

Analysis and cost evaluation in the life cycle of road tunnels

Maria Cortes Rezende

Under Supervision of Prof. Nuno Almeida and Prof. Carlos Cruz

Department of Civil Engineering, Architecture and Georesources, Instituto Superior Técnico (IST), University of Lisbon (ULisbon)

Abstract—*This dissertation, developed in business environment, is based on the portfolio of road tunnels managed by a concessionary operating in the Madeira island - Vialitoral. The developed work aims to contribute to a bigger applicability of the methodology of life cycle cost analysis (LCCA) compared to the amount and quality of the data and information usually available by the responsible organizations for the management of the portfolio of physical assets. The developed study leads to the conclusion of the existence of some important gaps on the catchment of the assets' life cycle. So, are estimated two scenarios inherence to the review. Therethrough, using the evolution of the items, it proves that the bigger the intensity of the associated data to each work of art, the bigger the cyclicity denoted when it is applied the LCCA. With the applied percentage of irregularities on the catchment of the data, it is suggested the creation of a proper costs profile based on the real expenses, because it is believed that these estimated profiles may not be overlapped with the reality of the concessionary.*

Index Terms—*Asset management, life cycle cost, life cycle cost analysis, road tunnels.*

1. Introduction

The life cycle cost analysis (LCCA) aims to support the management of physical assets, promoting informed decisions on the phases of construction of buildings, not exclusively based on the initial costs. This approach seems to be more complete and embracing.

LCCA methodology gives great importance to periods of maintenance/inspection both periodic and regular, and the impact that the detailed accounting of the associated costs have on the overall economic performance of construction projects.

This work falls within the following areas: management of physical assets, life cycle cost analysis and road tunnels.

This analysis must be developed for all kinds of physical assets, but road tunnels were the selected ones. This range of infrastructure has a particular interest when there is shortage of usable building area to the surface in urban areas. It is intended to test and enable the application of the method of life cycle cost analysis of the company's dealership portfolio, which has nearly three dozen road tunnels in charge.

2. Knowledge review

2.1. Physical assets management (PAM)

According to AMI (IAM 2012), the PAM is presented as a strategic vision and policy, always addressing the concept of continuous and dynamic improvement. The topics of essential importance on this concept have been established by the various entities involved in the implementation of PAS 55 (2008). These include, for example, work planning, materials management, among others.

Based on the PAS 55 specification and published by the British Standards Institution in 2004, it was published in 2014 a family of ISO 55000 standards on "Asset Management".

These standards highlight the relevance of the concept Life Cycle Cost (LCC). The ISO 55000 family includes the following standards:

- ISO 55000 - Definition of the physical asset and PAM concepts;
- ISO 55001 - PAM requirements;
- ISO 55002 - PAM policy definition (ISO 55001 interpretation and implementation).

2.2. Life cycle cost

According to the ISO 15686-5 standard, the LCC goes through the registration of all economic factors associated to a physical asset throughout all its useful life, from the design phase to the demolition, which should undergo through a systematic analysis in the course of any time interval associated with the operation of the asset. On the other hand, it may encompass a period of more limited analysis, or a particular stage of a physical asset already built. When this happens, the costs to considerer should always be taken into account of the performance level, reliability and safety during the selected period of analysis, as referred by Davis Langdon (2007b).

The existing literature on the LCC adopts different terminologies and nomenclatures for the stages of life cycle cost, as well as different departments within their own stages.

In Table 1 are summarised the different terminologies adopted in the analised literature.

Table 1 - Terminologies addressed in CCV major publications.

IEC 60300-3-3	Langdon (2007a)	ISO 15686-5	Directive 2014/UE of 26th february 2014
1. Study concept and definition; project and development; facturing; installation	1. Investment planning and pre-construction	1. Construction	1. Acquisition
2. Operation and maintenance	2. Project and construction	2. Operation	2. Operation
3. End of life	3. Operation and maintenance	3. Maintenance	3. Maintenance
	4. End of life	4. End of life	4. End of life

2.3. Life cycle cost analysis

LCCA is a process to evaluate the economic performance of a physical asset throughout its life making it necessary to balance the preponderance or not of the initial investment costs, face to the several applications of capital that will take place over the course of the period in which the constructions meets the specified requirements.

According to the ISO 15686-5 standard, the analysis period should not extrapolate hundred years due to the subjectivity that there may come. However, it is advised that the analysis period spans the entire life of the physical asset, but may be in the applicant's interest that the study is restricted to a range of time in which there is a special interest that this analysis is carried out, as a loan or even a maintenance contract to justify the realization of a more detailed study. The process of LCCA raises the need to review and continuous improvement.

To estimate the life cycle costs of road tunnel, which need challenging civil engineering constructive works, an appropriate model is required because of such complex and diversified structures. The modules as part of the tunnel (construction and facility) are connected with several essential processes during the life cycle, which guarantee the safety and the function of the modules.

Figure 1 represents the modular process model, which is able to estimate the life cycle costs in transparent and structured way Thewes et al. (s.d.).

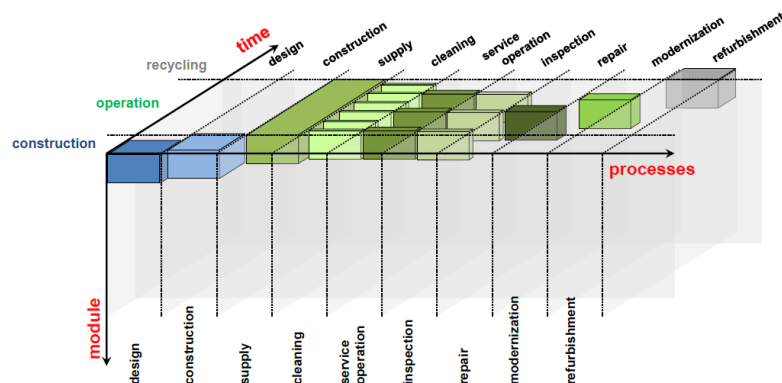


Figure 1 - Modular process model for the life cycle cost analysis of tunnels (adapted from Thewes et al. (s.d.).

3. Methodology LCCA to road tunnels

The development of LCCA depends on the quantity and quality of available data (could be a key topic), the limitation of time and the degree of accuracy required. Another relevant factor is the identification of the analysis phase in which the work of art is: design stage or physical asset already built. If the asset is still in the draft stage, it is possible to perform an analysis of sensitivity face to construction methods with practical implementation, where you can test different designs and equipment and also which types of maintenance to be adopted.

The review of knowledge carried out shows the main sources that support the systematization of LCCA in tunnels: (i) Langdon (2007b); (ii) ISO 15686-5; (iii) Angeles (2011); (iv) Thewes et al. (s.d.) and (v) Vogt (2012). The methodology used throughout this dissertation is summed up by the following steps, which compiles the approaches that the authors above have adopted:

- Step 1 - Purpose and goals of the analysis;
- Step 2 - Scope of the analysis;
- Step 3 - LCCA and their sustainability;
- Step 4 - Period of analysis and techniques of economic and financial assessment;
- Step 5 - The need for risk analysis and sensitivity;
- Step 6 - Specific requirements of the asset/project;
- Step 7 - Options to include in the LCCA;
- Step 8 - Identification, compilation and time profile of costs;
- Step 9 - Verification of financial metrics and analysis period;
- Step 10 - Implementation of economic analysis;
- Step 11 - Execution of sensitivity analysis;
- Step 12 - Interpretation and presentation of final results;
- Step 13 - Presentation of final results.

It is stated that, although not all authors have themselves associated with each of 13 steps, this does not imply that they do not go through them when the LCCA. It just means that, when carried out a review of knowledge, these steps were not directly exposed, as not all authors assume a methodology to systematize Langdon (2007b) and ISO 15686-5, and the last one is the one with bigger predominance in writing this document.

Even if one should take as a starting point of the LCCA step 1 on the purpose and goals of the analysis, to ensure that one could make a correct and complete application of the methodology, we initially studied the tariff which were listed the expenses incurred by Vialitoral. Thus, if all the data were to occur properly distributed and fully attributable to each work of art, they should start to implement this methodology.

Therefore, start-up will approach the case study by step 8: identification, compilation and time profile data.

At this step, five phases were defined to help the compilation of the associated costs for each tunnel. These phases are:

- B1 - Use;
- B2 - Maintenance;
- B3 - Repairing;
- B4 - Substitution;
- B5 - Remodelling.

4. Collection and analysis of tunnel's LCC

Since the 28th of January of 2000 that the award of public service in the VR1 exclusive regime was attributed to Vialitoral, through the concession agreement between that company and Madeira Island. Thus it became the responsible one for operation and maintenance for a period of twenty-five years. The representation of this operation is shown in Figure 2.

The phase between the late 80s and 2004 brought significant improvements to the archipelago in Funchal access to more distant parts of the island, reducing considerably time taken between courses. The volume of construction can be illustrated in the following points:

- 48 road tunnels built in 2004;
- 39 executed road tunnels in 2004 (27 of which had its finalization between 2010 and 2012);
- 36% of VR1 developed itself in road tunnels;
- average construction of 10 road tunnels/year (1994-2012);
- 76 road tunnels longer than 500 m (11 of the longer than 2 km and another 2 longer than 3 km).

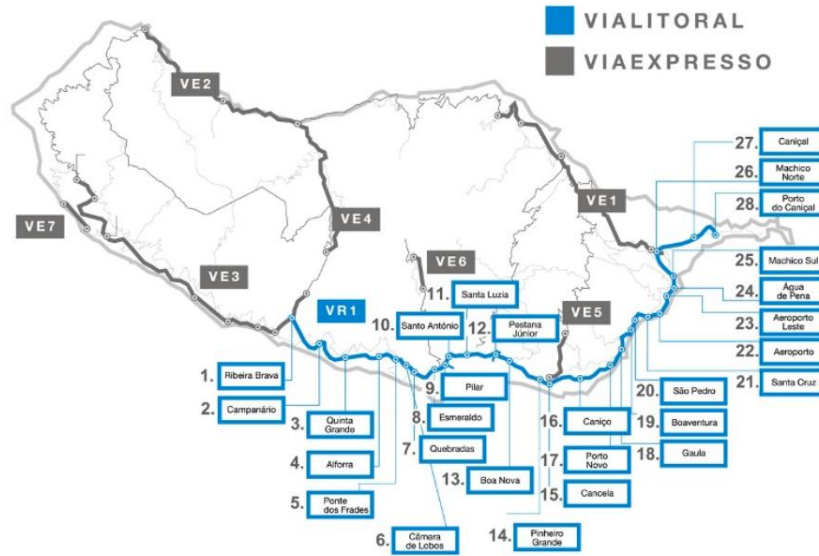


Figure 2 - Representation of Vialitoral operation at Madeira Island, adapted from (Concessões Rodoviárias da Madeira S.A., 2012).

4.1. Identification, compilation and analysis of data

In order to carry out an analysis of the cost of living for art work cycle, it is necessary to arrange access to a complete database, so that you can associate to each tunnel portions relating to each item. The same was not possible because the existing database only allowed to associate individual tunnels 48% of all costs raised, about 52% of the costs are not allocated to any specific work of art, in all the categories.

It was studied with more detail some tunnels to understand the current situation in view of the condition and maintenance associated with the time profile of costs. It was made a selection and gathered data from eleven tunnels, which are assigned a designation from A to L. That selection was the sole criterion of identification of tunnels that had more data to other members. Thus, it proceeded to filtration costs associated with each tunnel.

Table 2 details one of the studied lines, where it is possible to conclude that many are incomplete data over the years - including the category B1 - Use -, and this hinders the regular reading of the work and the needs required for each work of art.

Table 2 - B1 costs collected per tunnel.

	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Ano 14	Ano 15	Ano 16	Ano 17	Ano 18	Ano 19
Túnel A	- €	- €	- €	- €	114,23 €	77,36 €	197,00 €	- €	26,79 €	454,08 €	111,36 €	38 912,48 €	14 628,35 €	5 015,95 €	- €	5 161,06 €	- €	1 477,83 €	- €
Túnel B	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	142,44 €
Túnel C	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	206,82 €
Túnel D	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	3 074,50 €	835,21 €	- €	101,52 €	- €	- €	1 533,47 €	424,65 €	804,66 €
Túnel E	- €	- €	- €	- €	- €	- €	- €	79,04 €	- €	- €	54 548,62 €	4 187,32 €	1 554,07 €	130,02 €	373,82 €	- €	2 311,52 €	514,15 €	529,20 €
Túnel F	- €	- €	- €	- €	- €	232,95 €	3 071,20 €	- €	- €	8 792,50 €	12 505,06 €	- €	- €	- €	- €	- €	- €	- €	- €
Túnel G	- €	- €	- €	- €	- €	- €	- €	250,00 €	84,85 €	- €	- €	- €	- €	8 667,81 €	1 320,00 €	- €	- €	- €	- €
Túnel H	- €	- €	- €	- €	- €	- €	9,72 €	- €	- €	62,23 €	- €	- €	- €	6 356,39 €	968,00 €	- €	- €	- €	- €
Túnel I	- €	- €	- €	- €	- €	- €	- €	- €	24,12 €	- €	- €	- €	- €	18 202,40 €	2 772,00 €	- €	- €	- €	- €
Túnel J	- €	- €	- €	- €	- €	- €	- €	- €	24,12 €	- €	- €	- €	- €	19 069,64 €	2 904,00 €	- €	- €	- €	- €
Túnel L	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	183,20 €	- €	- €	13 290,64 €	2 024,00 €	- €	- €	- €	- €

Figure 3 shows that, with respect to the tunnel face repair (B3) can be seen maxima with gaps of about ten years and in that this interval of time assume values smaller proportions. Such evidence, if reproduced in other tunnels, could lead to take the conclusion that every work of art would take, in extreme ranges of ten years, more accentuated values than in other years. However, such regularity cannot be observed in the remaining elements of the set, leading to the conclusion that the current individualization of existing costs is not enough that you can carry to completion of the regularity of the costs associated with repairs.

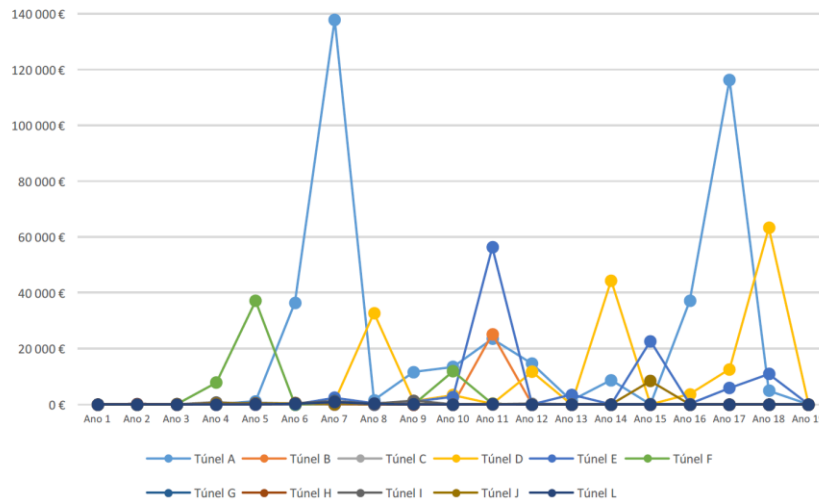


Figure 3 - B3 category costs collected.

4.2 Discussion of the application of step 8 of the methodology

In Table 3 are shown the costs that were directly associated to each tunnel.

Shortages of current costs associated with various items triggers an added difficulty when it comes to some critical points of the LCCA. This difficulty begins in the category: Construction. Having the construction costs (year 0) of some tunnels, this does not allow to extrapolate - for example by a factor of proportionality over the tunnel length - for other works of art, as per meter cost construction differ considerably.

As previously explained, the oscillations relate to the conditions for the construction companies have to go to make the construction of such works of art - the whole associated with geotechnical site - or even if it is a tunnel built or not the open, which can later be restored the initial relief of the terrain.

Table 3 - B1 and B2 costs collected by tunnel.

Rubrica/Año	Até 2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
B1														
B1.1	651,20 €	- €	- €	- €	9,72 €	4 305,00 €	16 500,00 €	17 444,43 €	739,79 €	37,19 €	- €	3 801,06 €	95 494,93 €	5 698,00 €
B1.2	- €	- €	- €	- €	- €	142,87 €	- €	19,51 €	- €	- €	- €	- €	- €	- €
B1.3	816,20 €	- €	- €	- €	165,00 €	920,00 €	325,00 €	1 412,74 €	- €	1 953,95 €	- €	- €	89,50 €	22 265,22 €
B1.4	156,34 €	77,36 €	36,39 €	- €	- €	- €	542,72 €	- €	- €	- €	- €	156 047,34 €	14 789,60 €	2 686,41 €
B1.5	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	849,30 €	391,44 €
B1.6	73 312,00 €	13 627,63 €	21 193,28 €	- €	- €	- €	- €	- €	- €	- €	- €	- €	4 169,05 €	20 034,03 €
B1.7	- €	- €	- €	- €	53,22 €	- €	- €	- €	- €	- €	- €	- €	177,63 €	- €
B1.8	118,21 €	- €	1 000,90 €	- €	88,79 €	107 837,80 €	2 083,55 €	36 447,92 €	739,79 €	8 606,98 €	- €	8 088,74 €	4 623,45 €	1 185,04 €
Total B1	75 053,95 €	13 704,99 €	22 230,57 €	- €	316,73 €	113 205,67 €	19 451,27 €	55 334,60 €	1 479,58 €	10 598,12 €	- €	168 114,77 €	120 015,83 €	52 260,14 €
B2														
B2.1	- €	- €	- €	5 172,18 €	20 250,74 €	3 192,59 €	17 996,69 €	38 862,22 €	4 591,43 €	- €	- €	- €	- €	- €
B2.2	- €	34 950,33 €	25 026,33 €	43 242,48 €	28 325,39 €	- €	- €	38,32 €	- €	- €	- €	28 830,50 €	8 776,20 €	24 615,85 €
B2.3	- €	- €	- €	43 242,48 €	28 325,39 €	- €	- €	- €	- €	- €	- €	- €	- €	- €
B2.4	- €	1 894,00 €	- €	- €	- €	- €	- €	- €	- €	- €	- €	6 010,20 €	- €	- €
B2.5	- €	9 091,75 €	41,73 €	19 815,87 €	114 949,53 €	- €	- €	11,42 €	- €	570,00 €	- €	73 102,65 €	3 025,37 €	4,96 €
B2.6	985,00 €	1 894,00 €	1 423,00 €	2 560,00 €	2 800,00 €	- €	- €	7 090,00 €	- €	- €	- €	- €	- €	- €
B2.7	- €	- €	- €	- €	- €	- €	- €	- €	516,00 €	- €	- €	- €	- €	- €
B2.8	- €	- €	- €	9,75 €	8 785,26 €	2 271,06 €	5 500,00 €	1 946,34 €	- €	15 128,02 €	- €	- €	- €	3 545,47 €
Total B2	985,00 €	47 830,08 €	26 491,06 €	114 042,76 €	203 436,30 €	5 463,65 €	23 496,69 €	47 948,29 €	5 107,43 €	15 698,02 €	- €	107 943,35 €	15 347,04 €	24 620,81 €

Table 3 - B3, B4 and B5 costs collected by tunnel.

Rubrica/Año	Ate 2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
B3														
B3.1	1 045,26 €	293,29 €	2 260,02 €	927,20 €	4 560,40 €	4 630,37 €	3 839,24 €	4 021,79 €	- €	2 568,55 €	8 203,14 €	41 246,94 €	117 061,69 €	492,61 €
B3.2	1 163,09 €	13 495,00 €	- €	- €	- €	- €	- €	11 090,97 €	- €	6 223,84 €	- €	2 362,63 €	586,39 €	4 689,63 €
B3.3	985,00 €	2 643,75 €	893,80 €	2 560,00 €	14 044,76 €	- €	14 580,00 €	71 267,00 €	45 729,01 €	388,77 €	201,86 €	7 368,46 €	9 000,48 €	- €
B3.4	- €	34 830,00 €	42 422,17 €	- €	- €	36 895,37 €	50 884,26 €	16 950,34 €	- €	23 481,54 €	- €	- €	- €	- €
B3.5	- €	- €	- €	24 613,48 €	- €	11 700,00 €	98 800,04 €	74 041,33 €	- €	- €	- €	- €	- €	- €
B3.6	- €	270,00 €	- €	2 849,37 €	799,13 €	3 943,55 €	- €	- €	- €	- €	- €	- €	- €	- €
B3.7	- €	- €	95 300,39 €	- €	3 606,86 €	68 905,00 €	8 022,04 €	23 294,75 €	141 158,43 €	11 236,69 €	20 660,75 €	12 280,00 €	82 113,24 €	- €
B3.8	3 516,62 €	2 354,00 €	1 363,35 €	827,80 €	6 868,77 €	838,76 €	952,00 €	- €	1 626,61 €	94,18 €	- €	- €	- €	- €
Total B3	6 709,97 €	53 886,04 €	142 239,73 €	31 777,85 €	29 879,52 €	103 513,05 €	177 077,58 €	200 666,18 €	188 514,05 €	43 993,57 €	29 065,75 €	63 258,03 €	208 761,80 €	5 182,24 €
B4														
B4.1	- €	- €	- €	- €	40 501,48 €	- €	19 231,40 €	34 580,52 €	- €	6 150,14 €	5 835,00 €	1 090,00 €	- €	- €
B4.2	- €	- €	- €	- €	1 167,00 €	- €	- €	908,00 €	- €	- €	- €	132,13 €	- €	- €
B4.3	- €	- €	4 380,00 €	- €	385,00 €	- €	643,28 €	1 232,55 €	- €	682,49 €	5 487,08 €	477,32 €	- €	- €
B4.4	- €	- €	- €	8 283,98 €	5 146,28 €	- €	- €	641,00 €	- €	- €	- €	3 421,88 €	- €	19 490,76 €
B4.5	- €	- €	5 774,95 €	- €	- €	- €	- €	- €	- €	- €	- €	35 127,00 €	- €	6 263,01 €
B4.6	- €	121,09 €	- €	- €	- €	- €	1 163,10 €	793,38 €	- €	- €	- €	- €	- €	- €
Total B4	- €	121,09 €	10 154,95 €	8 283,98 €	47 199,76 €	- €	21 037,78 €	37 578,54 €	- €	6 832,63 €	11 322,08 €	40 248,33 €	- €	25 753,77 €
B5														
Total B5	18 149,50 €	- €	- €	1 140,00 €	- €	23 674,00 €	5 900,00 €	1 764,74 €	- €	- €	35,40 €	- €	10 682,69 €	1 727,16 €

5. Estimation of life cycle costs

Through the analysis developed in Chapter 4, it is concluded that the available data are insufficient for a full LCCA. So, it was proceeded to the distribution of costs that are taken as general in the list provided by Vialitoral.

The displayed costs are divided into two categories, which are described in Table 4.

On this chapter to estimate it was spread over category 2 costs by the existing tunnels. There were, thus, made two iterations. The first one corresponded to allocate an equal share to each tunnel, by dividing the category 2 costs by the total number of tunnels.

On the second estimate, to provide a closer analysis of reality, category 2 was subdivided into sub 2.1 and 2.2, as reflected in Table 5. This division led to the allocation of a separate portion of each tunnel.

Note Table 5. This is the complement of Table 3. While the first one represents the cost category 2 costs, on Table 3 are reported the costs associated with category 1. As previously stated, the percentage of the costs exposed to Table 5 calls about 52% of all funding.

Table 4 - Costs distribution categorization.

Categories	Subcategories	Description
Category 1	-	-
Category 2	Subcategory 2.1	Directly proportional instalments number of tunnels.
	Subcategory 2.2	Directly proportional instalments tunnel length.
		Costs that generate doubts about what tunnel is associated therewith.

Table 5 - B1 and B2 costs to distribute - category 2.

Rubrica/Año	Ate 2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
B1														
B1.1	651,20 €	701,20 €	- €	370,53 €	7 966,75 €	2 666,94 €	- €	6 556,68 €	1 937,59 €	35 446,75 €	655,00 €	3 030,00 €	7 155,89 €	232 070,18 €
B1.2	- €	- €	- €	- €	108,41 €	145,42 €	- €	176,99 €	- €	14 034,07 €	13 833,00 €	5 855,00 €	154,10 €	16 118,00 €
B1.3	30,98 €	39,58 €	- €	- €	- €	- €	- €	840,00 €	- €	- €	- €	- €	- €	- €
B1.4	156,34 €	48,71 €	- €	- €	- €	- €	- €	93,86 €	- €	216,42 €	- €	- €	27,98 €	- €
B1.5	2 065,00 €	1 337,30 €	18 075,00 €	- €	- €	- €	201,00 €	974,50 €	350,88 €	618,00 €	- €	- €	33 925,95 €	128,81 €
B1.6	- €	- €	104,72 €	- €	- €	- €	- €	- €	- €	- €	- €	1 702,50 €	- €	- €
B1.7	- €	- €	- €	- €	- €	- €	- €	- €	643,60 €	- €	- €	- €	- €	247 514,46 €
B1.8	1 008,46 €	56,25 €	671,50 €	- €	41 764,99 €	5 231,60 €	1 025,84 €	8 546,83 €	24 548,93 €	2 421,49 €	- €	6 341,12 €	940,84 €	80 416,72 €
Total B1	3 911,98 €	2 183,04 €	18 851,22 €	370,53 €	49 840,15 €	8 043,96 €	1 226,84 €	17 188,86 €	27 481,00 €	52 736,73 €	14 488,00 €	16 928,62 €	42 204,76 €	576 248,57 €
B2														
B2.1	13 180,01 €	2 100,00 €	- €	8 517,21 €	- €	- €	- €	- €	- €	- €	- €	- €	1 672,56 €	- €
B2.2	- €	- €	- €	3 424,72 €	- €	- €	128 746,26 €	82 060,81 €	- €	- €	- €	- €	11 701,00 €	6 118,24 €
B2.3	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
B2.4	- €	- €	- €	- €	- €	- €	300,00 €	129,60 €	- €	- €	- €	- €	- €	300,09 €
B2.5	- €	902,00 €	275,00 €	779,50 €	14 206,92 €	6 519,90 €	35 348,63 €	51 556,52 €	2 783,80 €	9 537,49 €	7 015,97 €	56 057,49 €	120 420,60 €	177 922,94 €
B2.6	904,00 €	- €	9 221,76 €	- €	3 528,00 €	- €	3 582,00 €	2 932,52 €	72,50 €	334,30 €	725,00 €	725,00 €	693,75 €	3 376,00 €
B2.7	- €	- €	- €	- €	- €	19 642,75 €	37 337,45 €	35 174,25 €	175,45 €	- €	- €	- €	172,20 €	90,96 €
B2.8	- €	6 000,00 €	- €	- €	- €	11 700,00 €	782,00 €	6 370,40 €	- €	- €	- €	- €	- €	935,05 €
Total B2	14 084,01 €	9 002,00 €	9 496,76 €	12 721,43 €	17 734,92 €	37 862,65 €	206 096,34 €	178 224,10 €	3 031,75 €	9 537,49 €	7 350,27 €	56 782,49 €	134 660,11 €	188 743,28 €

Table 5 - B3, B4 and B5 costs to distribute - category 2.

Rubrica/Ano	Ano 2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
B3														
B3.1	13 239,03 €	- €	- €	5 616,53 €	12 639,79 €	- €	3 274,08 €	448,77 €	- €	- €	- €	52 971,49 €	- €	- €
B3.2	7 175,68 €	- €	8 896,60 €	- €	- €	727,65 €	6 741,09 €	35 489,86 €	20 885,16 €	1 101,24 €	- €	15,95 €	2 108,22 €	9 636,42 €
B3.3	452,00 €	32 623,50 €	9 221,76 €	- €	- €	23 867,20 €	44 754,00 €	49 996,25 €	1 472,40 €	5 450,94 €	167,15 €	126 967,24 €	99 059,76 €	1 988,98 €
B3.4	- €	- €	24 226,90 €	57 542,83 €	- €	- €	- €	- €	- €	574,60 €	- €	1 410,00 €	16 942,70 €	642,05 €
B3.5	- €	97 439,00 €	46 012,43 €	13 174,72 €	- €	11 700,00 €	48 826,50 €	2 587,50 €	- €	- €	- €	- €	- €	- €
B3.6	945,85 €	- €	- €	- €	- €	4 427,68 €	6 322,99 €	- €	- €	- €	- €	- €	- €	- €
B3.7	- €	- €	- €	- €	- €	225,52 €	2 465,54 €	- €	- €	- €	70,80 €	- €	- €	- €
B3.8	13 300,00 €	1 244,00 €	57,95 €	341,25 €	- €	15 975,00 €	- €	8 386,84 €	- €	250,00 €	54 145,69 €	6 136,00 €	- €	- €
Total B3	35 112,56 €	131 306,50 €	88 415,64 €	76 675,33 €	12 639,79 €	56 923,05 €	112 384,20 €	96 909,22 €	22 357,56 €	7 376,78 €	54 383,64 €	187 500,68 €	118 150,68 €	12 267,45 €
B4														
B4.1	5 152,85 €	- €	- €	1 825,61 €	- €	87,70 €	- €	71,02 €	4 235,36 €	- €	- €	- €	161,00 €	2 763,00 €
B4.2	- €	592,00 €	194 267,00 €	- €	- €	- €	- €	3 492,00 €	111,70 €	- €	- €	1 265,00 €	- €	- €
B4.3	- €	- €	- €	- €	- €	- €	- €	- €	- €	60,82 €	- €	160,16 €	- €	- €
B4.4	- €	- €	4 758,08 €	7 449,48 €	- €	7 043,85 €	- €	- €	- €	- €	- €	- €	- €	34 563,30 €
B4.5	- €	- €	- €	- €	- €	- €	- €	- €	5 957,17 €	- €	- €	- €	- €	- €
B4.6	- €	- €	807,00 €	- €	- €	928,77 €	- €	- €	665,98 €	- €	- €	- €	- €	- €
Total B4	5 152,85 €	592,00 €	199 832,08 €	9 275,09 €	- €	8 060,32 €	- €	3 563,02 €	10 970,21 €	60,82 €	- €	1 425,16 €	161,00 €	37 326,30 €
B5														
Total B5	- €	2 170,00 €	- €	- €	- €	- €	- €	- €	- €	- €	3 419,35 €	- €	- €	7 207,41 €

5.1. Simulation, compilation and time profile data

Initially the costs were distributed by the number of tunnels and they were added to the costs already established for each tunnel - subcategory 2.1.

However, this distribution does not resemble the reality, since it is known that the whole of the expenses taken is not directly proportional to the number of willing artwork. By comparing Figure 3 with Figure 4 denotes an increase in costs over the years, but many of them exhibit the same expenses - derived performed division - which does not allow to draw any kind of conclusion about the line of periodicity under review.

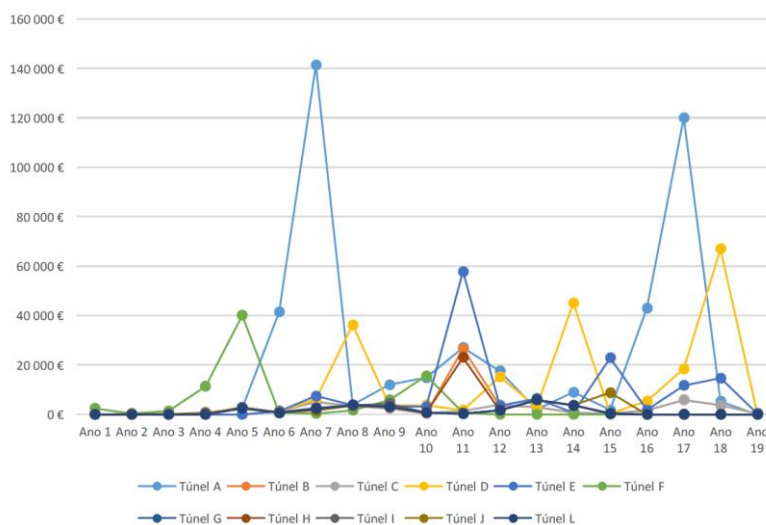


Figure 4 - B3 category costs caption.

To have another benchmark in view of the analyses that have been applied, comes Table 6 where can be found discriminated costs heading B1 (use) after the second simulation - where distribution costs were closest to reality. On the referred Table 6 are two types of parcels:

- Parcels composed by direct costs according to the tunnel and simulate costs
- Parcels composes by totally simulated costs



In Table 6 there is a majority blue spot, which is the whole of the lines had to be simulated. However, it also emphasizes the failure to register plots in the tunnels from A to L, where its value is a cost completely attributed to the tunnel in question. Attention in the comparison of Table 6 with Table 2.

Table 6 - B1 costs distribution per tunnel - simulation.

	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Ano 14	Ano 15	Ano 16	Ano 17	Ano 18	Ano 19
Túnel A	- €	- €	- €	- €	258,95 €	313,83 €	915,51 €	11,25 €	5 775,06 €	988,54 €	1 338,20 €	40 906,39 €	15 870,25 €	11 006,64 €	1 630,90 €	6 587,37 €	4 286,92 €	48 727,45 €	- €
Túnel B	- €	- €	- €	- €	- €	144,72 €	42,40 €	718,51 €	11,25 €	1 039,05 €	257,81 €	1 226,84 €	357,53 €	278,92 €	1 097,53 €	309,24 €	418,38 €	952,93 €	14 544,58 €
Túnel C	- €	- €	- €	- €	- €	144,72 €	46,07 €	718,51 €	11,25 €	1 128,05 €	263,04 €	1 226,84 €	388,47 €	297,13 €	1 190,04 €	334,23 €	347,44 €	1 015,97 €	15 230,03 €
Túnel D	- €	- €	- €	- €	- €	144,72 €	123,13 €	718,51 €	11,25 €	2 997,10 €	3 447,39 €	2 062,05 €	1 038,21 €	781,03 €	3 132,92 €	859,00 €	2 371,12 €	2 764,41 €	28 870,25 €
Túnel E	- €	- €	- €	- €	- €	144,72 €	157,58 €	797,55 €	11,25 €	3 832,73 €	54 970,62 €	5 414,16 €	2 882,77 €	980,49 €	4 375,38 €	1 093,63 €	3 328,09 €	3 445,76 €	34 425,90 €
Túnel F	11,25 €	6 883,52 €	601,30 €	1 226,84 €	2 389,25 €	1 707,57 €	10 244,07 €	1 950,21 €	1 669,82 €	13 884,90 €	67 690,52 €	- €	- €	- €	- €	- €	- €	- €	- €
Túnel G	- €	144,72 €	19,77 €	718,51 €	11,25 €	490,20 €	225,56 €	1 476,84 €	251,58 €	166,63 €	527,00 €	155,14 €	300,86 €	9 232,01 €	11 892,23 €	- €	- €	- €	- €
Túnel H	- €	144,72 €	14,45 €	718,51 €	11,25 €	369,88 €	217,91 €	1 226,84 €	183,76 €	140,03 €	391,82 €	118,62 €	273,01 €	6 820,49 €	10 632,79 €	- €	- €	- €	- €
Túnel I	- €	144,72 €	41,38 €	718,51 €	11,25 €	1 014,33 €	256,36 €	1 226,84 €	373,05 €	273,86 €	1 071,83 €	302,29 €	413,09 €	19 155,82 €	17 001,62 €	- €	- €	- €	- €
Túnel J	- €	144,72 €	43,42 €	718,51 €	11,25 €	1 063,77 €	259,27 €	1 226,84 €	390,24 €	283,98 €	1 123,22 €	316,18 €	423,67 €	20 040,08 €	17 478,66 €	- €	- €	- €	- €
Túnel L	- €	144,72 €	30,16 €	718,51 €	11,25 €	742,38 €	240,38 €	1 226,84 €	254,40 €	218,23 €	972,33 €	225,94 €	354,86 €	14 033,45 €	14 355,92 €	- €	- €	- €	- €

In the second simulation generated the graphic of Figure 5. Here can already be denoted a more unequal distribution of values associated with each tunnel. As it had been previously analysed, the maximum values associated with the tunnel A remain and can also noted some regularity in tunnel D.

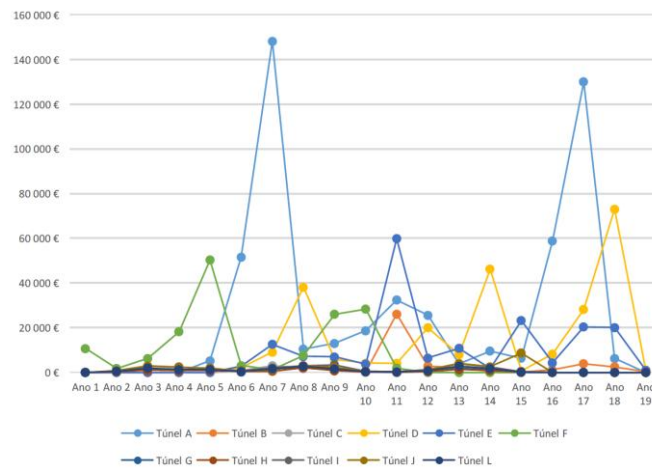


Figure 5 - B3 category costs caption.

It was not carried out a more detailed analysis of the category B5 - remodelling, because it represents only 1% of all captured expenses.

Regarding to category B3, even after the second iteration is not possible to draw any conclusions about the frequency of repair work because the development costs of stroke is not regular.

5.2. Analysis of the estimative

With all the work done so far, we can conclude that there is the need to implement a full cost capture system. This, in the context of this work, relates to the unenforceable applicability of cost analysis life cycle, also leading to the lower area of needs that have been recurring in each tunnel, so that also can carry out an optimization of costs.

From Figure 6 it suggest that, with the exception of B3 and B5 categories, all other evidence a range of majority of category costs 2 meet the costs associated with the category 1: 56%, 58% and 57%, respectively B1, B2 and B4.

Thus, despite the simulations performed, and since the actual picture points to large percentages of uncertainty it is suggested that it is carried out by the extraction method described herein.

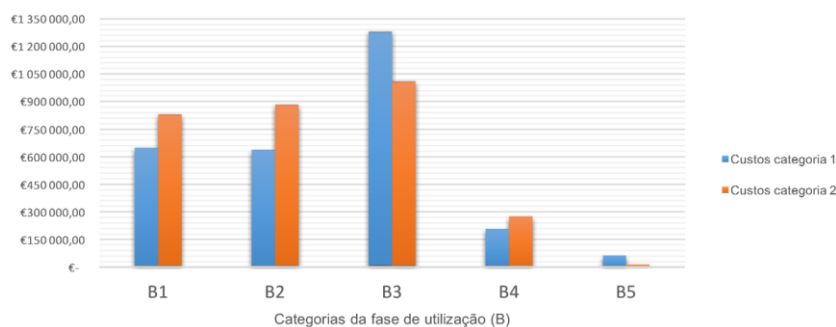


Figure 6 - Balance between the costs directly attributable to each tunnel and costs that have associated costs, from each item.

6. Conclusion

The case study, figured by Vialitoral dealership allowed to show that it is important to discrimination of all expenses taken over the years. Such illation comes with the fact that can not be drawn conclusions about the periodicities associated with each item, because the available data are incomplete. The absence of this information implies the impossibility of applying the step 8 of the methodology, this in sub chapter 3.2.

The capture of all costs leads to a domain of the needs of each work of art and the most frequent interventions of the same. With this, it would then be possible to establish, for example, an association between interventions and/or activities that evoke greater need for intervention and the type of construction of each tunnel.

Despite being estimated two scenarios to address gaps in data capture by the concessionaire - dividing the overall costs by the number of tunnels and division of general costs taking into account whether these were expenses related to the length of the tunnels or the number of art - it is suggested that the Vialitoral not give continuity to the same reason of the high percentage of costs without direct association with each tunnel (52%), it is believed that the simulations are far from reality observed over the year grant. However, it emphasizes the greater regularity noted where tunnels had a higher amount of data associated therewith.

Acknowledgements

I would like to thank all the people that have contributed to this dissertation. Firstly, my special thanks to my supervisors Prof. Nuno Almeida and Prof. Carlos Cruz.

In addition to that, I would also like to thank all my family and friends that have followed this academic path with me. A special thanks to my parents, Margarida and Martim.

Thank you all so much!

Bibliography

- Angeles, J. V. (24 de Junho de 2011). *The Development of a Life Cycle Cost Model for Railroad Tunnels*. Massachusetts, Cambridge, Estados Unidos da América: Massachusetts Institute of Technology.
- British Standards Institution. (2008). PAS 55-1: Asset Management. Part 1: Specification for the optimized management of physical assets. *ISO 55000 Standards for Asset Management - Introduction*. (B. S. Institution, Ed.)
- Concessões Rodoviárias da Madeira S.A. , V. (2012). Obtido em 29 de 05 de 2016, de <http://www.vialitoral.com>
- ISO 15686-5 Buildings and constructed assets - Service-life planning Part 5: Life-cycle costing. Genebra : International Organization for Standardization, 2008.
- ISO 55000 - Asset management - Overview, principles and terminology. Genebra : International Organization for Standardization, 2014.
- ISO 55001 - Asset Management - Management systems - Requirements. ISO 55001 - Asset Management - Management systems - Requirements. Genebra : International Organization for Standardization, 2012.
- Langdon, D. (2007b). Life cycle costing (LCC) as a contribution to sustainable construction Guidance on the use of LCC Methodology ant its application in public procurement - Final guidance. *Davis Langdon Management Consulting*.
- Management, T. I. (Fevereiro de 2012). *Asset Management - an anatomy. An Asset Management System*, 12. Reino Unido, Inglaterra.
- Thewes, M., Schwarz, J., Engelhardt, S., & Vogt, P. (s.d.). The economic optimization of tunnels by applying the life-cycle cost analysis. Alemanha.
- Vogt, P. (31 de Julho de 2012). *Modell für die Lebenszykluskostenanalyse von Straßentunneln unter Beachtung technischer und finanzieller Unsicherheiten*. Bochum, Alemanha: Fakultät für Bau- und Umweltingenieurwissenschaften.