Comparative Analysis of Methodologies for Calculating the Economic Life of Construction Equipment

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Abstract The most profitable period of owning and operating a machine is during its economic life. To find the "sweet spot", i.e. the time in the life cycle of the machine where owning and operating costs reach the minimum point, is a complicated task. It is evident that, in order to conclude with the best decision of either to keep or replace piece of equipment, repair-related cost information is indispensable, as it reflects machine's DNA. Construction companies are currently facing an imbalance between the huge amount of owning and operating and maintenance (O&M) data that they have and the lack of solid organizational structures in order to make the best use of this knowledge. Thus, there is a dynamic that remains unused. This research highlights the advantages and disadvantages of methodologies for calculating the economic life of construction equipment and proposes a conceptual model that determines the replacement period using owning and O&M costs.

Keywords Construction equipment · Economic life · Optimization methods · Replacement · Residual value

1 Introduction

In the construction industry, several attempts have been implemented to improve construction equipment's productivity. The main objective of these attempts has been to improve profitability (Edwards et al. 2003). Such initiatives are inextricably linked to the use of construction equipment, without which the efficient and cost-effective

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delivery of construction projects could not be realized. However, the construction equipment should be properly maintained so as to minimize incidences of breakdowns. Breakdown may cause important losses in machine utilization (Edwards et al. 2005). Apart from this, the performance (i.e. productivity) of construction equipment is gradually decreasing over time, while new equipment with comparatively higher performance is emerging (Naskoudakis and Petroutsatou 2016). The cost to operate and maintain construction equipment outweighs the profit of its use as time passes, and there is a point where replacing it is the only solution. The replacement decision is not an easy task to perform as it should take into account several parameters affecting the investment in the machinery. The factors that affect the economic life of equipment are discussed in the literature review. The purpose of this study is to present a methodology of replacing construction equipment based on factors identified in the literature and incorporating them in the proposed conceptual model.

According to Vorster (2009), for every machine, there is an economic ownership period or "sweet spot" when the sum of hourly and operating costs is minimized, due to the fact that the machine has worked long enough to reduce owning costs, but not long enough to experience unnecessary and usually high repair costs. Hourly cost calculations are very sensitive to estimates. Additionally, the age of a machine, as well its utilization, are key estimates in the owning and operating cost calculation, which in turn determines any proper decision making for equipment replacement.

2 Theory and Hypotheses

Gillespie and Hyde (2004), in their final report for the Virginia Department of Transportation, used historical records from a loader with a backhoe, in order to identify the best minimization method of the life cycle cost, as the key to getting the most out of the equipment budget. They applied their methodology on the basis that the optimal equipment replacement strategy is to keep and operate a piece of equipment as long as the expected marginal cost of operating it is less than or equal to the expected average total cost of a new piece over its lifetime. Their research indicated that an analysis using fuel cost, as the measure of service, produces findings that are interesting and plausible, but not very precise. To confirm the findings, they proposed further analysis using hours of service. This requires a more in-depth study of the recorded hours-of-use data and the downtime data, suggesting that these data should include the number of hours of availability (or, conversely, the number of hours of downtime), the dates it goes out of service for repairs and the dates it returns to service, and finally its residual value.

Nunnally (2006) noted that in order to estimate any equipment's hourly production, it is necessary to estimate many factors, such as fuel consumption and tire life. The best basis for estimating such factors is the use of historical data and if such data are not available, consulting the equipment manufacturer for recommendations could be another option. They also pointed out that replacement decisions require a precise investment amount for a particular year.

Vorster (2009) concentrated on the estimation of the residual market value (RMV) of equipment, by taking mostly into account the equipment's manufacturing year and the total working hours. He overlooked the O&M characteristics of the future equipment, which will replace the current.

Fan and Jin (2011) noticed that for a specific type of a dump truck there is a discrepancy between the manufacturer's recommended life and the actual life in a contractor's fleet. So, they published their study on the factors affecting the economic life of heavy construction equipment and how the combination of the influencing factors reduce or increase the equipment life span. Their study described seven affecting factors: (i) age of the equipment, (ii) manufacturer, (iii) operating division of the contractor, (iv) class of the equipment, (v) annual preventive maintenance cost, (vi) annual traveling distance and (vii) annual accumulated fuel cost. Their results proved that the annual accumulated fuel cost is the most important impact factor.

Gransberg (2015) in his final report for the Minnesota Department of Transportation, also argued that the fuel price is probably the most critical input when determining the economic life of the equipment, as a significant cost item of the O&M costs. He reached this conclusion, by comparing a deterministic and a stochastic model of a dump truck and proved that allowing fuel process to range probabilistically in the analysis provides a mean to quantify the certainty of the equipment replacement decision.

All of them agreed that equipment's historical data are necessary to form a predictive model and that there are critical factors that affect equipment's economic life, with fuel cost being the most crucial. Their focus is on estimating the Total Replacement Cost (TRC) or the Optimum Replacement Period (ORP) of the equipment that is in use. The company's profit originates from the equipment's productivity and from its residual value. A common characteristic of all these research approaches is that they did not consider any future investment on new equipment. In reality, the old equipment will be replaced by a new one, so it is required to obtain its O&M data and its RMV. This study focuses on this need.

Xirokostas (1999) highlighted this dynamic. His approach was based on the operating and maintenance characteristics of the equipment that will replace the current and how new equipment's RMV will evolve. So, for accomplishing his calculations he used values such as Estimated Residual Market Value (ERMV), O&M costs and acquisition cost for the new equipment; he sourced data for new equipment from original manufacturers or from the market. In order to estimate the minimum TRC and consequently the optimum replacement period for the new equipment, there are seven different methods of replacement (Table 1).

3 Methodology

This research introduces a conceptual model of Xirokostas's approach and applies a 2-step sensitivity analysis as described below.

Table 1 Equipment's replacement methods (Xirokostas 1999)

	Methods of replacement
1	Equipment of the same type
2	Improved equipment
3	Equipment, which follows a linear technological improvement
4	Equipment, which follows a continuous technological improvement of constant rate
5	Equipment, which follows a rapid linear technological improvement
6	Equipment, which follows a rapid, but continuous technological improvement of constant rate
7	Equipment, which follows a general form of continuous technological improvement

Original Equipment Manufacturers (OEMs) agree that machinery has a technological evolution over time at a constant rate. Furthermore, the decrease in residual value and the increase in O&M costs follow a rate according to the use of the machinery and its age. The impact factors taken into account are presented in Table 2.

The optimization process defines the optimum replacement time when the TRC (C_n) is minimized. C_n is given by the following mathematical equation:

$$C_n = C_n(s) + C_n(u) \tag{1}$$

where

$$C_n(s) = \frac{1}{1-(a\rho_s)^n} \cdot (I - a^n \cdot S_n)$$

for every $\rho_s = 1 - m_s$

Table 2 Construction equipment's impact factors

	Impact factor	Description
1	Interest rate (i)	The cost of capital invested in equipment
2	RMV the 1st year (S_1)	The residual market value of the new equipment, the first year of operation
3	RMV decrease per year	The decrease in equipment's residual market value each year
4	RMV decrease rate (m_s)	The % rate that the equipment's residual market value decreases each year
5	O&M cost the 1st year (u_1)	The operation and maintenance cost the 1st year
6	O&M cost increase rate (m_u)	The % rate that the equipment's O&M cost increases each year

and

$$C_n(u) = \frac{1}{1 - (a\rho_u)^n} \cdot \sum_{j=1}^{n} a^j \cdot u_j$$

for every $\rho_u = 1 - m_u$
where

$C_n(s)$	cost due to RMV decrease
$C_n(u)$	cost due to O&M
n	time period in years of use of the machine
i	interest rate
$\alpha = \frac{1}{1+i}$	present worth compound amount factor
I	cost of purchasing the new machine
S_n	RMV of the new machine for each year
u_j	O&M costs for each year of operation
m_s	decrease rate of RMV
m_u	decrease rate of O&M costs.

The RMV data are provided by the OEMs and the data on O&M costs are provided by the company's historical data log of the same or similar type of equipment. As it could be realized, both the two clauses of the mathematical equation are dependent on *i,* the interest rate that a company wants to apply, in order to calculate the cost of capital invested on a machine. This is not a simple issue to answer, mostly because of the capital-intensive nature of equipment operations. Usually, this information is dictated by the financial department of the company, taking into account a number of factors, including: (i) the availability and expected return from alternate investment opportunities, (ii) the availability and cost of capital of the company, and (iii) the relative risk involved in the investment, on the basis that equipment is a depreciating asset working in a volatile and competitive environment. Equation (1) is applied to an earthmoving dozer. The cost estimations of the dozer, combined with the company's data are presented in Table 3. Figure 1 shows the formulas applied on an excel sheet and the results generated.

The solution to the aforementioned deterministic approach revealed that the optimum replacement period for the new equipment is after 10 years of owning the equipment. By that time TRC reaches its minimum, which is 718.300€. Another indicator of the optimal replacement time is the year in which the equipment's RMV is still greater than its O&M cost. Currently, the solution showed that this condition occurs again approximately after 10 years of operation. The table also shows that if the company decides to keep the equipment longer, after 14 years of operation, the equipment will be totally depreciated. Another significant point (decisive point) is when RMV and O&M cost coincide (Fig. 2).

Table 3 RMV and O&M cost estimations

Parameters		Value
Purchase price	I	240.000€
RMV the 1st year (manufacturer)	S_1	115.000€
Annual RMV decrease (manufacturer)		9.500€
RMV decrease rate (manufacturer)	m_s	3%
O&M cost for the 1st year (company)	u_j	8.000€
O&M cost increase for the next 5 years (company)		1.500€
O&M cost increase after 6 years until the end of its life (company)		2.500€
O&M increase rate (company)	m_u	5%
Interest rate (company)	i	3%

n/j	$(\alpha\rho_u)^n$	$1-(\alpha\rho_u)^n$	$(\alpha\rho_s)^n$	$1-(\alpha\rho_s)^n$	a^n	S_n	$a^n S_n$	u_j	$a^j u_j$	$\sum_{j=1}^{n} a^j u_j$	$I-a^n S_n$	$\frac{(12)}{(5)}$	$\frac{(11)}{(3)}$	$C_n=(13)+(14)$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	0,922	0,078	0,942	0,058	0,971	115	111,65	8	7,77	7,77	128,35	2.203,333	100,00	2.303,33
2	0,851	0,149	0,887	0,113	0,943	105,5	99,44	9,5	8,95	16,72	140,56	1.242,633	111,99	1.354,63
3	0,785	0,215	0,835	0,165	0,915	96	87,85	11	10,07	26,79	152,15	923,359	124,38	1.047,74
4	0,724	0,276	0,787	0,213	0,888	86,5	76,85	12,5	11,11	37,89	163,15	764,404	137,14	901,54
5	0,667	0,333	0,741	0,259	0,863	77	66,42	14	12,08	49,97	173,58	669,547	150,27	819,82
6	0,616	0,384	0,698	0,302	0,837	67,5	56,53	15,5	12,98	62,95	183,47	606,714	163,78	770,49
7	0,568	0,432	0,657	0,343	0,813	58	47,16	18	14,64	77,59	192,84	562,159	179,52	741,68
8	0,524	0,476	0,619	0,381	0,789	48,5	38,29	20,5	16,18	93,77	201,71	529,008	196,88	725,88
9	0,483	0,517	0,583	0,417	0,766	39	29,89	23	17,63	111,40	210,11	503,442	215,48	718,93
10	0,446	0,554	0,549	0,451	0,744	29,5	21,95	25,5	18,97	130,37	218,05	483,172	235,12	718,30
11	0,411	0,589	0,517	0,483	0,722	20	14,45	28	20,23	150,60	225,55	466,738	255,65	722,39
12	0,379	0,621	0,487	0,513	0,701	10,5	7,36	30,5	21,39	171,99	232,64	453,169	276,96	730,13
13	0,350	0,650	0,458	0,542	0,681	1	0,68	33	22,47	194,46	239,32	441,792	298,97	740,76
14	0,322	0,678	0,432	0,568	0,661	-8,5	-5,62	35,5	23,47	217,93	245,62	432,126	321,63	753,76
15	0,297	0,703	0,406	0,594	0,642	-18	-11,55	38	24,39	242,32	251,55	423,819	344,88	768,70

i = 0,03

Fig. 1 Calculation table

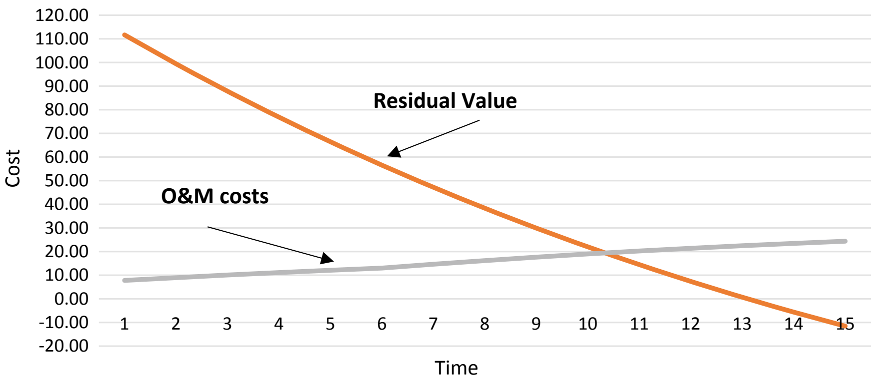

Fig. 2 Residual value and O&M costs

4 Sensitivity Analysis

The sensitivity analysis tests the behavior of minimum TRC, in changes of O&M costs for the 1st year, RMV the 1st year, m_u, and m_s with the interest rate fixed. The value of these factors is changing by 10%. Figure 3 depicts the tornado diagram for the above factors, expressed in percentage of increase or decrease of TRC.

The aim of the analysis is generally to identify if RMV is more sensitive than the equipment's O&M to TRC. Table 4 presents the analysis's results, which show that TRC is more sensitive to RMV than O&M variations.

According to Vorster (2009), the RMV of a machine when sold at any point in its life is an unknown that depends on many factors. Make, model, type and age when sold are the underlying determinants while other factors such as the condition of the machine and the amount of life left on major wear items affect individual transactions.

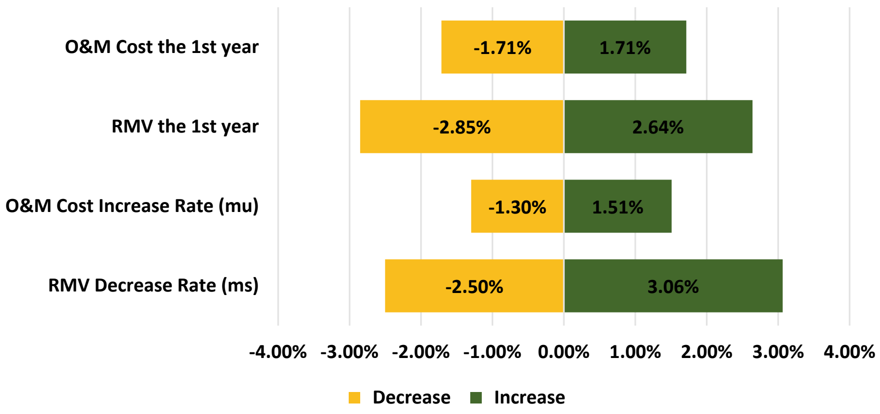

Fig. 3 % variations of TRC

Table 4 Sensitivity analysis results

Factors	10% factor decrease		10% factor increase	
	% of TRC variation (%)	TRC variation (€)	% of TRC variation (%)	TRC variation (€)
RMV decrease rate (m_s)	−2.50	−17.979	+3.06	+21.998
O&M cost increase rate (m_u)	−1.30	−9.326	+1.51	+10.832
RMV the 1st year	−2.85	−20.488	+2.64	+18.961
O&M cost the 1st year	−1.71	−12.307	+1.71	+12.307

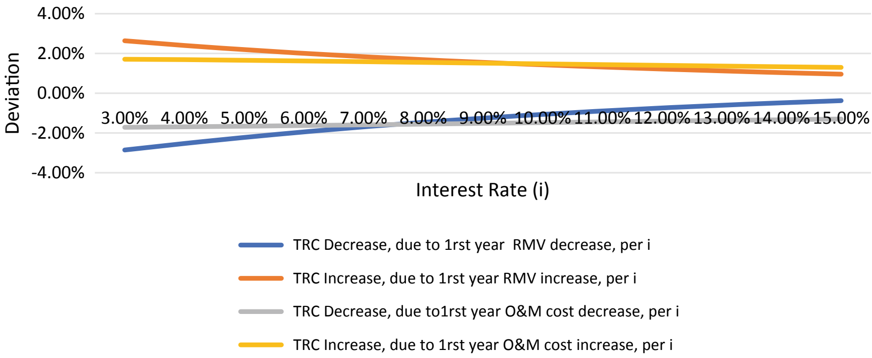

Fig. 4 Trend lines of TRC sensitivity in RMV and O&M cost for the 1st year, per interest rate (i)

The state of the economy, the amount of work in the area and the machine's ability to meet current environmental standards also have a major impact. This research exploits the equipment's historical data and OEMs' estimations for RMV and O&M cost.

The prevailing determinants of RMV value are the market itself. On the other hand, O&M costs can more easily be estimated if the company keeps good track records for its equipment (Peurifoy et al. 2011).

The next step in the sensitivity analysis is to investigate the changes in TRC to interest rate variations. The range of the interest rate is selected to be from 3 until 15%. The variation of factors in Table 4 remains the same at 10%.

Figure 4 shows the trend lines. From the figure, it is observed that the trend line for TRC decrease, due to 1st year's RMV decrease intersects the trend line for TRC decrease, due to 1st year's O&M cost decrease at 7.5% of *i*, above which TRC is more sensitive to RMV. The trend lines that present the increase variations intersect at 9.5%. So, the values of *i* between 7.5 and 9.5% make TRC more sensitive to RMV variations. This could be of importance for a company when it wants to minimize the risk involved in RMV estimations. The same happens when m_s and m_u are analyzed. Figure 5 depicts the corresponding trends. The values of *i* range between 4 and 7.5%, presenting an "interest rate window", in which the company should invest in the specific equipment.

5 Discussion and Implications

The investment in machinery is an important capital asset for every construction company. Through a comparative analysis of the methods that calculate the period after which the machinery should be sold, this study proposes a conceptual model that estimates the time of replacement. The 2-step sensitivity analysis, that is performed,

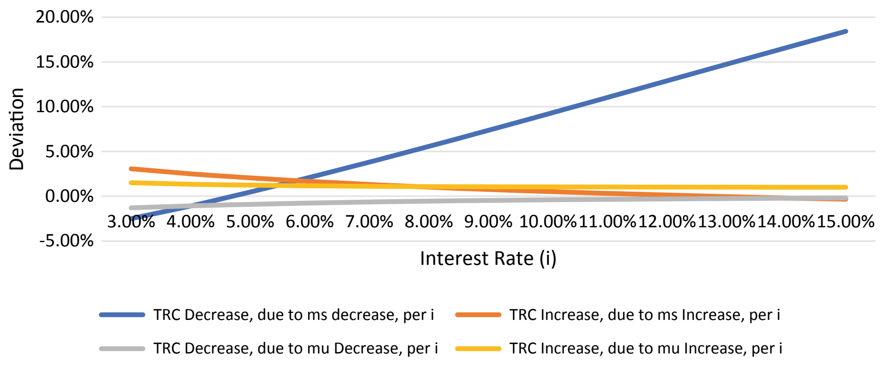

Fig. 5 Trend lines of TRC sensitivity in RMV and O&M change rates, per interest rate (i)

highlights some interest areas for further investigation of the factors that impact the economic life of the machinery.

These factors are RMV and O&M costs that determine the replacement period. TRC proved to be more sensitive to RMV. The risk is highly interrelated to the estimations that are made concerning the values of RMV. The results determined ranges of values of *i* for minimizing the risk in estimations of RMV. The values of *i* between 7.5 and 9.5% make TRC more sensitive to RMV variations. The values of *i* range between 4 and 7.5%, presenting an "interest rate window", in which the company should invest with the minimum risk undertaken in its estimations.

6 Conclusion and Further Research

This research introduces a conceptual model for the optimization of construction equipment's economic life and applies a 2-step sensitivity analysis. According to the methodology, economic life coincides with the optimum period for equipment's replacement.

There are several factors affecting the equipment's economic life that have been recorded in literature. For the proposed model, the factors taken into account are the interest rate of money invested in the machinery, the residual value and the O&M costs. TRC is more sensitive to RMV than O&M variations.

Furthermore, a 2-step sensitivity analysis is performed in order to investigate the behavior of minimum TRC, in changes of O&M costs for the 1st year, RMV the 1st year, m_u, and m_s keeping the interest rate fixed. Then, the ranges of *i* are determined where TRC are more sensitive to RMV. Out of these intervals, the owner could minimize the risk of not estimating accurately the RMV.

The practical limitation of this study is that the proposed methodology should be applied to a number of machines of the same type to reach more concrete results.

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