

# Fleet Replacement Analysis by Equivalent Uniform Annual Cost Method

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## Abstract

One of the most important standard operating procedures for any organization is running the business in a cost-effective manner. Normally during that business, workforces, equipment, fleet, etc are considered to be replaced after particular period of time, which depends on the operational situation. In this paper, replacement of grass fleet is studied in one of the universities. Equivalent Uniform Annual Cost (EAUC) method is used for that purpose for three years period of time. The parameters considered for the said fleet are its operation cost, maintenance cost, procurement cost, interest rate, resale value at the end of each financial year, depreciation, interest on procurement cost, and the total marginal cost. EAUC has been calculated for each year and should attracting output for the operators about the time they can replace the fleet in discussion.

## Keywords

Fleet, Engineering Economy, Economic Life, Replacement and Equivalent Uniform Annual Cost.

## 1. Introduction and Literature Review

The principles of engineering economy are utilized to analyze alternative uses of financial resources. The evaluation should depend on applying cost data analysis concerning the most important economic factors. Such factors are related to equipment usage as operation and maintenance costs, salvage values, depreciation, work delivered (i.e. working hours or vehicle distance), the cost of capital, tax credits, if exists (Dekker, 1996). The most important decision is the choice between keeping and replacing the operational vehicle during the remaining anticipated life. The existing vehicle operating in service (under study) is called the defender while, the challenger is the perspective of a replacement vehicle proposed as an alternative of the existing one, considered as the representative of the Defender vehicle group class (Newnan et al, 2013). Factors other than economy often enter into vehicle replacement analysis. Availability is defined as the probability that the system (such as a vehicle) is operating at any random time (Ireson et al, 1996). This can be accomplished when management guarantees that the service of a certain vehicle can be provided and performed with less down-time and high dependability (White et al, 2013).

In the transportation 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 any 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 (Aoudia and Belmokhtar, 2008). Replacing an asset is a common practice in business and is a strategic decision of the organization that considers the optimization of operating costs, maintenance, and better operational efficiency. With the equipment life progress, fleet can present excessive operational and maintenance costs, in addition to the new technological alternatives that make the fleet obsolete. In this way, the main difficulty in replacing assets is the definition of the optimal moment of substitution within their economic life (Carter, 1986). Fleet renewal or replacement can be observed as a concerned managerial issue that poses a significant challenge to logistics service providers or general business organization. This research addressed the fleet replacement analysis using equivalent uniform annual cost (EUAC). The concept of fleet is traditionally discussed in certain industries, such as military, marine, logistics, and aviation industries. In asset management context, the fleet can also consist of machineries or equipment (Kinnunen et al, 2020). It would be beneficial to exploit the learnings from the traditional fleet management fields in other environments, where fleets can be considered in an extended manner. For example, digitalization generates massive amounts of data which can be exploited more efficiently for fleet management purposes. Kauffmann et al. (2012) developed a model to identify the optimal asset life for six fleet (three on road and three off road). This model presented the opportunity to reduce overall cost, improve the age of the fleet

and its readiness to serve the public, and improve overall utilization. Furthermore, Raposo et al. (2017) discussed the dependence of a fleet reserve of buses on the maintenance policy of the whole fleet condition-based maintenance using a motor oil degradation analysis. EUAC was used efficiently for a study of replacement and maintenance related problems of brewery industries, which was carried out with view of appraising the maintenance policy of the industry in Nigerian situation (Nwajinka and Udoe, 2014).

Shurrah et al. (2016) developed a heuristic decision model for the replacement of an operational vehicle. The proposed model is based on analyzing economic measures incorporating the most important factors such as: operation and maintenance costs, salvage values, depreciation, cost of capital, and most importantly, unavailability costs to reflect the hidden off-road vehicle costs. Parameterization of life-cycle costs, classification of existing vehicles, and vehicle priority factors were demonstrated in a case study for the Royal Air Force vehicles fleet. It is worth mentioning that the proposed heuristic is a beneficial tool in replacement decision and in making trade-off analysis among viable replacement strategies.

Jin & Kite-Powell (2000) discussed the conditions for optimal utilization of several vessels in the fleet and optimal vessel acquisition and retirement strategies. They reached to a result that the optimal replacement schedule and fleet size are influenced by utilization schedules, and vice versa. The key factors in fleet replacement decisions included the ability to choose from multiple manufacturers, purchase price, and government regulations (Keles and Hartman, 2010). In addition, Parthanadee et al. (2012) used integer programming to focus on the main aspects of the fleet replacement problem, including the effects of some widely used replacement rules, consideration of alternative fuel fleet for replacement, and a new user preference utilization pattern. Zheng and Chen (2018) investigated the fleet replacement timing decisions when a shipowner faces uncertain demand on various routes and uncertain fuel prices. They utilized multi-option least squares Monte Carlo simulation algorithm is utilized to find the replacement probabilities in future years and the expected net present values of the cost savings after the replacement. In Spain, a combined model of support to asset management based in the association of the life cycle cost tool and the mathematical model of Monte Carlo simulation had been developed by performing a stochastic analysis considering both age and average annual mileage for optimum vehicle replacement (Riechi et al, 2017). Their utilized method was applied in an urban transport fleet, and the results indicated that the use of the stochastic model was more effective than the use of the deterministic model. Ansari-poor and Oliveira (2018) studied the use of flexible lease contracts in the fleet portfolio management problem of a firm that aims to minimize its cost and risk simultaneously, in a stochastic multi-period setting by deciding which technologies to use in its fleet.

For the electric fleet, a dynamic life-cycle assessment (LCA) of the Portuguese light-duty ones was performed (Garcia et al., 2015). Their model baseline projected a reduction about thirty five percent in the fleet life cycle greenhouse gas emissions depending on the battery penetration rate and internal combustion engine fuel consumption improvements. In another study, transport rate has been determined to minimize costs of tanker truck of an oil products distribution company (Mousavi et al., 2013). Emiliano et al. (2020) determined the optimal replacement plan for a fleet of diesel buses of different size, age, maintenance costs and emissions rates, with new (less polluting) diesel buses over a time horizon of fifty years. Their results indicate that it is possible to reduce emissions with a low annual budget. Neboian and Spinler (2015) analyzed the option to breach a leasing contract when replacing a fleet of internal combustion engine vehicles (ICV) and electric vehicles subject to cost uncertainty.

Recently in 2017, United States emitted about 14.36% of the total global Greenhouse Gas (GHG), 27% of which comes from the transportation sector. To address some of these emission sources, alternative fuel technology vehicles are becoming more progressive and market ready. Transit agencies are making an effort to reduce their carbon footprint by adopting these technologies. The overarching objective of this paper is to aid transit agencies make more informed decisions regarding the process of replacing a diesel fleet with alternative-technology buses to minimize GHG emissions. Therefore, Islam and Lownes (2019) investigated the complete course of fleet replacement using a deterministic mixed integer programming. Bus fleet replacement is optimized by minimizing the Life Cycle Cost (LCC) of owning and operating a fleet of buses and required infrastructures while reducing GHG emission simultaneously. Buses operated by Connecticut Department of Transportation (CTDOT) were used as a case-study. Results also showed a significant reduction in both cost and emission for optimized replacement schedule versus the unoptimized one. Results also showed that a fleet consisting of 79% Battery Electric Bus and 21% Diesel Hybrid Bus yields the least cost solution which conforms to the other operational and environmental constraints. Their study also included various sensitivity tests, that illustrates that although the magnitude of the results may vary depending on the input data, the direction remains the same. The problem formulated in their study can help any transit agencies determine the most optimized solution to their fleet replacement problem under customizable constraints or desired set of outcomes.

Autonomous taxi (AT) fleets have the potential to take over a significant amount of traffic handled nowadays by conventionally driven vehicles. In this regard, Bischoff and Maciejewski (2016) simulated a city-wide replacement

of private cars with AT fleets of various sizes. The simulation model comprises microscopic demand for all private car trips in Berlin (including incoming and outgoing traffic), out of which the internal ones are exclusively served by ATs. The proposed real-time AT dispatching algorithm was optimized to handle hundreds of thousands of vehicles and millions of requests at low computing times. Their simulation results suggested that a fleet of 100 000 vehicles will be enough to replace the car fleet in Berlin at a high service quality for customers. Eilon et al. (2017) described an interesting study in optimum replacement of fork-lift trucks using two models. The first one is related to minimum average costs per truck per year while the second one used the approach of discounted cash flow. The parameters were used in these models include the purchase price, the resale value, and the maintenance costs of the equipment.

Weissmann et al (2002) reported that The Texas Department of Transportation (DOT) owns and maintains an active fleet inventory of approximately 17,000 units and replaces about 10% of them annually. Any methodology that can improve Texas DOT's replacement procedures could potentially save millions of dollars. Private and public agencies do not routinely use life-cycle cost as a replacement criterion because the only way to automate inspection of thousands of life-cycle cost histories has been to define an acceptability threshold for annualized costs. Most fleet managers consider this practice too inaccurate. The most relevant information provided by a lifecycle cost graph is its trend. Units whose life-cycle costs have been increasing longer or at a faster rate should have higher replacement priority. The trend score concept allows a computer to mimic replacement decisions made by a person visually inspecting a series of life-cycle cost histories. A new economically sound methodology for assisting with equipment replacement at Texas DOT has been presented (Weissmann et al, 2003). This new method took full advantage of Texas DOT's comprehensive equipment operating system database and can prioritize the units based on comparisons among all units within any desired class of equipment, as well as used LCC trends as a replacement criterion. This methodology was implemented through the Texas Equipment Replacement Model, a menu driven software that allows the fleet manager to efficiently apply the methodology.

Recently, the use of more sustainable forms of transportation such as electric vehicles (EVs) for delivering goods and parcels to customers in urban areas has received more attention from urban planners and private stakeholders as an improvement situation for reducing transport's impact on climate (Liljestrand, 2016). To provide some insights toward the use of EVs, Ahani et al. (2016) developed an optimization framework using portfolio theory, which takes into account the cost and the risks associated with some input parameter uncertainties, for determining an optimal combination of EVs with internal combustion engine vehicles (ICEVs) in urban freight transportation (UFT) over some planning time period. This model can assist an urban freight operator to choose the best investment strategy for introducing new vehicles into its fleet while gaining economic benefits and having positive impacts on the urban environment. When considering the risks that are involved, their numerical results showed that EVs have the potential to compete with ICEVs in UFT.

Kauffmann et al. (2013) did a great study towards fleet management performance monitoring. Their report has resulted into multiple areas. Those related to the analytical model, points related to the analysis of the class codes, and finally those involving more general operational recommendations. The following improvements to the analytical model provide the ability to make data driven decisions in the management of the fleet and significantly reduce the analytical effort. Although utilization is an important metric of performance, it is limited in ability to reflect the actual wear and tear experienced by equipment in the various classes. Consequently, model options were provided which reflect both utilization and equipment usage (hours or miles per year) since this parameter more directly reflects operating costs (fuel, maintenance, and repairs), and cost related trends. In the long term, it is likely utilization will become a less important measurement tool and more emphasis will be given to actual equipment usage. A second approach to economic life modeling, based on dividing the present value of the life-to-date cost by usage (cost/mile or cost/hour) was also integrated into the analytical capability, in addition to the equipment analysis model employing EUAC. This rate model provides a second economic measure which presents an alternative perspective for the optimal life of some classes with high data variability in a particular fleet. An additional technique was developed to determine optimal life for fleet classes, which have no usage data (odometer or hour meter) such as various attachments. These classes are analyzed on an annual cost basis. To provide a flexible and efficient approach to modeling depreciation, a method was developed to model decline in value based on the sum of the years' digits depreciation. The management analysis capabilities of the model have been expanded and automated. The developed modeling application automates basic steps such as development of utilization and fleet age histograms as well as automates calculations of economic life based on both the EUAC and rate models. Most importantly, it provides management with the capability to examine "what if" scenarios based on various levels of fleet reduction.

Next section gives the way that EUAC has used and provides detailed equations that give the concern an easier way to do the required calculations.

## 2. Methodology

The EUAC of a new asset can be computed if the capital investment, annual expenses, and year-by-year market values are known or can be estimated (Blank and Tarquin, 2005). In this research, the economy life of a selected fleet is addressed to be checked. Fleet economic life can be defined as the period of time (years) that yields the minimum EUAC of owning and operating it (Miller, 2008).

Comparison must be done on EUAC to propose the best time of replacing the said fleet. The recommended parameters in this research are listed below. Then, anyone interesting can use the tabulated proposed format (Table 1) to visualize the said inputs efficiently.

- Maintenance Cost (MC), which includes changing oil and repairs.
- Operation Cost (OC), which includes washing and fuel/ Diesel.
- Purchasing Cost (PC), which is the capital investment.
- Interest Rate (i).
- Resale Value at the end of the financial year (RV).
- Depreciation (D), which can be calculated as per the following formulas:  
 $D_n = RV_{n-1} - RV_n$  -----(1)  
 Where:  
 $D_1 = PC - RV_1$  -----(2)  
 $n \geq 2$  -----(3)
- Interest on PC (IoP), which can be calculated as per the following formula:  
 $IoP_1 = PC * i$  -----(4)  
 $IoP_n = RV_{n-1} * i$  -----(5)
- Total Marginal Cost (TMC), which can be calculated as per the following formula:  
 $TMC = MC + OC + D + IoP$ -----(6)

Table 1: Data Arrangement

Preparation Part of Known Data			
Years	1	.....	n
MC (\$)	MC <sub>1</sub>	.....	MC <sub>n</sub>
OC (\$)	OC <sub>1</sub>	.....	OC <sub>n</sub>
PC (\$)	PC		
RV (\$)	RV <sub>1</sub>	.....	RV <sub>n</sub>
i (%)	All study periods should have the same value		
Calculation Part			
Years	1	.....	n
D (\$)	D <sub>1</sub>	.....	D <sub>n</sub>
IoP (\$)	IoP <sub>1</sub>	.....	IoP <sub>n</sub>
TMC (\$)	TMC <sub>1</sub>	.....	TMC <sub>n</sub>

Where:

n: The study period and it is recommended to be 3 or 4 years.

Now, EUAC for each year can be calculated as formulated below:

$$EUAC_1 = TMC_1$$
 -----(7)

$$EUAC_2 = [EUAC_1(P/F, i\%, 1) + TMC_2(P/F, i\%, 2)](A/P, i\%, 2) \text{-----}(8)$$

$$EUAC_3 = [EUAC_2(P/A, i\%, 2) + TMC_3(P/F, i\%, 3)](A/P, i\%, 3) \text{-----}(9)$$

$$EUAC_4 = [EUAC_3(P/A, i\%, 3) + TMC_4(P/F, i\%, 4)](A/P, i\%, 4) \text{-----}(10)$$

Where:

P/F, A/P, and P/A: Single payment compound amount factor. For example, the first term is read “P given F at i% interest per period for n interest periods.” These factors can be found using compound interest tables (Sullivan et al., 2015).

### 3. Application and Results

Here, in this research, the case study is applied at Alfaisal University, Riyadh, Saudi Arabia. It is a private, not-for-profit, research university, comprising the Colleges of Engineering, Science and General Studies, Medicine, Pharmacy and Business. It has a range of state-of-the art amenities and equipment spread across seven major buildings on 36.7-acre ( $\approx 149,000 \text{ m}^2$ ) campus.

It has several fleets/ vehicles that serving the university needs. In this research, the one is using for grass balancing (Fig. 1) is studied. In coordination with Landscaping section under Facility department, the below data (Table 2) have been collected. This paper studied when that section can advise the leadership to replace the fleet in discussion. The study period is three years excluding the holidays and weekends. The selected fleet is covering three large grass areas, which are a fancy view to campus.



Fig.1: Grass Fleet

Table 2: Collected Data

Years	1	2	3
OC (\$)	70	90	135
MC (\$)	80	110	165
PC (\$)	805		
RV (\$)	605	455	200
i (%)		10	

Noting that the department had purchased the said fleet in a promotional price. The next step here is the calculation mentioned in methodology part in order to determine EUAC for each year. Table 3 shows the pre-calculation while Table 4 shows the calculated EUAC for each year.

Table 3: Pre-Calculation for EUAC

Years	1	2	3
D (\$)	200	150	250
IoP (\$)	80.50	60.50	45.50
TMC (\$)	430.50	410.50	595.50

Table 4: EUAC Results

Years	1	2	3
EUAC (\$)	432	423	475

From table 4, the minimum EUAC is for year 2, and therefore, the fleet should be kept for two years before being replaced.

#### 4. Conclusion

EUAC has given a valid managerial support for the concern department to have a glimpse on the expected operational status of the fleet in discussion. All related costs have been considered. It is planned to cover other assets like other vehicles, some electrical equipment, some mechanical equipment, etc at the same place using the same method by considering the associated costs. Also, other department and colleges have shown their interest in doing the same about their business duties. EUAC has given the most optimum clue about the time of fleet replacement, which led to have an operational plan in a cost-effective manner. Also, it can be done with other heavy-duty equipment like chillers or power transformers by considering more than 4 years period of time.

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## Biography

**Malek Almobarek** is a Saudi national. He was born on April 1983 in Kuwait City. He took his primary and secondary education at AlMawardi School where he was a consistent honor student. He graduated in Industrial Engineering from King Saud University in the year 2009. He did assistance to his professors at the same university with tutorial & site visits for the students before starting his experience journey by taking up a job as Plants Equipment Specialist in O&M department at GASCO, Riyadh. He worked there from May 2009 to Sep 2011. He then moved to Dallah Hospital, Dallah Health Co., Riyadh to work as Engineering Department Manager from Sep 2011 to Nov 2013. Thereafter, He joined Alfaisal University as Facility manager in Dec 2013 and currently discharging his duties as Senior Facility Manager. The areas of responsibility in his current job include Buildings and grounds maintenance; Projects; Cleaning; Catering and Leasing; Health and Safety; Procurement and Contract management; Security; Space management; Waste disposal; Mails, Housing and Transportation; Utilities and Campus infrastructure. It is here that he decided to further his studies while continuing to work and joined in Master of Engineering Management (MEM) program that Alfaisal University was offering. He scored GPA 4.0/4.0 and completed a research thesis on Water Budget Control Framework Using DMAIC Approach for Commercial Buildings. He graduated in April 2020 with a first honor and now is a full time PhD student in Design, Manufacturing and Engineering Management at University of Strathclyde, UK. Eng. Malek is a result oriented, Innovative, resilient, and collaborative. He is not only very good in academics, but also, he is an expert in Facility and Project Management; Procurement and Inventory Management; Supply Chain Management; Emergency Response; Environmental Control; Security Control; Contractor Oversight; Resource Allocation; Building Regulations; Building Systems; Fire Safety; Scheduling; Processes and Procedures; Hazardous Waste, etc. He is a member of Saudi Council of Engineering in the capacity of Professional Engineer and loves travelling, reading, bowling, and watching debates on TV.