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Economic Life Cycle *versus* Lifespan – A Case Study of an Urban Bus Fleet

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Abstract: The maintenance policy and the quality of service throughout the bus's life cycle can be measured through their costs along time that, when evaluated using Lifespan or Economic Life Cycle methods, allow to determine the renewal or the replacement time. The paper discusses these two models, using real data from an urban bus fleet company. The maths that supports the models are presented. They are considered the functioning and maintenance costs, and also the apparent rate. The Life Cycle Cost of an urban transport bus is strongly dependent on the policy and quality of its maintenance, from which it depends on its reliability and availability. The final result is reflected on its Life Cycle Cost, that can be evaluated through the Lifespan or the Economic Life Cycle methods. Other aspects that can be considered are the fuel costs and the type of terrain, because they are intrinsically interrelated and have a strong effect on costs, namely because they imply strong variation in the bus's consumption and in their maintenance costs. As the company considered in the case study has a poor maintenance policy, it makes the analysis challenging, making difficult to compare the economic life cycle with the lifespan method in this situation. However, the results and conclusions that are taken from them are obvious, what demonstrates the models' utility and robustness.

Keywords: Equipment Removal, LCC, Lifespan, Assignment, Condition Monitoring, Scheduled Maintenance

1. Introduction

In the passenger transport sector, the determination of the most rational time for bus replacement is related to the efficient use of the buses and the company's global costs. The company needs to know the most adequate time to renewal or replace a bus to optimize its total costs, simultaneously guaranteeing the availability and quality of service and the customer satisfaction.

The value of money is directly linked to time, because the later an asset is withdrawn from service or renewed, the greater the action of external agents on it and the greater the influence of macroeconomic factors on its value, being this negative or positive. This has a relevant effect on the costs in the transportation sector.

This paper discusses the replacement methods of buses in companies of urban transportation buses. This is a strategic subject because in the today's globalized economy, the companies' survival depends on its ability to rationalize costs or, by other words, to maximize the Return On Investments (ROI).

One way to do so is to guarantee the maximum availability of the equipment, and this, in turn, requires an optimal maintenance program. A maintenance program will only be successful if maintenance interventions are adequately scheduled and incur rational costs throughout the entire life cycle of the equipment.

The paper uses real data from an urban bus fleet. It compares economic life cycle analysis with lifespan analysis and notes how other maintenance policies would have different consequences. However, the company has a poor maintenance policy, making comparison difficult.

The paper is structured in the following sections:

i) This section that corresponds to the introduction;
ii) Section two makes a summary of the state of the art;
iii) Section three presents a summary of the main econometric models used;
iv) Section four applies the data of a bus fleet company to the economic life cycle;
v) Section five applies the data of a bus fleet company to the lifespan;
vi) Section six presents the conclusions.

2. State of the Art Maintenance Management

The buses fleet's management is a strategic activity for guaranteeing the optimal compliance of its life cycle, which implies the combination of actions of management, technical and economical, with the objective of obtaining higher availability at rational costs, [1-5].

The cost of an asset's life cycle corresponds to the sum of all the spent capitals on the support of that asset since its conception and manufacturing, going through the operation until the end of its useful life [2]. It is understood that the useful lifetime goes until the withdrawal of the equipment and that this could be different from the effective lifetime of the item, like the situation of the equipment with fast technologic obsolescence.

The Life Cycle Cost (LCC) of an asset can be significantly higher to the value of the initial investment and, in many cases, it is defined right on the project phase, [3]. Many different methods can be used to analyse the LCC [7], including Activity-Based Costing (ABC) [8]. LCC analysis follows certain rules [9-10]. The rules discussed by for asset management can be applied to any sector [11].

Systematized study of asset management remains underdeveloped, however, and there is a need for new models that can bring more value to companies. It is important to improve productivity and quality of service, whilst considering environmental sustainability, quality management, safety, and energy consumption [12].

Many companies keep equipment functioning, even when operation is no longer viable because the LCC is too expensive. At a certain point in the life cycle of equipment, it is important to assess if it ought to keep running or be replaced. Such assessments must consider the following [12]:

i) Availability of new technologies;
ii) Safety standards or other mandatory rules;
iii) Availability of spare parts;
iv) Obsolescence.

It is also important to find a calculation method to determine the appropriate time to replace equipment. Such a method should consider the following variables [13]:

i) Acquisition value;
ii) Withdrawal Value;
iii) Operating costs;
iv) Inflation rate;
v) Capitalization rate.

Equipment replacement is widely discussed and different authors propose different solutions. According to William *et al.*, traditional production systems use the principle of the economy of scale; the author discusses equipment replacement using a Lean Thinking context [14]. Jennifer and Joseph say technological transformation is often the motivation to replace equipment [15]. Natali and Yuri show that by combining continuous and discrete time models, the time to replace equipment is lower when the technology variable is applied [16].

According to Assaf, the assessment of a profit is established by future benefits expected by cash flows referred to the present value by a discount rate that reflects the risk of the decision [17].

According to Casarotto, the method of Equivalent Uniform Annual Cost (EUAC) is appropriate for the analysis of the company's operational activities about investments that ought to repeat [18]. Furthermore, the standardization of the investment results in an equivalent to annual values that must be expended. This method helps to determine which is the year with the lowest annual equivalent cost that corresponds to the best time to replace the asset [19].

According to Vey & Rosa, Equivalent Uniform Annual Cost (EUAC) analysis helps to determine the year with the lowest annual equivalent cost and this corresponds to the best time to replace the asset [19]. The calculation is based on the Capital Recovery Factor. Two or more investment opportunities can be compared to determine the best time to replace the equipment, taking into account the value of the investment or acquisition, resale value or residual value at the end of each year, operating costs, and the cost of capital or the minimum rate [19].

The replacement of equipment is required in four situations [20]:

i) When the equipment is inadequate for its function;
ii) When the equipment has reached its life limit;
iii) When the equipment is obsolete due to technological advances;
iv) When more efficient solutions are more economical.

The variables in the decision making draw on historical data, with the exception of the withdrawal value. In this case, it is necessary to know the market value for each particular type of equipment, and this is not easy for many assets. An alternative is to simulate devaluation using one of the following methods [13]:

i) Linear method of depreciation - the decline of the value of the equipment is constant over the years;
ii) Method of the sum of digits - the annual depreciation is not linear;
iii) Exponential method - The annual depreciation charge is decreasing over the life of the equipment.

Two other ways to estimate the best time for replacement are the lifespan method and the analysis of the economic cycle are:

i) Lifespan - withdrawal occurs when the operating costs exceed the costs of maintenance plus the amortization of the capital cost of an equivalent piece of new equipment;

ii) Economic cycle - the optimal period is which that minimizes the average total costs of operation, maintenance and capital immobilization [12].

According to Farinha, there are several methods to determine equipment replacement using the economic cycle. The most common are the following [12]:

i) Method of Uniform Annual Rent (MRAU);
ii) Method of Minimizing Total Average Cost (MMTAC);
iii) MMTAC with the Reduction to the Present Value (MMTAC-RPV).

Feldens *et al.* say the effective use of fixed assets is a major objective in the management of companies in the urban passenger transport sector [21]. They and others link this to a well-structured policy of fleet replacement [21-24].

The adoption of a single decision criterion for replacement is restrictive, because several criteria, including the costs, efficiency and level of service, should be evaluated simultaneously. Methods such as Multi Attribute Utility Theory (MAUT), Analytical Hierarchy Process (AHP) and Quality Function Deployment (QFD) have been used to accommodate multiple decision variables and multiple decision criteria.

Campos, Vellasco and Lazo propose a generic stochastic process model based on neural networks called Stochastic Neural Process (SNP); it can be applied in problems involving stochastic phenomena with periodic behaviour and characteristics [25]. Some cases using neural networks and stochastic models are reported in [26-32].

Other tools can help to develop new models for the optimized replacement of vehicles, such as Fuzzy Logic. Some uses of Fuzzy Logic are reported in [33-38].

Support Vector Machine (SVM) is a learning technique that is receiving increasing attention from the machine learning community. SVM is based on statistical learning theory; it establishes a set of principles to be followed to obtain classifications with a good level of generalization. The results of the application of this technique are comparable to and often better than those obtained by other learning algorithms, such as Artificial Neural Networks (ANN). It has been successfully applied in several areas, such as the categorization of texts, complex systems optimization models for high-speed trains, image analysis, bioinformatics, maintenance prediction and process optimization. Some cases of SVM are reported in [39-42].

The use of econometric models mixed with maintenance variables and stochastic models is discussed in [43-50].

These type of models may include more deeply the policy models, like the condition monitoring and the predictive ones, influencing a strategic aspect of the bus passengers transport, that is the fleet reserve, as can be seen in [43].

The Center for Transportation Research and Education (CTRE) presents a guide to support transportation organizations in their implementation of Physical Asset management program which may use, among others, the Economic Life Cycle and Lifespan models. The document presents a guide focused on the several levels of the transportation organization's maturity undertaking the activities that comprise the Asset Management framework. Some of the levels of maturity presented are the following [46]:

i) Organizational goals and objectives;
ii) Knowledge of the age, condition, and deterioration of the assets;
iii) Availability of information to undertake Life Cycle cost analysis for all major asset types and classes;
iv) Information to develop the organization's financial plan to support investment;
v) Development of investment strategies to manage the network in its whole life.

3. Summary of the Econometric Models

There are several reasons to make economic simulations to evaluate the need to replace equipment. Deterioration is one of the main reasons to replace equipment; with deterioration, the operating costs and maintenance and functioning costs rise. However, it is important to pick the correct method to determine the right time to replace equipment. To do this, it is necessary to consider the following variables: acquisition cost; value of withdrawal; operating costs; maintenance costs; operating costs; inflation rate; and capitalization rate.

As explained above, most values of the variables can be obtained from historical data, with the exception of the withdrawal value. However, it may be not easy to get the market value for a particular piece of equipment. The solution is to simulate devaluation using one of the following methods [21]: linear depreciation method; digit sum method; exponential method;

The majority of the previous values of the variables, with the exception of the withdrawal value, are obtained from history. However, it may be not easy to get the market value for each particular equipment. The solution is to simulate through several types of devaluation, like above referred, such as the following [13]:

i) Linear depreciation method – the decline of the value of the equipment is constant along the years;
ii) Method of the sum of the digits - the annual depreciation is not linear, being almost exponential;
iii) The Exponential method - the annual depreciation charge is exponential along the time.

According to Farinha, equipment can be replaced by various criteria [12]. A common criterion is the *economic cycle*; in this approach, the optimal period to replace is which that minimizes the average total costs of operation, maintenance and capital immobilization.

Another popular method is the *lifespan* approach; in this approach, the optima time to replace is when the operating costs exceed the costs of maintenance plus the amortization of the capital cost of a new and equivalent piece of equipment.

Two other variables to consider are:

i) capitalization rate, i;
ii) inflation rate, θ.

These rates are related as follow:

$$i_A = i + i + \theta \times \theta \quad (1)$$

where i_A is the Apparent Rate.

This paper uses the Uniform Method of Annual Income (RAU) to determine the best time to replace a bus in an urban transportation fleet. This method needs the following data:

i) Equipment acquisition cost;
ii) Withdrawal values (calculated according to the above methods);
iii) Maintenance Costs and Exploration over the years;
iv) Apparent Rate.

The net present value in year *n* (*VPLn*) is given by:

$$VPL_n = CA + \sum_{j=0}^{n} \frac{CM_j + CO_j}{(1+i_A)^j} - \frac{V_n}{(1+i_A)^j} \quad (2)$$

With,

CA Equipment Cost of Acquisition
CM_j Cost of Maintenance in year $j = 1, 2, 3,... n$
CO_j Cost of Operation in year $j = 1, 2, 3,... n$
i_A Apparent rate
V_n Value of the equipment over a period $n = 1, 2, 3... n$

The Annual (*n*) Uniform Annual Rent (RAU_n) is given by:

$$RAU_n = \frac{i_A(1+i_A)^j}{(1+i_A)^j - 1} * VPL_n \quad (3)$$

where RAU_n indicates the period (multi-year) within which the equipment ought to be replaced. This value is equivalent to a minimum rent that the equipment would cost annually.

About the Lifespan method, this considers that the useful life of an equipment ends when the maintenance costs, at a given time, exceed the maintenance costs, plus the capital amortization of a new equivalent equipment, at that time. Usually, the Lifespan is higher than the Economic Life [12], and can be evaluated through the next formula:

$$\sum_{j=1}^{n} \frac{CM_j}{(1+i_A)^j} > CA + \frac{CM_j}{(1+i_A)^j} \quad (4)$$

With,

CA Equipment Cost of Acquisition
CM_j Cost of Maintenance in year $j = 1, 2, 3,... n$
i_A Apparent rate
j Number of years $j=1, 2, 3\ldots n$

4. Economic Life Cycle Models Applied to Bus Fleet

The urban transport companies always have reserve fleet buses that varies from company to company and are related to the dimension of the active fleet, that has variations according to the life cycle of the buses. A low fleet reserve ratio is a synonym of high reliability, relying essentially on the implementation of an efficient planned maintenance that results from the application of good maintenance management methods.

A common set of factors affects the optimal number of vehicles in a reserve fleet:

i) Composition of the bus fleet;
ii) Brands and models;
iii) Age of the fleet;
iv) Annual distance travelled;
v) Commercial speed at which the buses work;
vi) Surroundings and operating environment;
vii) Daily demand fluctuations;
viii) Maintenance policies and maintenance management;
ix) Ratio of vehicles per mechanic;
x) Maintenance training;
xi) Number of interventions *per* maintenance routine team;
xii) Changes in the routes;
xiii) Changes in services;
xiv) Inventory management;
xv) Administration and finance.

To assess the management practices in transport companies, the Federal Transit Administration (FTA) in the USA conducted a survey of 36 North American and Canadian companies, eight small companies with fleets of 33 to 199 buses, eight medium enterprises with 225 to 472 buses, 12 large companies with 537 to 963 buses and eight very large companies with 1009 to 3664 buses. A synthesis of their activity is shown in Table 1.

Table 1. *Indicators of operating fleets, according to their size.*

Company Classification	Number of Companies	Fleet Reserve (%)	Average Velocity (km/h)	Average of Km per bus	Average Age of Fleet (Years)
Small	8	19	20.0	54768	7.7
Medium	8	22	20.6	59901	8.1
Big	12	21	20.9	65026	8
Very Big	8	17	19.3	62771	9.3
Total	36	20	20.3	61141	8.3

The FTA survey found that the measurement and monitoring of reserve fleets is important to maintenance managers. Ten percent of the buses in most fleets are undergoing repairs at any one time. On average, each bus is removed for maintenance nine times a year. The combined effects of new legislation on pollution, the need for dedicated maintenance, the high demand of transport and a skewed distribution of age and type of the bus have led many to increase the number of reserve vehicles.

At the same time, however, survey responses indicated maintenance managers are making efforts to reduce the number of spare buses. Many follow the guidelines of the FTA, where the number of reserve buses equals 20% of the whole fleet. The new philosophy is "the smaller the better".

Bus companies have different reserve rates. The indicators measured differ from company to company. In addition, the technologies used, the accuracy, the frequency of measurement, as well the methodology and management of the data vary significantly. It is important to study the discrepancies and create a model to optimize bus replacement aiming at the rationalization of the reserve fleet.

The study developed an equipment replacement model considering variables related to aspects such as direct operating costs, downtime costs, and maintenance costs, as well as economic indicators, such as the inflation and interest rates, among others. Based on these considerations, it developed a simulation model and applied it to a small number of buses for validation.

4.1. Buses Characterization

The variables used to characterize the buses in this study were the following: operational costs; maintenance costs; inflation and interest rates. Other aspects that might affect the buses' operating performance, such as on-board and type of air-conditioning, engine power etc., were also considered

The following variables were used to create the models: the year of the buses' manufacture; operation starting year; brand; model; type of vehicle; the values of the variables above. Ten buses were divided into two brands and five different models, as shown in Table 2.

Table 2. *Buses' Characterization.*

Nº Fleet	Brand	Model	Type	Manufacturing Year	Age	Engine Type	Fuel	Power	Capacity	Acquisition Cost
X1	Brand A	Mod. A	Standard	1993	21	EURO 1	Diesel	157 KW	96	110 658.31 €
X2	Brand A	Mod. A	Standard	1993	21	EURO 1	Diesel	157 KW	96	110 658.31 €
X3	Brand A	Mod. A	Standard	1993	21	EURO 1	Diesel	157 KW	96	110 658.31 €
Y1	Brand B	Mod. B	Standard	1996	18	EURO 2	Diesel	180 KW	84	120 459.69 €
Y2	Brand B	Mod. C	Standard	1998	16	EURO 2	Diesel	180 KW	87	130 005.68 €
XX1	Brand A	Mod. D	Standard	2002	12	EURO 3	Diesel	205 KW	95	164 453.66 €
XX2	Brand A	Mod. D	Standard	2002	12	EURO 3	Diesel	205 KW	95	164 453.66 €
XX3	Brand A	Mod. D	Standard	2002	12	EURO 3	Diesel	205 KW	95	164 453.66 €
YY1	Brand B	Mod. E	Standard	2004	10	EURO 3	Diesel	202 KW	90	159 515.57 €
YY2	Brand B	Mod. E	Standard	2004	10	EURO 3	Diesel	202 KW	90	159 515.57 €

4.2. Buses Data

At this stage, the focus corresponds to the identification and collection of primary data that for the study. The data should be relevant to the description of fleet costs and related activities, and ought to support the understanding of strategic economic and business information. It must be given priority to the information concerning procedures of operation, maintenance and planning. The data needed to be relevant to the description of fleet costs and related activities and support the understanding of strategic economic and business information. Therefore, the study collected historical data on operation, maintenance and planning. The data for each vehicle are shown in Tables 3-7.

Table 3. *Km / year travelled by each bus.*

Nº Fleet	Brand	2004 [km]	2005 [km]	2006 [km]	2007 [km]	2008 [km]	2009 [km]	2010 [km]	2011 [km]	2012 [km]	2013 [km]	2014 [km]
X1	Brand A	64 360	60 330	57 723	55 042	56 345	49 740	43 303	43 925	52 969	52 419	57 101
X2	Brand A	65 115	56 358	56 884	51 397	49 177	46 204	51 157	51 717	51 288	46 269	45 462
X3	Brand A	59 443	61 288	54 267	48 957	57 007	44 875	48 723	53 096	49 445	48 462	19 247
Y1	Brand B	76 259	66 421	62 647	62 666	66 841	60 873	59 402	68 950	71 618	59 899	65 658
Y2	Brand B	53 133	62 303	57 642	54 533	59 897	54 270	53 632	56 046	62 425	46 375	47 292
XX1	Brand A	51 664	54 267	51 732	53 327	57 290	59 664	51 306	56 715	51 042	41 007	5 885
XX2	Brand A	53 276	52 633	50 798	51 557	55 364	59 841	54 027	58 395	47 335	47 462	1 845
XX3	Brand A	53 174	61 196	65 235	67 506	69 173	65 386	63 213	59 034	59 707	53 134	60 611
YY1	Brand B	45 241	62 290	59 294	45 689	43 728	39 754	37 387	36 907	33 382	38 483	39 879
YY2	Brand B	41 407	60 632	58 460	42 029	41 095	38 199	36 405	32 364	35 887	43 630	37 990

Table 4. *Fuel consumed / year by each bus.*

Nº Fleet	2004 [lt]	2005 [lt]	2006 [lt]	2007 [lt]	2008 [lt]	2009 [lt]	2010 [lt]	2011 [lt]	2012 [lt]	2013 [lt]	2014 [lt]
X1	30264.90	28353.93	27130.49	25866.42	26481.91	23381.02	20354.18	20644.52	24894.14	24636.11	26834.14
X2	30617.19	26475.37	26734.20	24157.15	23111.62	21715.97	24042.82	24306.36	24102.71	21746.87	21358.46
X3	27990.50	27677.71	25507.27	23011.81	26793.50	21097.89	22898.15	24664.45	23235.53	22774.84	9046.70
Y1	36267.52	31942.05	30107.66	31058.06	34924.41	31651.68	30889.30	35850.56	37244.90	31147.31	34142.29
Y2	30679.80	34036.58	32398.69	30308.99	32339.88	29307.74	28962.79	30260.56	33708.88	25040.15	22579.81
XX1	25673.88	25921.47	26030.97	30514.56	32282.50	33170.70	29524.83	32271.03	29954.20	24657.51	3424.48
XX2	26142.80	26092.65	27977.90	30000.89	31285.99	32287.05	29208.69	31261.21	25879.38	26580.96	992.53
XX3	23865.20	27541.68	29357.93	30382.90	31133.31	32516.44	31603.41	29520.86	29856.96	26568.58	30305.31
YY1	27941.84	36188.67	34506.67	26820.73	25206.95	23787.89	23262.57	23246.87	21031.75	24247.10	25127.67
YY2	26271.53	35545.74	34636.80	25666.56	24857.18	23641.87	23002.26	23780.90	22872.63	26173.33	22790.68

Table 5. *Operating Costs.*

Nº Fleet	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]
X1	18464.62	20746.57	22010.97	21732.97	26301.83	17919.21	17986.99	21459.98	27517.98	25959.07	26826.09
X2	18679.55	19372.03	21689.46	20296.84	22954.46	16643.12	21246.64	25266.46	26643.14	22914.68	21352.05
X3	17077.00	20251.78	20694.05	19334.52	26611.30	16169.42	20235.10	25638.70	25684.55	23997.85	9043.99
Y1	22126.81	23372.00	25296.46	26094.98	34686.92	24257.85	27296.87	37266.66	41170.51	32819.92	34132.05
Y2	18717.75	24904.57	26285.06	25465.61	32119.97	22461.45	25594.42	31455.85	37261.80	26384.81	22573.04
XX1	15663.63	18966.74	21118.93	25638.33	32062.98	25422.02	26091.09	33545.74	33111.37	25981.62	3423.45
XX2	15949.72	19091.99	22698.47	25206.75	31073.25	24744.80	25811.72	32496.03	28607.07	28008.36	992.23
XX3	14560.16	20152.25	23818.09	25527.71	30921.60	24920.60	27927.93	30686.93	33003.88	27995.31	30296.22
YY1	17047.32	26479.25	27995.26	22534.78	25035.54	18231.04	20557.13	24165.12	23248.50	25549.17	25120.13
YY2	16028.26	26008.82	28100.84	21565.04	24688.15	18119.13	20327.10	24720.25	25283.41	27578.84	22783.84

Table 6. *Maintenance Costs.*

Nº Fleet	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]
X1	3908.61	5971.08	5134.67	5397.20	6064.17	7050.35	10061.22	8609.97	6377.63	8716.76	9360.49
X2	5517.32	5318.20	5066.54	5709.37	14500.47	7273.48	6115.87	5342.18	4126.68	13216.78	11557.40
X3	4996.68	3770.21	7374.57	5379.87	6815.23	10834.24	3977.56	3265.32	4875.61	10624.25	4732.38
Y1	7115.05	5315.53	4832.60	7096.32	6801.93	7106.36	12328.56	8211.22	7299.78	8141.77	16838.07
Y2	10500.79	9115.06	9223.43	4096.72	11546.11	7893.59	7688.06	10846.80	5616.88	17882.29	8269.66
XX1	5446.47	6426.15	3864.72	10921.46	13181.90	8095.07	10019.38	6841.37	8514.28	14833.22	3928.24
XX2	3336.12	2124.77	6297.20	12937.47	16911.04	5472.29	7818.86	8972.57	12976.35	10701.69	2745.37
XX3	3686.90	5074.46	4285.44	10163.36	10810.04	10151.96	7435.38	11036.17	3442.14	14438.05	7868.41
YY1	1251.81	1341.93	2727.56	4738.54	4788.54	3223.05	3457.63	7153.10	10595.44	6804.86	6583.95
YY2	357.88	1707.18	2332.44	4950.46	8310.39	8077.59	8421.54	5908.82	8359.97	6090.84	11484.71

Table 7. *Intervals of scheduled maintenance.*

Nº Fleet	Brand	Model	Review periodic intervals [km]	Reviews Programming	Lubrication periodic intervals [km]	Lubrication schedule
X1	Brand A	Mod. A	30 000	A1. A2. A1. A3. A1. A2…	25 000	L2. L4. L2. L4...
X2	Brand A	Mod. A	30 000	A1. A2. A1. A3. A1. A2…	25 000	L2. L4. L2. L4...
X3	Brand A	Mod. A	30 000	A1. A2. A1. A3. A1. A2…	25 000	L2. L4. L2. L4...
Y1	Brand B	Mod. B	20 000	A1. A2. A1. A3. A1. A2…	15 000	L2. L3. L2. L4...
Y2	Brand B	Mod. C	20 000	A1. A2. A1. A3. A1. A2…	15 000	L2. L3. L2. L4...
XX1	Brand A	Mod. D	50 000	A1. A2. A3. A1. A2. A3…	50 000	L2. L3. L2. L4...
XX2	Brand A	Mod. D	50 000	A1. A2. A3. A1. A2. A3…	50 000	L2. L3. L2. L4...
XX3	Brand A	Mod. D	50 000	A1. A2. A3. A1. A2. A3…	50 000	L2. L3. L2. L4...
YY1	Brand B	Mod. E	25 000	A1. A2. A3. A1. A2. A3…	15 000	L2. L3. L2. L3. L2. L4...
YY2	Brand B	Mod. E	25 000	A1. A2. A3. A1. A2. A3…	15 000	L2. L3. L2. L3. L2. L4...

Using the above data, the next section analyses the ability of the Uniform Annual Rent (RAU) method to determine the economic cycle of bus replacement. Table 8 shows the values for the Linear Depreciation method. Table 9 shows those for the Digit Sum method, and Table 10 shows the Exponential method.

Table 8. *Linear Depreciation Method.*

Nº Fleet	Acquisition Cost	Exploration Cost	Annual Depreciation Cote	1	2	3	4
X1	110 658.31 €	1 500.00 €	2 728.96 €	107 929.35 €	105 200.39 €	102 471.44 €	99 742.48 €
X2	110 658.31 €	1 500.00 €	2 728.96 €	107 929.35 €	105 200.39 €	102 471.44 €	99 742.48 €
X3	110 658.31 €	1 500.00 €	3 638.61 €	107 019.70 €	103 381.09 €	99 742.48 €	96 103.87 €
Y1	120 459.69 €	1 500.00 €	3 965.32 €	116 494.37 €	112 529.04 €	108 563.72 €	104 598.40 €
Y2	130 005.68 €	1 500.00 €	4 283.52 €	125 722.16 €	121 438.63 €	117 155.11 €	112 871.59 €
XX1	164 453.66 €	1 500.00 €	5 431.79 €	159 021.87 €	153 590.08 €	148 158.29 €	142 726.51 €
XX2	164 453.66 €	1 500.00 €	5 431.79 €	159 021.87 €	153 590.08 €	148 158.29 €	142 726.51 €
XX3	164 453.66 €	1 500.00 €	5 431.79 €	159 021.87 €	153 590.08 €	148 158.29 €	142 726.51 €
YY1	159 515.57 €	1 500.00 €	5 267.19 €	154 248.38 €	148 981.20 €	143 714.01 €	138 446.83 €
YY2	159 515.57 €	1 500.00 €	5 267.19 €	154 248.38 €	148 981.20 €	143 714.01 €	138 446.83 €

Table 9. *Method of Sum of Digits.*

Nº Fleet	Acquisition Cost	Exploration Cost	Annual Depreciation Quota	1	2	3	4
X1	110 658.31 €	1 500.00 €	406	103 130.15 €	95 870.85 €	88 880.42 €	82 158.85 €
		Annual depreciation quota		7 528.16 €	7 259.30 €	6 990.43 €	6 721.57 €
X2	110 658.31 €	1 500.00 €	406	103 130.15 €	95 870.85 €	88 880.42 €	82 158.85 €
		Annual depreciation quota		7 528.16 €	7 259.30 €	6 990.43 €	6 721.57 €
X3	110 658.31 €	1 500.00 €	406	103 130.15 €	95 870.85 €	88 880.42 €	82 158.85 €
		Annual depreciation quota		7 528.16 €	7 259.30 €	6 990.43 €	6 721.57 €
Y1	120 459.69 €	1 500.00 €	406	112 255.57 €	104 344.46 €	96 726.35 €	89 401.25 €
		Annual depreciation quota		8 204.12 €	7 911.11 €	7 618.11 €	7 325.10 €
Y2	130 005.68 €	1 500.00 €	406	121 143.22 €	112 597.28 €	104 367.85 €	96 454.94 €
		Annual depreciation quota		8 862.46 €	8 545.94 €	8 229.43 €	7 912.91 €
XX1	164 453.66 €	1 500.00 €	406	153 215.48 €	142 378.66 €	131 943.20 €	121 909.11 €
		Annual depreciation quota		11 238.18 €	10 836.82 €	10 435.46 €	10 034.09 €
XX2	164 453.66 €	1 500.00 €	406	153 215.48 €	142 378.66 €	131 943.20 €	121 909.11 €
		Annual depreciation quota		11 238.18 €	10 836.82 €	10 435.46 €	10 034.09 €
XX3	164 453.66 €	1 500.00 €	406	153 215.48 €	142 378.66 €	131 943.20 €	121 909.11 €
		Annual depreciation quota		11 238.18 €	10 836.82 €	10 435.46 €	10 034.09 €
YY1	159 515.57 €	1 500.00 €	406	148 617.94 €	138 109.52 €	127 990.30 €	118 260.27 €
		Annual depreciation quota		10 897.63 €	10 508.42 €	10 119.22 €	9 730.02 €
YY2	159 515.57 €	1 500.00 €	406	148 617.94 €	138 109.52 €	127 990.30 €	118 260.27 €
		Annual depreciation quota		10 897.63 €	10 508.42 €	10 119.22 €	9 730.02 €

Table 10. *Exponential Method.*

Nº Fleet	Acquisition Cost	Experation Cost	Annual Depreciation Quota	1	2	3	4
X1	110 658.31 €	1 500.00 €	0.14	94 901.61 €	81 388.51 €	69 799.56 €	59 860.76 €
		Annual depreciation quota		15 756.70 €	13 513.09 €	11 588.96 €	9 938.80 €
X2	110 658.31 €	1 500.00 €	0.14	94 901.61 €	81 388.51 €	69 799.56 €	59 860.76 €
		Annual depreciation quota		15 756.70 €	13 513.09 €	11 588.96 €	9 938.80 €
X3	110 658.31 €	1 500.00 €	0.14	94 901.61 €	81 388.51 €	69 799.56 €	59 860.76 €
		Annual depreciation quota		15 756.70 €	13 513.09 €	11 588.96 €	9 938.80 €
Y1	120 459.69 €	1 500.00 €	0.14	102 994.71 €	88 061.92 €	75 294.17 €	64 377.56 €
		Annual depreciation quota		17 464.98 €	14 932.80 €	12 767.75 €	10 916.60 €
Y2	130 005.68 €	1 500.00 €	0.15	110 854.33 €	94 524.19 €	80 599.67 €	68 726.40 €
		Annual depreciation quota		19 151.35 €	16 330.14 €	13 924.52 €	11 873.27 €
XX1	164 453.66 €	1 500.00 €	0.15	139 055.48 €	117 579.79 €	99 420.79 €	84 066.27 €
		Annual depreciation quota		25 398.18 €	21 475.69 €	18 158.99 €	15 354.52 €
XX2	164 453.66 €	1 500.00 €	0.15	139 055.48 €	117 579.79 €	99 420.79 €	84 066.27 €
		Annual depreciation quota		25 398.18 €	21 475.69 €	18 158.99 €	15 354.52 €
XX3	164 453.66 €	1 500.00 €	0.15	139 055.48 €	117 579.79 €	99 420.79 €	84 066.27 €
		Annual depreciation quota		25 398.18 €	21 475.69 €	18 158.99 €	15 354.52 €
YY1	159 515.57 €	1 500.00 €	0.15	135 026.97 €	114 297.82 €	96 750.98 €	81 897.91 €
		Annual depreciation quota		24 488.60 €	20 729.15 €	17 546.84 €	14 853.07 €
YY2	159 515.57 €	1 500.00 €	0.15	135 026.97 €	114 297.82 €	96 750.98 €	81 897.91 €
		Annual depreciation quota		24 488.60 €	20 729.15 €	17 546.84 €	14 853.07 €

4.3. Application of the Method of Uniform Annual Rent (RAU)

The study used historical data for vehicles grouped into homogeneous groups, for a period from 1993 to 2012. Buses were 19, 16, 14, 10 and 9 years old. Table 11 shows the data used to calculate the Uniform Annual Rent (RAU), using the Linear Depreciation method, for the buses X1, X2, X3, Y1, Y2, XX1, XX2, XX3, YY1 and YY2.

Table 11. *RAU Buses.*

		RAU [€ Year n]									
Vehicles		**Linear Method**									
Year j	**i_A [%]**	**X1**	**X2**	**X3**	**Y1**	**Y2**	**XX1**	**XX2**	**XX3**	**YY1**	**YY2**
0	16%										
1	14%	31431.86	31883.37	32681.38	30189.42	23829.43	31317.11	34085.80	34343.95	31315.53	29402.54
2	13%	29544.83	30167.53	30882.24	29094.74	26399.07	33111.01	33635.10	33259.43	36015.59	34985.60
3	9%	25102.58	25870.85	26509.32	28876.78	26932.40	35600.62	34630.70	35650.06	41807.40	41000.92
4	6%	22490.34	23378.41	23947.66	31369.48	26427.65	39985.53	40176.25	40744.98	42565.40	41768.46
5	5%	21340.69	22310.95	22817.22	31930.68	26613.57	42896.73	43328.15	43374.58	41655.70	41561.24
6	5%	21152.58	22193.88	22650.98	31370.76	27546.22	44318.52	45081.46	44226.37	32203.48	32995.81
7	7%	23282.58	24346.80	24769.98	30606.23	29626.18	37421.14	37681.03	37466.93	35147.97	36391.02
8	7%	23716.30	24788.40	25179.60	30535.92	33482.91	41020.51	40978.09	40994.89	41883.04	42762.33

		RAU [€ Year n]									
Vehicles		Linear Method									
Year j	i_A [%]	X1	X2	X3	Y1	Y2	XX1	XX2	XX3	YY1	YY2
9	7%	23251.83	24313.91	24674.90	31234.70	34412.98	47186.31	47293.45	47321.09	40593.37	41416.75
10	5%	22683.15	23607.18	23972.91	33967.21	34991.84	46369.50	46455.21	46090.61		
11	5%	22449.67	23435.98	23619.12	34844.05	30438.02					
12	5%	23265.96	24059.94	24190.22	34905.29	32817.22					
13	7%	25662.79	26419.34	26642.17	30601.15	37184.52					
14	7%	26343.28	27022.57	27183.44	33077.47	36918.02					
15	6%	26200.73	27047.13	27019.11	37042.71						
16	0%	22882.77	23597.20	23585.12	36912.23						
17	3%	24570.45	25241.86	25118.79							
18	7%	27488.64	28217.51	28166.10							
19	6%	27115.83	27711.55	27616.98							

Table 12 shows the calculation of the Uniform Annual Income for bus X1.

***Table 12.** RAU - Bus X1.*

Vehicles: X1							RAU [€ Year n]		
Year j	CA [€]	i_A [%]	CM [€]	CO [€]	$\sum_1$ [€]	VP [€]	Meth. Linear	Meth. S. Dig.	Meth. Exp.
0	110 658.31	16%			110 658.31				
1		14%	979.31	11223.87	12203.18	121376.62	31431.86	35061.50	43290.04
2		13%	1018.09	10712.00	11730.09	130758.77	29544.83	32833.56	39646.93
3		9%	1116.33	10464.39	11580.72	140808.26	25102.58	28186.06	34021.54
4		6%	1274.04	10481.04	11755.08	151244.06	22490.34	25421.50	30485.98
5		5%	1491.22	10761.95	12253.17	161222.27	21340.69	24113.90	28485.31
6		5%	1767.86	11307.12	13074.98	171748.15	21152.58	23754.63	27493.13
7		7%	2103.96	12116.55	14220.51	176876.00	23282.58	25561.41	28542.27
8		7%	2499.54	13190.24	15689.78	185280.22	23716.30	25790.77	28257.81
9		7%	2954.58	14528.19	17482.77	197634.26	23251.83	25211.20	27326.15
10		5%	3640.07	15540.83	19180.90	213048.38	22683.15	24563.34	26401.66
11		5%	3908.61	18464.62	22373.23	231462.31	22449.67	24254.38	25848.89
12		5%	5971.08	20746.57	26717.65	245997.26	23265.96	24912.60	25482.15
13		7%	5134.67	22010.97	27145.64	238942.00	25662.79	26961.97	27890.77
14		7%	5397.20	21732.97	27130.17	246119.14	26343.28	27481.61	28209.44
15		6%	6064.17	26301.83	32366.00	268792.13	26200.73	27294.27	27916.57
16		0%	7050.35	17919.21	24969.56	397088.13	22882.77	24441.11	25225.71
17		3%	10061.22	17986.99	28048.21	359094.55	24570.45	25753.42	26276.62
18		7%	8609.97	21459.98	30069.95	285597.01	27488.64	28191.34	28461.93
19		6%	6377.63	27517.98	33895.61	319022.09	27115.83	27808.35	28037.96

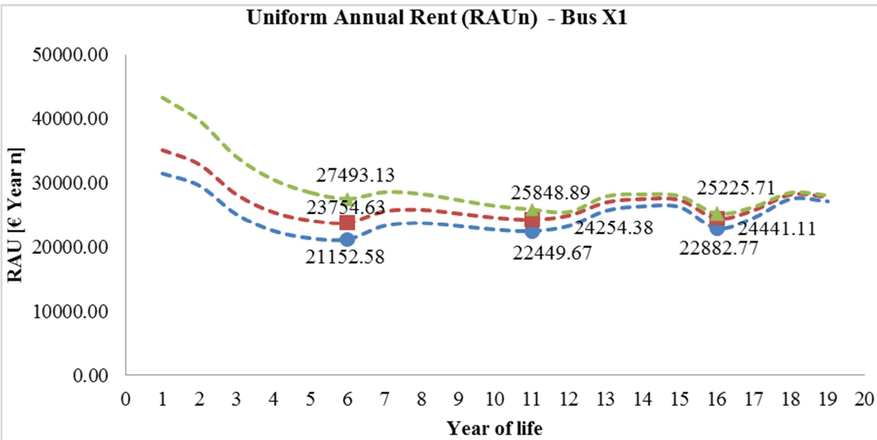

***Figure 1.** RAU - Bus X1.*

As Figure 1 shows, the replacement period varies from homogenous group to homogeneous group of vehicles. Several variables influence the decision to replace, such as the apparent rate of each year, as well as the depreciation value for each model and brand. Another very important variable is the maintenance cost. This, in turn, depends on the maintenance management policy.

As a result, as shown in Figure 1, there is no well-defined economic time to replace the buses. There are other variables that could be considered, environmental and technological ones, among others, but that discussion is beyond the scope of this paper.

5. Lifespan Model Applied to Bus Fleet

Lifespan defines that the life cycle ends when the maintenance costs overpass the maintenance costs plus capital amortization of a new equivalent asset. The LCC in the economic perspective ends when the maintenance costs exceed the sum of maintenance costs with the depreciation of value.

The cost of operation comprises the costs used in the production of services, such as fuel for public passenger transport. The annual costs of maintenance and operation have a variable behavior. Their growth is usually gradual; sometimes there is a peak. These costs depend on the maintenance policy, which, in turn, depends on various factors (nature of the failure modes; criticality and management goals etc.). In all analyses of replacement of equipment, it is necessary to know the historical maintenance costs.

The *Lifespan* variables considered are the same ones of the Economic Life Cycle discussed in the previous section.

To implement the lifespan method, the study used historical data for vehicles distributed into homogeneous groups for a period between 1993 and 2012; buses were 19, 16, 14, 10 and 9 years old, as in the study of the calculation of Uniform Annual Income in the previous section. Figure 2 shows maintenance costs of vehicle X1, along with operation costs and the sum of the two costs. However, only the maintenance cost was used to determine the best replacement time.

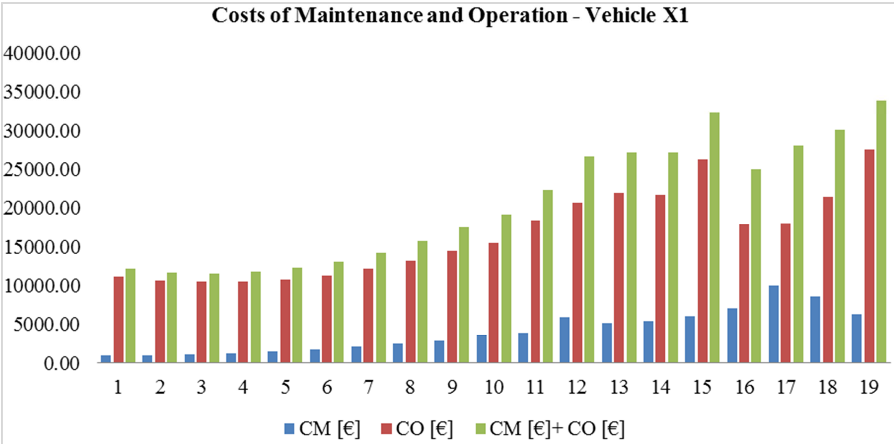

Figure 2. *Costs of maintenance and operation – Bus X1.*

Table 13 shows the data used to calculate the *lifespan* for the bus X1, Brand A, Model A, with 19 years old. In this table it is shown the acquisition costs, depreciation and maintenance cost of equipment, as well as depreciation and maintenance costs Referred to the Present Value (RPV).

Table 13. *Costs maintenance and devaluation.*

Vehicle: X1							
Year	**Acquisition cost**	**Devaluation**	**Dev.+Maint.**	**Maint. Accumulated**	**Devaluation RVP**	**Dev.+Maint. RVP**	**Maint. Accum. RVP**
0	110658.31	110658.31	110658.31		110658.31	110658.31	
1	111211.60	105628.39	106607.70	979.31	92775.62	93635.77	860.15
2	111767.66	100598.46	101616.55	1997.40	79403.88	80207.47	1576.58
3	112326.50	95568.54	96684.87	3113.73	74329.42	75197.66	2421.74
4	112888.13	90538.62	91812.66	4387.77	70553.55	71546.36	3419.23
5	113452.57	85508.69	86999.91	5878.99	65605.90	66750.03	4510.61
6	114019.83	80478.77	82246.63	7646.85	59701.63	61013.08	5672.67
7	114589.93	75448.85	77552.81	9750.81	46780.78	48085.30	6045.82
8	115162.88	70418.92	72918.46	12250.35	40099.50	41522.85	6975.87
9	115738.70	65389.00	68343.58	15204.93	37096.15	38772.33	8625.98
10	116317.39	60359.08	63999.15	18845.00	35366.75	37499.60	11042.02
11	116898.98	55329.16	59237.77	22753.61	33658.48	36036.21	13841.74
12	117483.47	50299.23	56270.31	28724.69	28871.76	32299.16	16487.97
13	118070.89	45269.31	50403.98	33859.36	18720.96	20844.38	14002.41
14	118661.24	40239.39	45636.59	39256.56	14873.94	16868.94	14510.65
15	119254.55	35209.46	41273.63	45320.73	13912.42	16308.57	17907.71
16	119850.82	30179.54	37229.89	52371.08	28046.36	34598.37	48669.33
17	120450.08	25149.62	35210.84	62432.30	15941.37	22318.78	39573.41
18	121052.33	20119.69	28729.66	71042.27	5821.42	8312.62	20555.32
19	121657.59	15089.77	21467.40	77419.90	5139.40	7311.55	26368.34
20	122265.88	10059.85	18776.61	86136.66	5715.71	10668.32	48940.36
21	122877.21	5029.92	14390.41	95497.15	3498.23	10008.29	66416.67

Figure 3 shows the analysis of the life of the X1 bus, firstly without the present value correction of its costs, and, secondly, with its reduction to present value.

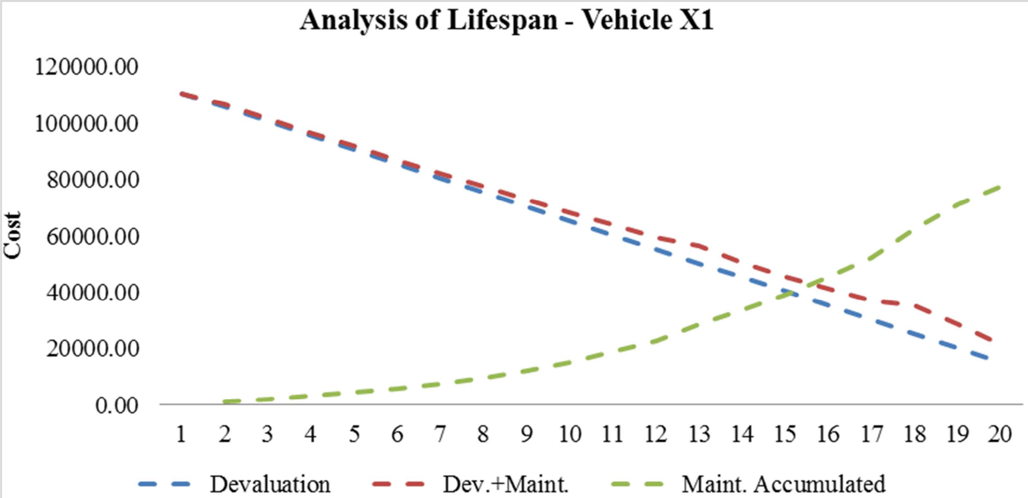

Figure 3. *Analysis of Lifespan – Vehicle X1.*

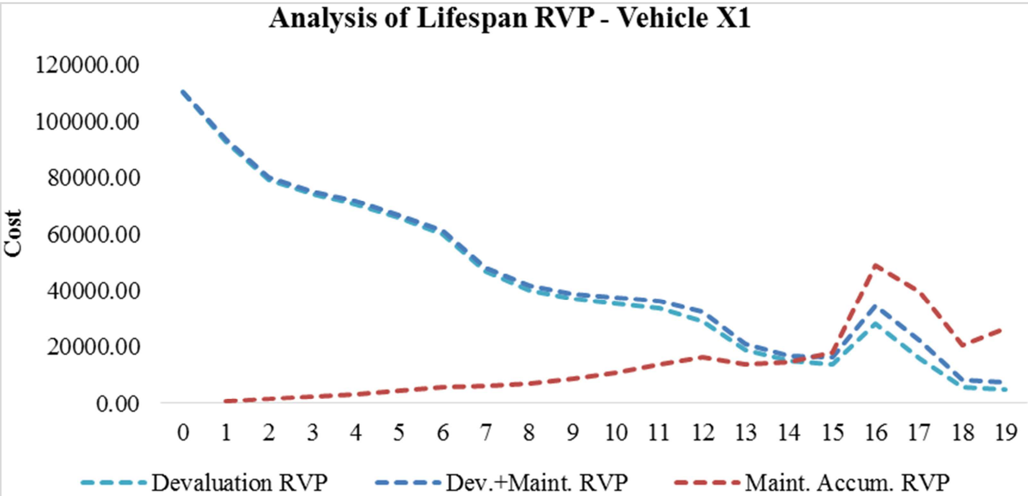

Figure 4. *Analysis of Lifespan RVP – Vehicle X1.*

Through the previous data analysis, it can be verified that the lifetime of the bus should be 15 years according to Figures 3 and 4, which take into account the reduction of the values of each year to the present value.

The calculations performed ought to be recalculated periodically, not only because more data is being collected, allowing the revaluation of the previous calculations, but also because some variables may change significantly, what may cause a modification of the replacement time.

Bellow, it will be performed a comparison between the method that determines the vehicle replacement time according to the economical point of view and the method of lifespan. To do this it will be used the vehicle X2, being the data shown in Table 14 and the calculation made by the two above referred methods (Tables 14 and 15), as well as the corresponding graphs shown in Figures 5, 6 and 7.

Table 14. *RAU / Bus X2.*

Vehicles: X2							**RAU [€ Year n]**		
Year j	**CA [€]**	**i_A [%]**	**CM [€]**	**CO [€]**	**$\sum_1$ [€]**	**VP [€]**	**Meth. Linear**	**Meth. S. Dig.**	**Meth. Exp.**
0	110 658.31	16%			110 658.31				
1		14%	976.77	11677.92	12654.69	121773.19	31883.37	35513.01	43741.55
2		13%	1013.11	11532.36	12545.47	131803.49	30167.53	33456.25	40269.63
3		9%	1109.01	11563.30	12672.31	142762.07	25870.85	28954.33	34789.81
4		6%	1264.48	11770.74	13035.22	154290.99	23378.41	26309.56	31374.04
5		5%	1479.52	12154.70	13634.22	165372.18	22310.95	25084.16	29455.58
6		5%	1754.12	12715.00	14469.12	177016.09	22193.88	24795.93	28534.44
7		7%	2088.29	13452.14	15540.43	182598.07	24346.80	26625.64	29606.49

Vehicles: X2							RAU [€ Year n]		
Year j	CA [€]	i_A [%]	CM [€]	CO [€]	$\sum_1$ [€]	VP [€]	Meth. Linear	Meth. S. Dig.	Meth. Exp.
8		7%	2482.02	14365.62	16847.64	191610.14	24788.40	26862.87	29329.91
9		7%	2935.32	15455.60	18390.92	204703.27	24313.91	26273.27	28388.22
10		5%	1904.25	16509.89	18414.14	220016.39	23607.18	25487.36	27325.69
11		5%	5517.32	18679.55	24196.87	239820.04	23435.98	25240.69	26835.20
12		5%	5318.20	19372.03	24690.23	253141.01	24059.94	25706.58	26276.13
13		7%	5066.54	21689.46	26756.00	245254.87	26419.34	27718.51	28647.31
14		7%	5709.37	20296.84	26006.21	251930.98	27022.57	28160.89	28888.72
15		6%	14500.47	22954.46	37454.93	276809.27	27047.13	28140.68	28762.97
16		0%	7273.48	16643.12	23916.60	408084.92	23597.20	25155.54	25940.15
17		3%	6115.87	21246.64	27362.51	368138.34	25241.86	26424.83	26948.03
18		7%	5342.18	25266.46	30608.64	292859.14	28217.51	28920.21	29190.80
19		6%	4126.68	26643.14	30769.82	325757.10	27711.55	28404.07	28633.68

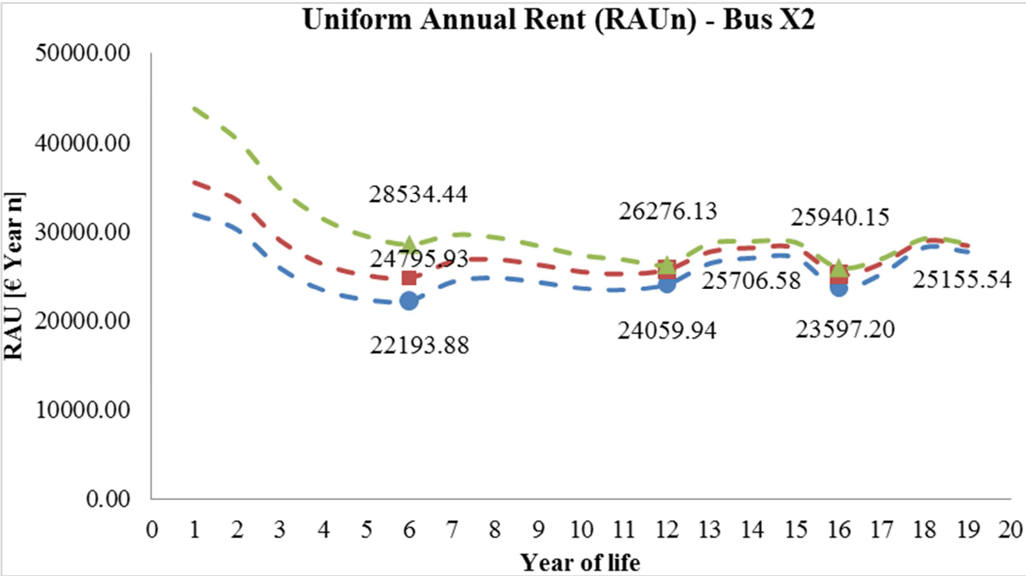

Figure 5. *RAU Analysis – Bus X2.*

Table 15. *Maintenance costs and devaluation.*

Vehicle: X2							
Year	Acquisition cost	Devaluation	Dev.+Maint.	Maint. Accumulated	Devaluation RVP	Dev.+ Maint. RVP	Maint. Accum. RVP
0	110658.31	110658.31	110658.31		110658.31	110658.31	
1	111211.60	105628.39	106605.16	976.77	92775.62	93633.54	857.92
2	111767.66	100598.46	101611.57	1989.88	79403.88	80203.54	1570.64
3	112326.50	95568.54	96677.55	3098.89	74329.42	75191.96	2410.19
4	112888.13	90538.62	91803.10	4363.37	70553.55	71538.91	3400.22
5	113452.57	85508.69	86988.21	5842.89	65605.90	66741.05	4482.91
6	114019.83	80478.77	82232.89	7597.01	59701.63	61002.89	5635.70
7	114589.93	75448.85	77537.14	9685.30	46780.78	48075.59	6005.21
8	115162.88	70418.92	72900.94	12167.32	40099.50	41512.87	6928.58
9	115738.70	65389.00	68324.32	15102.64	37096.15	38761.40	8567.95
10	116317.39	60359.08	62263.33	17006.89	35366.75	36482.52	9965.00
11	116898.98	55329.16	60846.48	22524.21	33658.48	37014.84	13702.19
12	117483.47	50299.23	55617.43	27842.41	28871.76	31924.41	15981.54
13	118070.89	45269.31	50335.85	32908.95	18720.96	20816.21	13609.38
14	118661.24	40239.39	45948.76	38618.32	14873.94	16984.33	14274.73
15	119254.55	35209.46	49709.93	53118.79	13912.42	19642.03	20988.98
16	119850.82	30179.54	37453.02	60392.27	28046.36	34805.73	56123.56
17	120450.08	25149.62	31265.49	66508.14	15941.37	19817.98	42156.93
18	121052.33	20119.69	25461.87	71850.32	5821.42	7367.12	20789.12
19	121657.59	15089.77	19216.45	75977.00	5139.40	6544.90	25876.90

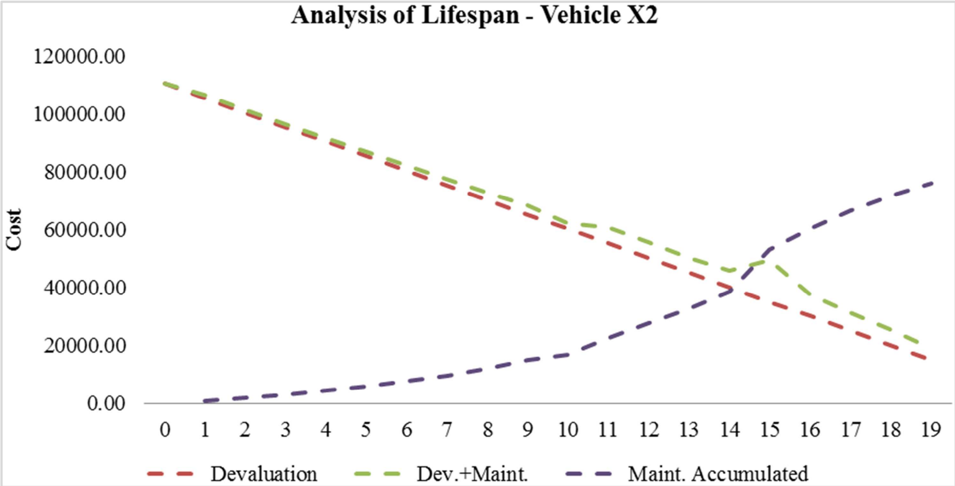

Figure 6. *Analysis of Lifespan – Vehicle X2.*

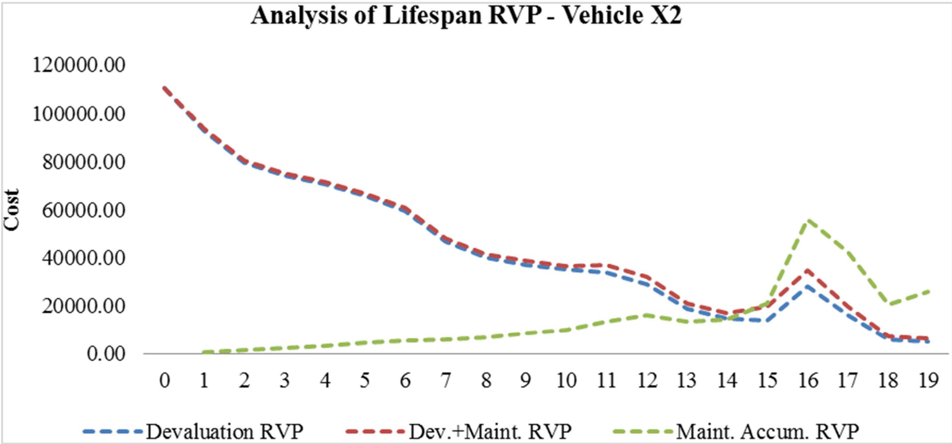

Figure 7. *Lifespan RVP / Bus X2.*

Based on the preceding analysis, it seems that the Lifespan method allows the decision maker to make a more objective decision. We also note there is a discrepancy in the replacement time proposed by the two methods.

6. Conclusions

The paper compares the use of economic life cycle and lifespan models in the determination of when to retire urban buses. It defines the economic aspects according to the relevant indicators and the cash flow, including the cost of acquisition, maintenance, and operation, among others.

The study assesses the life cycle of buses in an urban transportation fleet using the two models. It finds there are different withdrawal times for the model of the annual uniform rent and the lifespan model. Nonetheless, both can be used in future models to support a rational decision. The models allow a detailed assessment of the present performance of a bus against the performance of a potential substitute when the company updates its assets to ensure quality and customer satisfaction.

However, the conclusions are obvious, what demonstrates the models' utility and robustness, the research must be deepen to include other variables like a buses' technological comparison, environmental impacts, among others. An additional analysis must complement this new research that is the relation between production levels with the most adequate maintenance policy and the expected Life Cycle Cost.

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