vary according to the structural material
Surrounding environment	The different surroundings and how aggressive they are for the structural materials of bridges have a major influence on the periodicity of the maintenance activities
Length of bridge	The costs associated with each LC phase of railway bridges vary according to the length of each bridge
Number of railroads	The costs associated with each LC phase of railway bridges vary with the number of railroads

Step 7 – Identify options to include in the LCCA
In the present LCCA there aren´t any options in study.

Step 8 – Gatherer LCCA relevant costs and its periodicity
The model proposed in Rocha (2015) generated the cost categories presented in table 6. Due to data limitation, the cost model wasn't applied in all of its extension. All the costs were calculated based on real data, supplied by REFER´s bridges management office.

Step 9 - Verify the financial parameters and the period of analysis
The hypothesis assumed at step 4 maintain themselves valid, therefore the parameters established are suitable.

Step 10 - Perform the economic analysis
Following the indications of the methodology, the economic analysis was performed in Microsoft Excel. The CBS is fully parametrized.

Step 11 – Perform sensitivity analysis
As explained at step 5, there is no need of carrying a sensitivity analysis.

Step 12 – Interpret obtained results and present it suitable format
By applying the developed methodology, there is place at this step for revising the LCCA. This revision has the purpose of verifying the accomplishment of the LCCA's objectives (if the model developed is suitable and the assumptions made are valid). Since there are no relevant assumptions to validate and the LCCA produced results for comparison with the AMP, it is adequate to validate the LCCA. The main results of the analysis are presented in table 7, and all of them are shown in monetary units, which mean that the values presented don't represent the real values involved in the REFER's AMP.

a) Results of LCCA
Analyzing the table 7, it is easy to conclude that the majority of costs are related with the utilization phase, followed by the construction phase, and with a smaller impact, the end-of-life phase (that result can be related with the low range of application of this LC phase). In the construction phase, the most relevant costs are related to steel bridges, while in the utilization phase the majority of costs are related with reinforced concrete bridges. The table 7 shows also that the most relevant cost categories are B.2.1 - Preventive Systematic Maintenance and B2.2 - Long Periodicity Preventive Maintenance.

b) Comparison with the AMP
To fulfill the purpose of the LCCA is necessary to compare its results with the AMP. The total difference found between the LCCA and the AMP represents approximately 43% of LCCA results, as presented in table 8 and graphic 1.

Table 6 - Cost categories of LCCA.

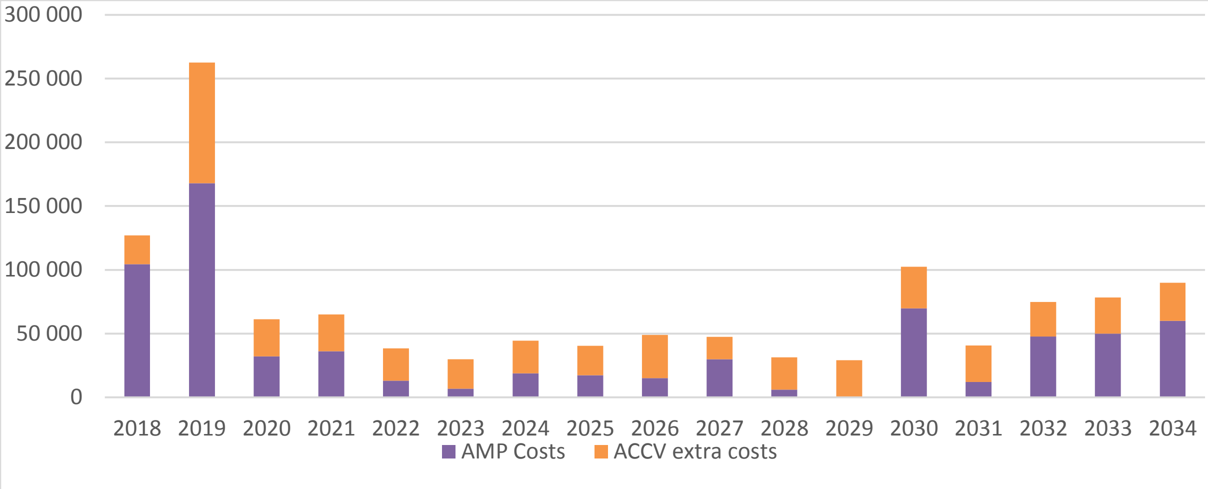
LCC phase	Application rate	Encoding	Designation	Application on LCC	Application on AMP
Construction – A5	75% (3/4)	A.5.1	Design fees	Yes	Yes
		A.5.2	Land acquisition/ compensatory costs	No	No
		A.5.3	Installation, construction and comissioning	Yes	Yes
		A.5.4	Construction inspection	Yes	Yes
Utilization – B1 A 7	50%(6/12)	B1.1	Civil lyability insurance	Yes	No
		B2.1	Preventive Systematic Maintenance	Yes	No
		B2.2	Long Periodicity Preventive Maintenance	Yes	Yes
		B2.3	Routine Inspection	Yes	No
		B2.4	Main Inspection	Yes	No
		B2.5	Management planning and monitoring of maintenance	Yes	No
		B3.1	Immediate Corrective Maintenance (replacement)	No	No
		B4.1	Immediate Corrective Maintenance (repair)	No	No
		B3.2	Management planning and monitoring of replacement	No	No
		B4.2	Management planning and monitoring of repair	No	No
		B6.1	Energy usage in operation	No	No
		B7.1	Water usage in operation	No	No
End-of-lifespan – C1 A 4	20%(1/5)	C1.1	Final condition inspections	Yes	No
		C1.2	Demolion/deactivation	No	No
		C2	End-of-life waste transport	No	No
		C3	Management of end-of-life waste	No	No
		C4	Cost of solution for end-of-life waste	No	No

Table 7 - Results of LCCA.

Category		CCV Total		Concrete		Steel		Stone Masonry	
		% LCC	Absolute Value (u.m)	% total LCC	Absolute Value (u.m)	% total LCC	Absolute Value (u.m)	% total LCC	Absolute Value (u.m)
A.5.1	Design fees	39,63	611 604	3,68	22 513	96,32	589 090	0,00	0
A.5.3	Installation, construction and commissioning								
A.5.4	Construction inspection								
A.5.2	Land acquisition/ compensatory costs	0,00	0	0,00	0	0,00	0	0,00	0
B1.1	Civil liability insurance	0,09	1 446	70,89	1 025	15,37	222	13,74	199
B2.1	Preventive Systematic Maintenance	18,11	279 466	70,89	198 122	15,37	42 953	13,74	38 391
B2.2	Long Periodicity Preventive Maintenance	23,11	356 565	31,63	112 785	68,37	243 781	0,00	0
B2.3	Routine Inspection	12,54	193 494	70,89	137 174	15,37	29 739	13,74	26 581
B2.4	Main Inspection	4,02	62 036	65,08	40 375	24,20	15 015	10,71	6 645
B2.5	Management planning and monitoring of maintenance	0,58	8 917	70,89	6 322	15,37	1 371	13,74	1 225
B3.1	Immediate Corrective Maintenance (replacement)	0,00	0	0,00	0	0,00	0	0,00	0
B4.1	Immediate Corrective Maintenance (repair)	0,00	0	0,00	0	0,00	0	0,00	0
B3.2	Management planning and monitoring of replacement	0,00	0	0,00	0	0,00	0	0,00	0
B4.2	Management planning and monitoring of repair	0,00	0	0,00	0	0,00	0	0,00	0
B6.1	Energy usage in operation	0,09	1 446	70,89	1 025	15,37	222	13,74	199
B7.1	Water usage in operation	18,11	279 466	70,89	198 122	15,37	42 953	13,74	38 391
C1.1	Final condition inspections	1,92	29 582	0,24	72	99,76	29 510	0,00	0
C1.2	Demolition/deactivation	0,00	0	0,00	0	0,00	0	0,00	0
C2	End-of-life waste transport	0,00	0	0,00	0	0,00	0	0,00	0
C3	Management of end-of-life waste	0,00	0	0,00	0	0,00	0	0,00	0
C4	Cost of solution for end-of-life waste	0,00	0	0,00	0	0,00	0	0,00	0

Table 8 - Differences between AMP and ACCV results.

	2018	2020	2022	2024	2026	2028	2030	2032	2034	Total
ACCV ($x10^4$) u.m.	12,71	6,12	3,85	4,45	4,91	3,13	10,25	7,47	8,98	121,24
PGA ($x10^4$) u.m.	10,44	3,22	1,32	1,87	1,51	0,61	6,98	4,77	6,00	68,80
Difference (%)	17,84	47,36	65,82	57,92	69,26	80,43	31,93	36,11	33,21	43,25



Graphic 1 - Annual difference between AMP and ACCV results.

Step 13 - Present results in suitable format
The results presentation should be agreed with the client. More information on this step can be found in Rocha (2015).

6 -Conclusions and future developments

Conclusions
The LCCA presented some relevant costs that aren´t taken in account on the AMP. The LCCA was made with a 11/19 range of appliance, due to lack of available data; the impact of the excluded cost categories can't therefore be valued. Analyzing the results and without differentiating the bridges structural material, it is possible to conclude that the most relevant phase of the LCC is the utilization phase. Within the different structural materials being considered, the biggest contribution comes from both steel bridges (61.67%) and reinforced concrete bridges (38.15%). Stone masonry railway bridges have the smaller contribution to the total costs, representing a share of 4.7%.

a) Concrete Bridges
The utilization phase is the most relevant phase in concrete bridges, with relevance for the cost category B2.1 - Preventive Systematic Maintenance (38,27% of LCC).
Within the concrete bridges and by the length criteria, the most cost-relevant bridges are the ones with 100 or more meters. If the criteria relies on the number of railways, the most relevant group is the 2 railroads bridges group.
Since the AMP only takes into account 26,7% of the LC costs in what respects to the reinforced concrete bridges (the ones related with the construction phase and the category B2.2 - Long Periodicity Preventive Maintenance), it was concluded that the AMP doesn't take into account most of the costs associated with the reinforced concrete railway bridges.

b) Steel Bridges
The construction phase is the most relevant LC phase in steel bridges, representing 61.9% of the LCC. Since the construction phase represent three aggregate categories, is not possible to identify the most relevant one in the most relevant LC phase (this conclusion might be a consequence of the assumed hypothesis that every time a bridges achieves its lifespan, a new one is built, with similar characteristics).
Within the steel bridges if the results are analyzed by the length criteria, the most cost-relevant bridges are the ones with 100 or more meters. If the criteria of analyzes relies on the number of railways, the most relevant group is the 1 railroad bridges group.
Since the AMP takes into account 87.52% of the steel bridges LC costs (the ones related with the construction phase and the category B2.2 - Long Periodicity Preventive Maintenance), it was concluded that the AMP takes into account most of the costs associated with the reinforced concrete railway bridges.
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c) Stone Masonry bridges
The utilization phase is the most relevant phase in stone masonry bridges, with relevance for the cost category B2.1 - Preventive Systematic Maintenance (46.6% of LCC). IT is important to explicit that the LCCA only had data about the utilization phase of stone masonry bridges.
Within the stone masonry briges, the ones with more cost relevance are the ones with less than 25 meters of length. There are no conclusions to present about the number of railroads most relevant group, due to the fact that there are only stone masonry bridges with one railroad in REFER's ralway bridge park.
It was verified that the AMP doesn´t take into account any costs related to stone masonry bridges.

d) Comparison with the AMP
The comparison with the AMP, which means the measurement of LCCA cost categories impact not taken into account in the AMP. The results show a estimated difference of 43.25%, which means that a relevant part of the costs are not considered in the AMP

cost framework. Is also adequate to remind that any demolition/waste treatment costs were taken into account, therefore, the real deviation between the two documents predictions can be larger than the one studied.

Future Developments

The exclusion of costs related to the Whole Life Cycle Cost (WLCC) concept shows by itself a path in the appliance of this methodology, enlarged to the WLCC scope. Costs related to social and environment impacts of railway assets, and also the income they can generate, are certainly precious information for a proper asset management.

The available data about the railway assets, as its reliability is suitable of having a robustness increase. One way of doing this is by developing a more standardized and systematic approach to data gathering. Another possible way to improve the reliability of the LCCA results, relies on performing sensitivity /risk analysis. The accuracy of the studies that support the optimal maintenance activity frequency on the different bridges is also a field where improvement potential may be achieved (and therefore cost reductions). One specific way to materialize this evaluation is by developing a bridge condition index (dependent on criteria such as load cycles, surrounding environments and others).

In a general sense the application of this methodology to other types of physical assets, namely engineering infrastructures, is a possible path to develop the reliability of the developed methodology.

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