A life cycle costing framework for effective maintenance management in a rolling stock environment

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Abstract

Having a life cycle framework in place to support the reliability, availability maintainability and safety of all mission critical assets has become an integral part of decision-making in the railway environment. In this paper, one such framework is investigated and developed for use in a railway rolling stock environment with emphasis on the cost of ownership and effective maintenance and replacement strategies that influence it. The framework consists of taking typical mission critical components, in this case a traction motor, together with their failure and maintenance history. All costs related to the operation and maintenance of these traction motors throughout their life-cycle were determined. The next step involved considering different scenarios under which the component can be used in terms of operations, maintenance and replacement considerations. In this study, the three scenarios are: 1. Keep running the component as-is with the current maintenance strategy; 2. Replace the component with a completely new one and develop a maintenance strategy to support it; 3. Operate with a standby or redundant component. The decision on which scenario to take is then based on the one with the most favourable net present value after performing life cycle costing over a specified period of time. A typical railway rolling stock maintenance organisation in South Africa is used to highlight the practical implications of such a framework and how the company can make informed decisions on the appropriate decisions to take. The overall conclusion of this study is that such a framework is useful and that it can be used as a basis for estimating LCC across a spectrum of critical assets found in the rolling stock environment.
Keywords: life cycle costing, maintenance strategies, railway rolling stock.

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1 Introduction

Maintenance has been described by Takata *et al.* [1] as an essential means for life cycle management. Having effective maintenance management techniques in place during the operational phase of the life cycle of a product or system can make the difference between profit and loss for an organisation. This becomes even more paramount as the condition of the product or system deteriorates with age. This paper acknowledges the important role that maintenance has on the life of a product or system and incorporates it into the traditional economic life cycle costing (LCC) approach.

The rest of the paper is organised as follows. The literature regarding LCC and the financial calculations that are involved is discussed in Section 2. LCC and its application in the railway environment is then discussed in Section 3. The relationship between LCC and maintenance is then investigated in Section 4. In Section 5, a framework that incorporates maintenance management principles and LCC is then developed and applied in a case study in the rolling stock environment. A discussion then follows in Section 6 and the paper is concluded in Section 7.

2 Life cycle costing

Life cycle costing (LCC) is a major requirement of life cycle management and it refers to the technique used to "provide increased visibility of the total costs of doing business" as defined by Blanchard [2]. Life cycle costs consider the cost estimates from inception to disposal of either equipment or projects as determined by an analytical study and estimate of total costs experienced during their life, this is according to Barringer and Weber [3]. This analytical study of life cycle costs is commonly referred to as "Life Cycle Cost Analysis" and has been used mostly in the evaluation of building design alternatives and other capital investment decisions. It takes a much longer term view than other economic analysis methods such as the Payback Method, which is more concerned about getting return on investment in the shortest possible time as observed by Fuller and Petersen [4].

Life cycle costs can sometimes be spoken of in terms of the Total Cost of Ownership which is a concept that involves identifying all future costs and reducing them to their present value by use of discounting techniques. These discounting techniques help to assess the value of products or product options before the investment is actually made, as explained by Kumar *et al.* [5]

2.1 Discounting and present value calculations in LCC

Life cycle cost analysis considers the costs that will be incurred sometime in the future and therefore it is necessary to discount all costs to a specific decision point or value. The decision point or present value in question is known as the Net Present Value (NPV) and is calculated as shown:

$$NPV = \sum_{n=0}^{T} C_m(1+x)^{-n} \quad (1)$$

where

- C_m is the nominal cash flow in the n-th year.
- n is the specific year in the life cycle costing period
- x is the discount rate.
- T is the length of time period under consideration.

Discount rates vary from organisation to organisation and are highly dependent on the desired cost profile. It is also worth noting that high discount rates favour options with low capital cost, short life and high recurring cost whilst low discount rates have the opposite effect, as discussed by Kumar *et al.* [5].

3 LCC in the railway environment

Practitioners in the railway environment have in recent years started to make use of the principles of life cycle costing in their capital investment decisions. In literature, there has been a fair distribution of LCC studies covering both railway infrastructure and railway rolling stock i.e. passenger service vehicles that operate on a railway. In these studies, LCC finds its use mainly in capital acquisition decision-making and maintenance strategies decision-making problems. A snapshot of some of the railway LCC literature available in the body of knowledge is presented in Table 1.

Table 1: Literature on railway LCC studies.

Author (s)	Year	Field	Objective of LCC
Zoeteman [7]	2003	Railway infrastructure	To create a decision support system for analysing the long term impacts of design and maintenance decisions in railway infrastructure.
Patra [8]	2007	Railway infrastructure	Optimisation of maintenance strategies for maintenance and renewal decisions.
Kumar *et al.* [5]	2004	Rolling stock	Prediction of cost of ownership of capital assets and estimation of design life of wagons.
Jun and Kim [6]	2007	Rolling stock	Estimation of life cycle costs on the brake disks and pads of commercial operating subway vehicles.
Puig *et al.* [9]	2013	Rolling stock	To provide a framework of maintenance decisions involving acquisitions of passenger service rolling stock.

4 Maintenance management and LCC

Having a well-structured maintenance programme in place can lead to achieving low LCC without increasing the acquisition cost (Jun and Kim [6]). The performance indicators for checking the desired objectives or targets during the operation and maintenance phase of a product or system can be given by taking RAMS into consideration. RAMS is an acronym meaning a combination of Reliability, Availability, Maintainability and Safety as defined by the European Standard EN 50126-1:1999 [10] with specific application to the railway environment. The standard further goes on to define it as “a characteristic of a system’s long term operation and is achieved by the application of established engineering concepts, methods, tools and techniques throughout the life cycle of the system”. A commonly used performance indicator in RAMS is the Mean Time between Failure (MTBF) which addresses the availability part of RAMS, as described by Patra [8]. Kim *et al*. [11] also explain that setting RAMS targets that are too high can make the purchase, operations and maintenance cost prohibitively high, but on the other hand, setting low RAMS targets will affect the service quality of the product or system. Any effective life cycle management system will be one that achieves the right balance of RAMS.

5 Application of maintenance/LCC framework

5.1 LCC framework

The framework that is going to be used in this research is based on the premise that in order to perform effective life cycle costing, the maintenance and operational costs have to be accurately identified and calculated. The objective of the framework is to determine which maintenance and operational conditions will result in the most ideal life cycle costs over a given period of time. The framework will be in the form of three alternatives or scenarios that have either capital investment or maintenance implications involved in the running of the traction motors. This framework uses concepts developed in a LCC tutorial by Barringer and Weber [12].

In order to test the applicability of such a framework, a case study in the railway rolling stock maintenance environment was chosen. The DC traction motors used on the standard “5M2A” motor coaches, as defined by the company in question, were considered. Each motor coach contains four such traction motors fitted onto individual axles which are in turn fitted onto two bogies. The maintenance department of the organisation currently practises a combination of routine maintenance and condition-based maintenance on all motor coaches. The former is done every 8 weeks during which the condition of mission-critical components such as the traction motors are also tested. If the condition of the traction motor is still good, the only work that is done on it is to renew the carbon brushes and replace the brush boxes. In the event that the condition of the traction motor has deteriorated, it will then have to go through stripping and replacing of worn-out or defective parts such as bearings and insulation. At the present moment, this work is mostly carried out by contractors hired by the organisation and this work is classified as “standard work”. The contractor may, upon further testing, determine that more work needs to be done and this is classified as “additional work”. This additional work includes tasks such as armature rewinding, fitting new shafts, refurbishing commutators etc. The decision to perform standard or additional work is also taken when there is an outright failure of the traction motor and it is brought into the workshop for investigation and repairs. Shown in Table 2 is a list of tasks carried out during standard work and additional work of the traction motor armature.

Table 2: Standard vs. additional work for 5M2A traction motor armature.

Standard work	Additional work
Strip, clean, mechanical checks, electrical tests, assess	Renew PTFE ring
✓ Megger at 5000 V	Supply and fit new shaft
✓ Hi pot at 4500 V AC for 15 sec	Bore out old shaft
✓ Megger test at 5000 V	Repairs on shaft: pinion end and commutator end journal, shaft threads, shrink ring journal
✓ Surge comparison test at 500 V bar to bar (250 V)	Replace labyrinth seals – per set
✓ Commutator bar to bar test	Replace resi-binder – commutator and pinion ends
✓ Check polarity	Commutator:-
Clean and paint armature	Repair commutator: front V-ring only
Skim, undercut and bevel commutator	Repair commutator: old steel parts, new copper pack, new V-rings
Fine proof commutator	Repair commutator: refurbish steel parts, new copper pack, new V-rings
Balance armature	Supply and fit complete new commutator
Renew pinion key	Replace core
Final test armature (tests as per Item 1)	Renew pinion
	Rewind armature complete

5.1 Framework calculations and assumptions

Table 3 shows the base cost figures that were used in the calculations that follow. These cost figures were obtained from interviews with systems engineers dealing directly with the maintenance and day-to-day operations of the 5M2A traction motors. The "Lost Gross Margin" figures for delays and cancellations are based on a study conducted by Conradie [13] which investigates the cost implications of train failures. All figures are in the local currency of South African Rands (R).

The following assumptions were made for the purpose of simplifying the calculations and illustrating the concepts involved in the model:

- Mean Time between Failure (MTBF) of the different components on the traction motor is uniform. The MTBF values used in the calculations are historical average values obtained from the organisation's CMMS database.
- Time to perform standard maintenance work on different components on the traction motor is uniform.

- Time to perform additional repair work on different components on the traction motor is uniform.
- The failure of one traction motor results in the whole motor coach being forced to stop operating.

Table 3: Maintenance and operational baseline costs.

Cost breakdown	Carcass	Armature	Field coil	Interpole coil
Maintenance crew/hr	R 673,00	R 673,00	R 673,00	R 673,00
Part replacement	R 80 192,00	R146 715,00	R 69 017,00	R 63 928,00
Part renewal	R 16 297,00	R 6 326,00	R 21 444,00	R 16 481,00
Lost gross margin (cancellation)	R 56 175,00	R 56 175,00	R 56 175,00	R 56 175,00
Lost gross margin (delay)	R 10 000,00	R 10 000,00	R 10 000,00	R 10 000,00
Logistics cost/incident	R 500,00	R 500,00	R 500,00	R 500,00
Stripping and testing	R 5 171,00	R 5 171,00	R 5 171,00	R 5 171,00
Assembling	R 6 094,00	R 6 094,00	R 6 094,00	R 6 094,00

5.2 The three alternatives

5.2.1 Alternative 1: do nothing

The first alternative considered is to keep running the traction motors as-is with the current expected failure rate and maintenance regime as described in the previous section. The cost implications of this scenario is shown in Table 4.

5.2.2 Alternative 2: replace traction motor

Alternative 2 involves replacing the current traction motor with a new one. It is expected that the performance of the new traction motor in terms of MTBF, will significantly improve from the current one which has been in existence for over 50 years. The percentage improvement will be around 60% as estimated by the systems engineer interviewed. Shown in Table 5 is the expected maintenance and operational costs associated with this alternative. The requirements for preventative maintenance will not be as great by virtue of the components being in a newer state. There will however be capital costs involved in acquiring the new motors together with training and installation costs.

5.2.3 Alternative 3: redundant traction motor

Alternative 3 involves having a standby/redundant traction motor in place so that as soon as the current operational one ceases, the standby motor kicks in. The current design of the 5M2A motor coach allows for the “cutting out” of one of the motors and allowing it to run with three instead of four motors. The MTBF will virtually remain the same for the new one although if the motor coach remains in this ‘cut-out’ stage for many trips, the likelihood of failure will significantly increase. The Lost Gross Margin due to cancellations will be eliminated although there will be some delays experienced as a technician would have to be called out to the site to effect the cutting out of the failed traction motor. The costs associated with this option are shown in Table 6.

Table 4: Alternative 1 – do nothing.

Cost element	MTBF, years	Failures per or activity, per year	Elapsed repair or activity, hours	Cost for labour, exp, and mat, ZAR	Part cost, ZAR	Logistics cost, ZAR per incident	Lost gross margin, ZAR	Total cost, ZAR/yr
Electricity								R 0,00
Testing and stripping								R 12 065,67
Carcass –standard work	3	0,33	120	R 26 920,00	R 5 432,33	R 0,00	R 22 058,33	R 54 410,67
Carcass – additional work	4	0,25	200	R 33 650,00	R 20 048,00	R 125,00	R 16 543,75	R 70 366,75
Armature –standard work	3	0,33	120	R 26 920,00	R 2 108,67	R 0,00	R 22 058,33	R 51 087,00
Armature – additional work	4	0,25	200	R 33 650,00	R 36 678,75	R 125,00	R 16 543,75	R 86 997,50
Field coil renewal	3	0,33	120	R 26 920,00	R 7 148,00	R 0,00	R 22 058,33	R 56 126,33
Field coil repairs	4	0,25	200	R 33 650,00	R 17 254,25	R 125,00	R 16 543,75	R 67 573,00
Interpole coil renewal	3	0,33	120	R 26 920,00	R 5 493,67	R 0,00	R 22 058,33	R 54 472,00
Interpole coil repairs	4	0,25	200	R 33 650,00	R 15 982,00	R 125,00	R 16 543,75	R 66 300,75
Assembling								R 14 219,33
PM maintenance visits			52	R 34 996,00				R 34 996,00
Training costs								R 0,00
TOTAL		2,33	1332	R 277 276,00	R 110 145,67	R 500,00	R 154 408,33	R 568 615,00

Table 5: Alternative 2 – replace traction motor.

Cost element	MTBF, years	Failures per or activity, per year	Elapsed repair or activity, hours	Cost for labour, exp, and mat, ZAR	Part cost, ZAR	Logistics cost, ZAR per incident	Lost gross margin, ZAR	Total cost, ZAR/yr
Electricity								R 0,00
Testing and stripping								R 8 273,60
Carcass –standard work	5	0,2	120	R 16 152,00	R 3 259,40	R 0,00	R 13 235,00	R 32 646,40
Carcass – additional work	6	0,167	200	R 22 433,33	R 13 365,33	R 83,33	R 11 029,17	R 46 911,17
Armature –standard work	5	0,2	120	R 16 152,00	R 1 265,20	R 0,00	R 13 235,00	R 30 652,20
Armature – additional work	6	0,167	200	R 22 433,33	R 24 452,50	R 83,33	R 11 029,17	R 57 998,33
Field coil renewal	5	0,2	120	R 16 152,00	R 4 288,80	R 0,00	R 13 235,00	R 33 675,80
Field coil repairs	6	0,167	200	R 22 433,33	R 11 502,83	R 83,33	R 11 029,17	R 45 048,67
Interpole coil renewal	5	0,333	120	R 26 920,00	R 5 493,67	R 0,00	R 22 058,33	R 54 472,00
Interpole coil repairs	6	0,167	200	R 22 433,33	R 10 654,67	R 83,33	R 11 029,17	R 44 200,50
Assembling								R 9 750,40
Maintenance PM visits			52	R 17 498,00				R 17 498,00
Training costs				R 72 000,00				R 72 000,00
TOTAL		1,6	1332	R 254 607,33	R 74 282,40	R 333,33	R 105 880,00	R 453 127,07

Table 6: Alternative 3 – add redundant traction motor.

Cost element	MTBF, years	Failures per or activity, per year	Elapsed repair or activity, hours	Cost for labour, exp, and mat, ZAR	Part cost, ZAR	Logistics cost, ZAR per incident	Lost gross margin, ZAR	Total cost, ZAR/yr
Electricity								R 0,00
Testing and stripping								R 12 065,67
Carcass –standard work	3	0,33	120	R 26 920,00	R 5 432,33	R 0,00	R 0,00	R 32 352,33
Carcass – additional work	4	0,25	200	R 33 650,00	R 20 048,00	R 125,00	R 16 543,75	R 70 366,75
Armature –standard work	3	0,33	120	R 26 920,00	R 2 108,67	R 0,00	R 0,00	R 29 028,67
Armature – additional work	4	0,25	200	R 33 650,00	R 36 678,75	R 125,00	R 16 543,75	R 86 997,50
Field coil renewal	3	0,33	120	R 26 920,00	R 7 148,00	R 0,00	R 0,00	R 34 068,00
Field coil repairs	4	0,25	200	R 33 650,00	R 17 254,25	R 125,00	R 16 543,75	R 67 573,00
Interpole coil renewal	3	0,333	120	R 26 920,00	R 5 493,67	R 0,00	R 0,00	R 32 413,67
Interpole coil repairs	4	0,25	200	R 33 650,00	R 15 982,00	R 125,00	R 16 543,75	R 66 300,75
Assembling								R 14 219,33
Maintenance PM visits			52	R 34 996,00				R 34 996,00
Training costs								R 0,00
TOTAL		2,33		R 277 276,00	R 110 145,67	R 500,00	R 66 175,00	R 480 381,67

5.3 NPV calculations

Given the following as input into the LCC cost profile:

- A 10 year project lifespan;
- A 12% discount rate (source: PRASA [14];
- Capital Equipment Cost, on the applicable scenarios;
- Annual recurring costs in terms of the maintenance and operational calculations given in the three scenarios discussed.

The Net Present Values of the three alternative scenarios was determined and are shown in Figure 1 in the form of a graphical comparison. Left out of these NPV calculations were the disposal and depreciation costs which could not be immediately determined but will however have little influence on the cost comparisons carried out in this study.

6 Discussion

The negative NPV values obtained in the previous section can be attributed to the absence of expected revenues from the operation of fully functional motor coaches. The absence of these costs was due to insufficient data being available at the time of performing the calculations. Therefore, from the results of the NPV calculations given in section 5.3, it is apparent that Alternative 2 – Replace current traction motor, would be the most desirable alternative as it has the least negative NPV value. There is a difference of approximately R30 000 between Alternative 1 and 3 and about R115 000 between Alternative 2 and Alternative 3, which is the next best option. The worst option is Alternative 1 – Do nothing and keep running with the current traction motor.

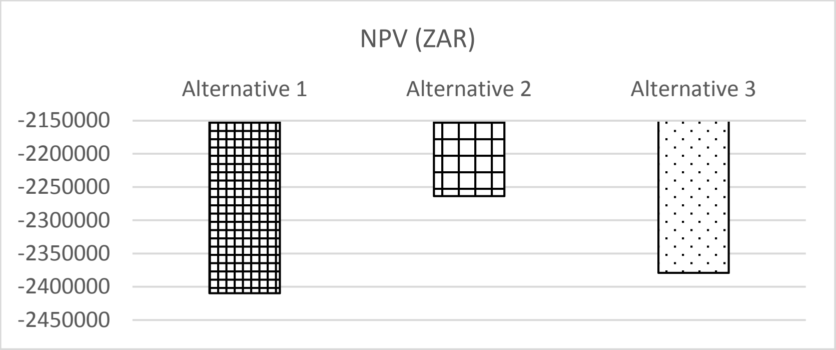

Figure 1: Comparison of NPV values across the three alternative scenarios.

One possible improvement to this study would have been the use of stochastic models and simulations in order to obtain more accurate estimations of failure costs as suggested by Seif and Rabbani [15]. Another possible improvement would be to determine the remaining life in the current batch of 5M2A traction motors by using lifetime prediction models such as the one developed by Herrmann *et al.* [16]. Knowing the remaining life of the component will help in developing a more accurate timeline for the LCC cost profile.

7 Conclusion

The focus of this paper has been in developing and testing a Life Cycle Costing framework for mission-critical assets, such as railway rolling stock traction motors, through the use of their maintenance, operations and failure history. The end result being that the decision-maker can make informed financial decisions about which strategy to follow in order to obtain the best performance of their components or systems in terms of reliability, availability, maintainability and safety (RAMS).

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