

# An Integrated Model for Dimensioning the Reserve Fleet based on the Maintenance Policy

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**Abstract:** Usually, the Reserve Fleet, or Spare Fleet, of passenger urban buses, is based on indicators used in some international relevant companies and extrapolated for many others, almost as a dogma. However, it must be taken into consideration pragmatic variables intrinsic to the buses namely their maintenance and in a more pragmatic approach, indexing their availability and by consequence the reserve fleet indexed to the maintenance policy used in each company.

The paper discusses these subjects and presents a global model that integrates the maintenance planning policy, based on a condition monitoring model, maintenance Key Maintenance Indicators (KPI), and an economic life cycle model.

The paper presents some results based both in theoretical considerations and also in real data from an urban fleet of a European Country.

**Keywords:** Econometric models; Maintenance policies; Time series; Oil analysis; Diesel engines.

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## 1 Introduction

Nowadays, the public transport users are increasingly demanding about the quality of services provided, maintenance stands out as a competitiveness factor. The Life Cycle Cost (LCC) of a bus in urban transport is intrinsically dependent on the quality of the management of its maintenance, which is reflected on reliability and availability. There are still other aspects that need to be considered, such as fuel costs, inflation and real discount rates. The bus replacement time or renewal may be assessed by methods such as "economic life" or "useful life". These models are strongly discussed throughout the paper using data from a city bus company for its validation. The paper also refers to an approach about the conditioning maintenance based on oil analysis of urban buses engines, in which the evolution of its degradation is monitored in order to evaluate the potential impact of a conditioning maintenance policy on the reserve fleet. This approach should usually, lead to enlarge the maintenance intervals when compared to the systematic ones that would be used by default. As a result, the maintenance costs are reduced, and economic and useful lives are increased. The combination of the foregoing aspects has implications for the dimensioning of the reserve fleet, as demonstrated throughout the paper, which implies that maintenance, and in particular oil

analysis should be considered within a strategic perspective in the companies of road passengers transport. The determination of the time considered the most rational for the replacement of a passenger bus when framed in a fleet, has implications in determining the size of the respective reserve fleet implying to equation the economic variables, that can be divided into endogenous and exogenous: the first ones relates to operating and maintenance costs as well as the assets devaluation; the second ones to the imponderables of the market such as inflation and real discount rates, as well as energy costs, namely the fuel. The paper also presents an overview of the econometric models for replacement through a global model, with emphasis on availability and maintenance costs. The paper also discusses the relationships between some maintenance Key Performance Indicators (KPI), specifically the MTTR (Mean Time Between Repairs), the Mean Time Between Failures (MTBF), the Availability (D), and the Reserve fleet. The Return On Investment (ROI) is a financial indicator to evaluate the financial performance of the equipment that is used as a "bridge" between the maintenance and the financial management fields, showing the time when the equipment begins to generate profits to the company. It also analyses models to evaluate the influence of these variables on the withdrawal time and in the reserve fleet size, using the oil analysis as

an example. The paper also presents a framework synthesis of the preceding variables, through a global model, demonstrating its relevance to the analysis of the reserve fleet size and the withdrawal buses time. Finally, a Model Integrated Reserve Fleet Assessment (MIFRA) is presented, which can be integrated into a maintenance information system, through the addition of new conditioning and predictive maintenance modules, as well as the mentioned replacement models, thereby extending the potential of the existing information systems to global equipment lifecycle management perspective.

## 2 State of the Art

The current competitive environment increasingly demands companies for a constant improvement in all aspects. Thus, in order to obtain a leading position companies, aim to maintain their operating standards above the competitors.

Consequently, business development has led to a significant advance in terms of quality and productivity in most of the various industrial sectors. In the last three hundred years humanity has evolved greatly, production has increased, services have expanded, causing true industrial revolutions.

It is increasingly recognized that improving the quality of products and services is an extremely important issue for the organization's competitiveness. For those who produce or provide services, quality means greater customer or user satisfaction, increased competitiveness and success, as well as return on the assets invested.

It is under this perspective that the identification of the optimum time to replace a physical asset can be a determining element in the organization's competitiveness, through the costs reduction that can result from it, what can be indexed to the maintenance policy used.

Equipment replacement is a broad concept that ranges from the selection of similar assets, to the evaluation of assets that have different performance to the same function, such the ones with more functions and that are more efficient. Replacement decisions are of critical importance for organizations in any sector, often implying the survival of the organizations themselves.

There are several non-exclusive reasons that make equipment replacement economical. Deterioration is one of the causes that is revealed by excessive operating and maintenance costs. There are situations in which the change of a current operation an equipment loses the capacity to operate efficiently, that is, the equipment becomes inadequate.

The efficient use of physical assets is one of the main objectives in the management of organizations, namely public or private. These organizations are

subject to a large set of mandatory rules, including the exigence of the players that use the facilities (employees, users, service providers and visitors).

The set of ISO 5500X standards appears to respond to this need to better manage the life cycle of the organization's physical assets, ensuring the level of competitiveness, without compromising the level of excellence of the products / services offered. The ISO 55001 standard proposes a methodology to manage assets in accordance with the Organization's strategic objectives, supporting decisions on acquisition, replacement and or their disposal; this is in line with practices aimed at the environmental, social and economic sustainability of the equipment and of the company itself, ([33], [78], [79], [80] and [90]).

According [32], the mechanization associated with the Industrial Revolution of the 19<sup>th</sup> Century highlighted the need to regularly repair machines; however, these interventions were left to the operators themselves. Only after World War I the industry was pressured to reach minimum production standards, leading to the establishment of specialized teams to repair the damages in the shortest possible time. These teams, however, were limited to corrective maintenance, remaining dependent on production.

Unplanned maintenance corresponds to a policy in which interventions seek to recover the equipment to reach its normal operating state after the failure has occurred.

Unplanned maintenance is the simplest and most primary form of intervention being a management option, usually very expensive when economically evaluated from the point of view of the system's operation [42]:

- Low utilization and reduced equipment life, consequently impacting the productivity of the resources of production, regardless of whether they are products or services;
- The stop for maintenance at random, and often inopportune moments, with very high indirect costs.

In the 1930s, mass production in industrialized countries and the international situation that preceded World War II, forced them to produce more and more. The companies then started to worry, not only in correcting the failures, but also in preventing their appearance, which widened the scope of maintenance that also started to act on the prevention of anomalies.

On systematic planned maintenance, interventions follow a program that is intended to be executed periodically, with intervals being measured according a certain time unit or in another parameter of use that translates the operation of the equipment, also called "systematic preventive maintenance".

Systematic planned maintenance or preventive planned maintenance consists of a methodology for the prevention of defects that are likely to cause the stoppage or low performance of production equipment or systems [25]. It is associated with traditional maintenance management systems, currently supported by computer media. They do not prevent faults from occurring, but they do allow shorten downtime. This prevention is usually developed based on statistical studies, equipment status, location or operating conditions and data provided by the manufacturer (optimal operating conditions, lubrication points and frequency, etc.). The indexes usually extracted from the database are MTBF and MTTR [35]. Although the degradation processes of the equipment are different from case to case, and the causes of failures themselves are also different, these indices are especially useful, particularly in situations where the standard deviation of the times between occurrences is reduced. Among the advantages that are associated with this maintenance profile, the following can be enumerated:

- Decrease in the total number of corrective interventions, consequently reducing the associated costs;
- Strong reduction in the number of breakdowns occurring at inopportune moments, such as, for example, night periods, weekends and critical periods of production;
- Significant increase in utilization / availability ratios.

The expansion of commercial aviation, starting in the 1940s, brought new challenges to maintenance. On the one hand it compelled to develop preventive methods, since the repair of breakdowns during the flight is rarely possible, and on the other hand it accentuated the problem of the safety of people and goods.

The advent of computers has led many companies to implement systematic preventive maintenance strategies. This approach still dominant today, typically uses maintenance planning programs to control calendar-based maintenance activities to trigger work orders automatically.

[19], stats that the designation of conditioned maintenance appeared in the 70-80's to designate a new approach to preventive maintenance, based on knowledge of the real state of the machines, from the implementation of a condition control system.

It is a matter of deciding the opportunities for interventions in equipment based on knowledge of its real state, instead of carrying out planned maintenance work at fixed intervals, as is the case with systematic maintenance, they are carried at variable intervals determined by the state of the

equipment. Conditioned maintenance focus on equipment considered individually, replacing revisions at fixed intervals with inspections at fixed intervals. The economic benefits of conditioned maintenance arise from gains from reduced production losses, due to increased equipment availability and gains from reduced maintenance costs, however this methodology needs to consider the additional costs of data collection, either manually or automatically.

There are several techniques for controlling the condition of machines and equipment with application in maintenance, of which the following stand out: vibration analysis, thermography, analysis of performance parameters, visual inspection, ultrasonic measurements, and analysis of service lubricants.

In the mid-1980's, technological advances in instrumentation and the growing of the personal computers enabled the ability to predict problems in machines by measuring their condition using vibration, temperature and ultrasound sensors, this technology is often referred to as predictive condition maintenance. Another more advanced maintenance strategy called Proactive Maintenance allows to prolong the failure cycles of the machines by systematically removing the sources of failure.

According to [65], one of the main objectives of modern maintenance management is to maximize the availability of equipment, while lowering the cost and raising the quality, maintaining safety and preserving the environment.

Around the year 2000, industrial processes gained new challenges in terms of productivity and quality with the trend of globalization of the economy. The large investment in fixed assets, together with the increase in costs, begins with a process of high expectations regarding maintenance. Such expectations are found in the functions and results of the maintenance, in the new interpretations of the processes of equipment failures and in the new techniques of analysis and implementation of the maintenance, thus creating alternatives that can maximize the useful life of the physical assets. Since 2000, maintenance has been part of integrated management systems, considering the improvement of maintenance and maintenance engineering, using advanced technology of interconnected systems, optimized investments, and intelligent products. According to [68], maintenance has evolved more than other management functions, due to the increase in the number, complexity and diversity of facilities, equipment and production systems.

If before the maintenance objective was to restore the original conditions of a certain equipment or system, according to [32], currently maintenance guarantees the availability of equipment and systems

in order to meet the production process at an appropriate cost, with safety, reliability and preservation of the environment.

The vision presented by [32], in which he states that “with the evolution of the various maintenance concepts, and with the development of new approaches and methodologies applied to other management aspects, namely in the area of quality and production, the activity maintenance started to mesh, to include and adapt these new concepts”, being of high importance for organizations.

For [101], many years after the appearance of the first information system for maintenance management, some basic problems remain, now with new frontiers. The concept started with simple maintenance, went through therotechnology [45], total productive maintenance, therology [31], until reaching maintenance centered on reliability [69]. Therology is defined as the combined use of operational research, information management and engineering techniques, with the aim of monitoring the equipment's life cycle. It includes the definition of the specifications regarding its acquisition, installation, and reception, as well as the management and control of its maintenance, modification and replacement and, also, its monitoring in service.

The maintenance of passenger transport buses is a strategic activity to guarantee the fulfilment of its life cycle, which implies combining management, technical and economic actions, in order to obtain a high availability at rational costs, ([6], [9], [10], [14] [48] and [54]).

[6] report that poor maintenance management contributes to a significant financial cost. The theoretical basis of this subject shows that the life cycle cost (LCC) of an asset represents the sum of all the capital spent to support the asset, from design and manufacture, through the operation until the end of its useful life (CAPEx + OPEx - Capital expenses + Operating expenses), [9].

The LCC of an asset corresponds to the sum of all capital spent on supporting that asset from its conception and manufacture, through the operation until the end of its useful life [10].

The LCC of an asset can be significantly higher than the value of the initial investment and, in many cases, is defined right at the project stage [9].

[14] goes further and reinforces this idea, pointing out that 70 to 90% of these total LCC costs are defined in the design and manufacture phase.

The initial investment costs are usually the most used as a primary criterion, and sometimes, the only one in the purchase decision. Despite the obvious long-term benefits of LCC analysis, its adoption has been relatively slow. Possible reasons for this include the lack of standard or formal guidelines and the absence

of reliable previous data. The number of cross-case studies in the field of LCC is extremely low and most of them are limited to a single industry [54].

[48] provide an overview of the use of the LCC and its feasibility of implementation, through a summary of the work and its application.

Life cycle cost analysis is a forecast of the future and, as such, different methods are generally used to make cost estimates, such as Activity-Based Costing (ABC), ([29] and [30]).

To support the LCC analysis, there are related standards and documents, such as those referred to in ([11], [12], and [46]). The asset management standards that followed [12], that is, [46] (ISO 55000:2014, ISO55001:2014 and ISO55002:2018), are good sources as guidelines for the management of assets and can be applied in any sector.

[10] illustrates how, throughout the life cycle of an equipment, the mastery of concepts and some financial calculation tools become essential for maintenance managers and organizations.

However, the systematic study in this area remains underdeveloped, with the need to apply and create new models of equipment management that can bring added value to companies, in order to improve their productivity and quality of service, taking into account the aspect environmental sustainability, including standards for quality management, environment, safety, maintenance and energy, [32]. It is also noted that many companies keep equipment in operation, even when its operation is no longer economically viable, because it does not follow its economic cycle, [32], which has exogenous implications, namely in the size of the reserve fleet, in the case of bus fleets.

[112], traditional production systems are built on the principle of economies of scale. This author also illustrates an equipment replacement problem, in the context of Lean Thinking.

[114] refer to technological change as a motivator for the replacement of equipment. In scientific references, it is commonly assumed that technology develops continuously according to a well-defined function.

[73] demonstrate that combining continuous and discrete models, over time the equipment replacement period is shorter when the incorporated technology is longer.

According to [8], “the valuation of an asset is established by the expected future benefits of the cash flows referred to the present value, through a discount rate that reflects the risk of the decision”. Consequently, the methods that consider the value of money over time are the most suitable.

According to [23], the Equivalent Uniform Annual Cost method is adequate in the analysis of the company's operational activities, with investments

that can be repeated. In addition, the standardization of investment results to equivalent annual values makes the analysis of these results easier for decision making. The use of this method aims to determine in which year the lowest equivalent annual cost occurs, which indicates the best period for replacing the technical asset [23].

The calculation of the equivalent annual cost is due to the use of the Capital Recovery Factor and it is through it that two or more investment opportunities can be compared and determine the ideal time for the replacement of the equipment, taking into account information such as: investment or acquisition value, resale value or residual value at the end of each year, operating costs and capital cost or the attractive minimum rate [107].

The problem of determining the economic life of equipment for replacement purposes is seen in four types of situations [67]:

- i. When the property is already inadequate for the activity;
- ii. When the asset has reached its useful life limit;
- iii. When the good is already obsolete, due to technological advancement;
- iv. When more efficient methods prove to be more economical.

At a certain point in the asset's life cycle, it's important to assess whether is of interest to keep it in operation or to replace it. For this purpose, the following aspects must be considered [32] and [33]:

- i. Availability of new technologies;
- ii. Compliance with safety or other mandatory standards;
- iii. Availability of spare parts;
- iv. Obsolescence that may limit its use.

After listing the aspects related to the last point of the equipment's life cycle, it is important to characterize some calculation methods to determine the appropriate time for its replacement. For this purpose, it is necessary to consider several variables, such as: acquisition value, assignment amount, operating costs, maintenance costs, operating costs, inflation rate, and capitalization rate.

The values of most of the preceding variables are obtained through history, except for the assignment value, in this case, the market value for each specific piece of equipment will have to be obtained, which may prove difficult for many goods. Alternatively, several types of devaluation can be simulated, such as the following ([32], [33] and [76]):

- Linear depreciation method - the decline in the value of the equipment is constant over the years;
- Digit sum method - annual devaluation is non-linear;

- Exponential method - the annual depreciation charge is decreasing over the life of the equipment.

Another method usually used is the "useful life" method, which defines that it ends when its maintenance costs exceed the maintenance costs plus the amortization of the capital of an equivalent new equipment. According to [32], there are several methods for determining the economic cycle of equipment replacement. The most common are the following:

- Uniform Annual Income Method (MRAU);
- Average Total Cost Minimization Method (MCMT);
- MCMT method with reduced present value (MCMT-RVP).

[34] illustrate the efficient use of fixed assets as one of the main objectives in the management of companies in urban passenger transport sector.

In companies of road transport sector, the efficient use of assets is linked to a well-structured fleet assessment and replacement policy. Some cases of fleet replacement applied to the city bus segment are reported in ([13], [28], [39], [47], [84], [88], [89], [91], [92], [93], [94], [95], [96], [97], [98], [99], [111] and [118]).

[13] proposes a policy for optimal replacement intervals for programming technical systems based only on the maintenance cost parameter: a system is replaced by a new one as soon as the maintenance cost within a replacement cycle reaches or exceeds one certain level.

[39] studied and described an industrial application of an Energy Law Process (PLP - Power Law Process) for bus engine failures and a theoretical replacement model.

[84] adopted a model for a problem of replacing the transit fleet with various types of buses. However, many costs were highly simplified or were not based on real data, and the variability in vehicle characteristics, uses and market fluctuations have not been studied. The cost of replacing, remanufacturing and rehabilitating a bus has been a focus of research by [47], as well as the optimal allocation proposed by the Federal Transit Administration (FTA). Other lines of investigation have focused on statistical analysis of fleet data and on the relationships between age, use and costs, [28].

[88] present a new approach to economic models for determining the most suitable time for replacing buses in a company's urban fleet. The presented study allows the assessment of the equipment's life cycle by the managers and, obviously, it is a decision support tool. It was shown in the study that there is a variation of the ideal moment for the replacement of

a vehicle in a fleet, given by the analyses carried out by the Uniform Annual Income model.

A numerical solution is proposed and illustrated by [99], using data from a given fleet, they considered a two-cycle replacement model, with decision variables based on the age of replacement of the current fleet, where the size of the new fleet is considered, the optimal values for the decision variables can be found by minimizing the total cost discounted per unit of time or the value of the equivalent income.

Many studies consider reliability parameters and maintenance costs to help assess more rational replacement decisions, for example: ([88], [89], [91], [92], [93], [94], [95], [96], [97], [98], [99], [111] and [118]).

[22] present a proposal for a generic model of stochastic process based on neural networks, called Neuronal Stochastic Process (PEN), which can be applied to problems, involving phenomena of stochastic behavior and or with periodic characteristics. Through the PEN neural networks, the behavior of the historical series of these phenomena is modeled without needing a priori information about the series, generating synthetic time series, equally adaptable to the historical series. Some cases of use of neural networks and stochastic models are reported in ([3], [7], [22], [38], [43], [44], [55], [62], [71], [109] and [117]).

There are other tools that can contribute to the development of a new model of vehicle replacement optimization, such as, Fuzzy Logic and the Support Vector Machine (SVM): ([21], [24], [27], [86], [106] and [115]).

Regarding predictive maintenance, and specifically the analysis of oils, some mathematical models and concepts were used, which are referenced by the following authors: ([4], [5], [17], [19], [32], [33], [40], [56], [57], [58], [66], [88], [89], [91], [92], [93], [94], [95], [96], [97], [98], [99] and [116]).

[5] justifies the utility and necessity of mathematics in engineering, analysing the main mathematics courses in engineering courses, reflecting on the real or desirable connection between mathematics and engineering courses. Finally, it points out the interest in carrying out statistical analyses and details these analyses with some examples.

Predictive maintenance is often referred to as condition monitoring or condition-based maintenance, that is, it evaluates the real state of the equipment using specific equipment, with the aim of adjusting the preventive maintenance planning, detecting possible failures early, avoiding the emergence of complex problems, and provide decision-making based on real data.

The standard [74] defines predictive maintenance as "conditioned maintenance carried out in accordance

with the extrapolated forecasts of the analysis and evaluation of significant equipment degradation parameters".

[66] defines predictive maintenance as regular monitoring of the current state of mechanical conditions, efficiency of operation, and other indicators, in order to provide data that ensure the maximum interval between repairs and that minimize the number and cost of unscheduled stops. [17] presents predictive maintenance as an approach that compares the trend of measurements of the analysed physical parameters (vibration, pressure, current, temperature, ...) with the limits established for these parameters, in order to detect, analyse and correct problems before that lead to equipment failure.

According to [53] the adoption of predictive maintenance details the physical items for control and maintenance of the quality of the final product that is generated in the equipment. [104], on other hand, defines that predictive maintenance is the one that indicates the real operating conditions of the machines based on data that inform about their wear or degradation process.

According to [77], predictive maintenance corresponds to interventions that ensure the desired quality of service, based on the systematic application of analysis techniques, using centralized supervision or sampling methods to minimize preventive maintenance and reduce corrective maintenance.

These points of view and the definitions of predictive maintenance mentioned above reinforce the importance of this type of maintenance in the life cycles of the equipment, thus allowing better monitoring and better management of the equipment.

Regarding oil analysis, [57] show the results of a fleet test, whose main objective was to measure the influence of low viscosity oils (LVO - Low Viscosity Oils) on the fuel consumption and CO<sub>2</sub> emissions of city buses. To perform this test, 39 city buses were used, classified in groups according to the viscosity of the engine oil they use; in this study the vehicles covered 60,000 km, which correspond to two oil change intervals, these authors have over the years published articles on bus fleets.

[87] and [93] present a study referring to urban bus engine oils, in which the evolution of its degradation is monitored, with the aim of evaluating the potential impact of a conditioned / predictive maintenance policy on management companies related with fleets of city buses. Through the analyses obtained in the lubricants in service, precious information about the operating conditions of the engines can be collected, which are indispensable for the optimization of their operation. Based on this information it is possible to

assess the condition of the engines, determine the most appropriate moment for their replacement and, additionally obtain a diagnosis in the condition of the equipment and its evolution. In this study, the time intervals corresponding to a required level of reliability were determined, consequently obtaining more suitable intervals for planned maintenance interventions. With this monitoring of the degradation of lubricating oils, the safety of the operation of buses is further increased, costs are reduced, and energy efficiency is improved., in the study of the influence of a conditioned / predictive maintenance policy on the reserve fleet, the KPIs considered most suitable for this purpose were used. [20] read: "the term used for maintenance performance indicators in an Industry is the acronym KPI". KPIs can measure different performances, ranging from the time of equipment failure to the production process. Currently, software programs installed in many companies can offer a few dozen KPIs, but you need to pay attention to those that really add value. In this sense, it is important to select the most appropriate to achieve the desired objectives.

According to [20], the standard [75], "Maintenance - Maintenance Performance Indicators (KPI)", in its introduction, "... establishes maintenance performance indicators, to support management in order to achieve excellence in maintenance and use of fixed assets in a competitive manner. Most of these indicators apply to all industrial facilities and services (equipment, buildings, infrastructure, transport, among others)".

Regarding the maintenance performance indicators that are used to measure and evaluate the management of equipment and maintenance, the following authors refer: ([35], [37], [49], [50], [63], [70], [72], [81], [105], [108] [110], and [114]). The definition of an indicator must include at least the following characteristics: name, type (economic, technical, organizational, etc.), precise definition and data necessary for its calculation, by definition, it refers to the mathematical formula that relates the name of the indicator with the data necessary for its calculation. The maintenance indicators must be evaluated for the objects under analysis, in each time interval, and the analysis of the results can focus on the absolute values of that indicator or on the trend it demonstrates [63].

Along with the definition of the indicators, a hierarchy must be established for them.

Used correctly, performance indicators should highlight opportunities for improvement in companies and subsequently be subject to more in-depth analysis to discover the reason for their value. They can even point directly to the solution of the problem [114].

Unlike the case of other functions, such as production, the measurement of maintenance performance is still very incipient, many tools and techniques have been developed and applied in other fields and areas, but the application of these tools to the maintenance function still needs to be increased, although their correct use can help more efficient maintenance management, given their great technical growth and technological complexity. [82]. To know what to measure it is necessary to outline the entire maintenance process within the organization and all its interrelationships, is essential to understand the entire process in detail, before starting any study for the development of a maintenance performance measurement system in organizations with some complexity, so that this implementation can be done with the least possible difficulty [83]. It is not too much to repeat that the failure rate in the implementation of these systems is very high (70%) ([15] and [16]), within the few attempts at implementation that are attempted.

The fundamental objective of managers is to maximize the profit of organizations and, to achieve this, the contribution of maintenance is increasingly important. Thus, a different approach is needed to make top management aware of the need to be involved in the maintenance improvement process [6].

A performance management system acts as an early warning system [83] and can promote a management system for maintaining knowledge within the company, which is certainly one of the main concerns of top management.

As subjectivity grows, with the increasing integration of information into higher-level indicators [49], great care must be taken when preparing executive reports. Active support from top management to the maintenance performance measurement system is achieved using useful and accurate information at the right time.

Also, the environmental, safety and health issues, with the enormous legislative burden they have, give maintenance managers a unique responsibility in managing the risk of the installations, since the maintenance actions or omissions contribute to the level of risk to be reached. that the organization, its workers and the surrounding communities are exposed [64], being matters of close monitoring by top management, for their direct consequences.

From the maintenance manager's perspective, resources are costly, finite and usually below the level they should be, which is why they must be applied in fact where they are important. The degree of importance of each machine, operation or process must be clear at all levels: operational, control, and management, and it must derive from the company's strategy.

Production interruptions, breakdowns, power failures, lack of labour, stock rupture, intervention requests and others, affect production making the maintenance planning process dynamic. The limited existing capacities must be shared by all systems that need them all the time and this competition can result in waiting times for some of those systems. Maintenance must achieve its defined objectives through production objectives and, simultaneously manage operational constraints with production [41]. Performance measurement helps to show and decide from existing trade-offs in all aspects of performance, not all performance indicators will be of equal importance for all operations and will have a profit or loss ratio or other [102].

The trend in the use of performance measurement systems in maintenance shows that more complex systems are being abandoned in favour of simpler models, also demonstrates that the use of standard management systems is a way of not implementing these systems, as it is necessary to have a great knowledge of the maintenance process in question as well as its strategic positioning in each organization [49].

For the implementation of a system to be successful it is imperative to obtain support from top management, which will only exist when it is shown the importance of maintenance.

With the selection of performance indicators appropriate to each area, it is possible to detect deviations at initial stages, identifying the origins of these deviations, and thus achieve problem solving and more economical continuous improvements [1]. Below are some examples of indicators that can be used in the maintenance management of some organizations:

- Activity indicators
  - Number of interventions by type of maintenance;
  - Degree of compliance with preventive maintenance plans;
  - Percentage of Preventive versus Corrective Maintenance.
- Indicators of effectiveness
  - Reliability (MTBF);
  - Maintainability (MTTR);
  - Availability.
- Financial indicators
  - Damage repair cost;
  - Maintenance cost per equipment / bus;
  - Cost / Km or Hour of the equipment / bus;
  - Cost of subcontracted maintenance.
  - Equipment / bus ROI.

[105] critically analyse the standardized indicators, in order to find the essential indicators to guide the maintenance values and to estimate the Net Present

Value (NPV), terminology that contains the performance guidelines and maintenance indicators has few published, and is not described in detail, namely in asset management.

[50] provide an overview of the research and development of the measurement of maintenance performance, they consider the various measurement problems and comment on the lack of structure and references for measuring maintenance performance. The focus is to determine how value can be created for organizations, measuring maintenance performance, examining maintenance strategies, such as condition-based maintenance, reliability-centered maintenance, etc. In other words, it aims to find structures or models that can be used to evaluate different maintenance strategies and determine the value of those structures for an organization.

According to [35], increasing availability is a classic objective of maintenance services, which implies an increase in equipment reliability (MTBF) and a reduction in intervention times (MTTR), [36], increasing availability consists of reducing the number of stops due to damage and repair and inspection times: from this it is concluded that it is not enough to have reliable equipment to obtain high rates of availability, but that it is also necessary to guarantee maximum speed in repair, maintenance and inspection operations.

In order to improve the availability and operational safety of the equipment, all malfunctions known as having catastrophic consequences must be eliminated, as well as the life of the components must be increased, because each time a breakdown occurs due to a malfunction or replacement of components, check if an important stoppage of the equipment and or a loss of operational safety. The decisive factors to prevent this from happening are based on a correct design of the equipment and installations, and on an effective and efficient maintenance, after its start-up [37].

The indicators of the quality criteria most valued in terms of importance given by the regular transport customer are the reliability of the equipment and its availability, as their malfunctions lead to increases in waiting times, leading to punctuality failures and non-compliance with timetables, which are decisive factors for the choice of transport to be taken by the end customer.

The service provider must pay attention to the size of its fleet, and the quantity must meet the needs, the larger the size of the fleet, the greater the investments with its acquisition and maintenance. Thus, and in accordance with the principles of rationalization of investments and minimization of costs, the actions taken should be directed towards increasing the availability of buses.



According to [2], there are some methods for evaluating investments. For example, decision trees can be used to make a probabilistic analysis of the various possible scenarios or use traditional methods, translated into the form of financial indicators. As an example of financial indicators of these methods, we can refer to the Net Present Value (VAL), the payback (which corresponds to the investment recovery period), the Internal Rate of Return (IRR), and the Return on Investment (ROI). The economic climate is increasingly complex, and organizations have an absolute need to improve their performance, by increasing their ROI ratios [36]. In this context, industrial organizations of all types and sizes, but especially those with capital intensive, must face levels of uncertainty, as to whether or not they are able to achieve their economic and financial objectives, [6], the effect of this uncertainty on the objectives of organizations represents the "risk". In order to ensure that this risk is controlled and that the ROI ratios are ensured in a sustained manner, it is necessary to manage the equipment taking into account its entire life cycle.

In finance, ROI and the Rate of Return (ROR), profit rate or simply return, is the relationship between the amount of money earned (or lost) as a result of an investment and the amount of money invested.

Advance knowledge has an important impact not only within the organization that manages the investment process, but also with potential investors. In addition to the internal and external "sale" of the equipment, it is essential for its monitoring, giving a clear indication of the impact of physical assets on the business in relation to the pre-defined goals.

The innovation that differentiates the approach, which will be presented in this article, lies in the fact that improved econometric models were developed through the introduction of maintenance KPI which allows a better monitoring of the equipment's LCC.

### 3 Econometric Models

This model of analysis allows determining the most rational period for replacing buses and, consequently, the Reserve Fleet, given that the first involves the second. This approach is valid for new and used buses. Obviously, the technological and environmental aspects are left out of this analysis.

To give the final step to implement the integrated model for determining the reserve fleet, we will discuss the influence of MTTR on the Economic Cycle for replacing buses throughout their life cycle. It is also intended to integrate the ROI of a bus with the replacement business cycle. For this, several systems of equations are presented, starting with the Uniform Annual Income Method (RAUn), taking into account the Return on Investment (ROI) as a function of the Mean Time of Repair (MTTR).

The first tool that is necessary to introduce is the exponential smoothing, it's very important for the prediction of the oil degradation. The formula for exponential smoothing is given by:

$$S_{t+1} = \alpha \times x_t + (1 - \alpha)S_t \Leftrightarrow S_{t+1} = \alpha \sum_{i=0}^t (1 - \alpha)^i x_{t-i} \quad (1)$$

$$0 \leq \alpha \leq 1$$

Where,

- $S_{t+1}$  Is the forecast for the next time;
- $x_t$  Is the real value recorded in the present time;
- $S_t$  Is the forecasted value for the present time;
- $\alpha$  Is the smoothing parameter.

Based on this tool, and the result of the oil analysis, namely Soot, among others, it is possible to forecast the next maintenance intervention based on the oil condition.

The econometric models to support the evaluation of the bus's replacement time and some additional considerations to aid their analysis, are made next.

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, because the operating, 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 discount rate.

The most values of the variables can be obtained from historical data, except for the withdrawal value. However, it may be not easy to get the market value for an equipment in particular. One solution is to simulate devaluation using one of the following methods ([32], [33] and [76]):

- 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 [32] equipment can be replaced by various criteria. 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 relevant variables above referred that must be considered are:

- i) real discount rate,  $i$ ;
- ii) inflation rate,  $\theta$ .

These rates are related as follow:

$$i_A = i + i + \theta \times \theta \quad (2)$$

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  $n$  ( $VPL_n$ ) is given by:

$$VPL_n = CA + \sum_{j=0}^n \frac{CM_j + CO_j}{(1+i_A)^j} - \frac{V_n}{(1+i_A)^j} \quad (3)$$

Where,

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

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

$$RAU_n = \frac{i_A(1+i_A)^j}{(1+i_A)^j - 1} * VPL_n \quad (4)$$

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.

The  $RAU$  indicates the period (in years), when a bus ought to be replaced. This value is equivalent to the minimum annual cost of the bus.

To apply the models, we consider variables related to direct operating and maintenance costs, as well as the relevant economic indicators, such as inflation and interest rates.

Initially, we performed a survey of the operating data for the Life Cycle Cost (LCC) from a bus fleet belonging to a medium-sized public urban transport company.

Another important variable that must be considered in econometric models to replace equipment is the Cost of Maintenance (CM). This variable is very relevant in determining the most adequate time to replace an equipment, in this case an urban passenger bus. One of the advantages of condition monitoring maintenance (with prediction) based on oil analysis is the reduction of maintenance costs, what also influences the replacement time. Monitoring the degradation of oil influences the maintenance KPI's, namely, the Mean Time to Repair (MTTR) and the Mean Time Between Failures (MTBF): lower MTTR and higher MTBF values indicate that maintenance is supporting well the production operations, because the availability increases. The following equations express the Availability (A), the MTTR and the MTBF respectively:

$$A = \frac{MTBF}{MTBF + MTTR} \quad (5)$$

$$MTTR = MTBF \times \frac{(1-A)}{A} \quad (6)$$

$$MTBF = \frac{MTTR}{\frac{(1-A)}{A}} \quad (7)$$

To determine the size of the reserve fleet, the following calculation can be used:

$$FR = \frac{m \times MTTR}{k} \quad (8)$$

where

$FR$  Reserve Fleet;  
 $m$  Number of fleet buses;  
 $MTTR$  Mean Time To Repair;  
 $k$  Number of days per year.

## 4 Predictive Maintenance versus reserve fleet

The Life Cycle Cost (LCC) of equipment covers their all costs, from project to disposal; it is a very important approach for determining the optimum time for replacement of a bus.

When deciding on equipment management, the maintenance costs, the operating costs, the total cost of ownership, the accrued costs, and the Return on Investment (ROI) are considered.

The previous section describes the models and tools necessary to implement an integrated model for determining the reserve fleet. Based on them, it can be implemented a new integrated management model that can be named by: Integrated Model for Evaluation of the Reserve Fleet (MIAFRA), which is summarized in the following approach:

- Econometric models for determining the minimum LCC value
  - Uniform Annual Income considering the following variables:
    - Functioning costs
      - Maintenance Costs
      - Fuel Costs
    - Replacement Value
    - Inflation Rate
    - Capitalisation Rate
- Useful life model considering the following variables:
  - Functioning costs
    - Maintenance Costs
    - Fuel Costs
  - Replacement Costs
  - Inflation Rate
  - Capitalisation Rate
- Conditioning / predictive maintenance models to maximize availability
  - MTBF
  - MTTR
  - Availability

The above approaches constitute a single model of analysis that allows determining the most rational period for replacing buses and, consequently, the Reserve Fleet, given that the first involves the second.

It should be noted that the previous integrated approach is valid for new and used buses, considering the effect of monetary correction. Obviously, the technological and environmental aspects are left out of this analysis.

Next, to give the final step to implement the integrated model for determining the reserve fleet, we will discuss the influence of MTTR on the Economic Cycle for replacing buses throughout their life cycle. It is also intended to integrate the ROI of a bus with the replacement business cycle. For this, several systems of equations are presented, starting with the Uniform Annual Income Method ( $RAU_n$ ), considering the Return on Investment (ROI) as a function of the Mean Time of Repair (MTTR).

$$\left\{ \begin{array}{l} RAU_n = \frac{i_A(1+i_A)^n}{(1+i_A)^n - 1} * (CA + \sum_{j=0}^n \frac{(t * MTTR * \frac{CM_j}{d}) + CO_j}{(1+i_A)^j} - \frac{V_n}{(1+i_A)^n}) \\ ROI = \sum_{j=1}^n \frac{CF_j}{(1+i_A)^j} - CA \end{array} \right. \quad (9)$$

Being,

$t$  Number of periods considered for MTTR  
 $d$  Number of days per year

The Total Average Cost Minimization Method (MCMT) and the ROI as a function of MTTR can be described as follows:

$$\left\{ \begin{array}{l} C_{n(MCMT)} = \min_{n \in \{1, 2, \dots, N\}} \frac{1}{n} \left( CA - V_n + \sum_{j=1}^n \left( (t * MTTR * \frac{CM_j}{d}) + CO_j \right) \right) \\ ROI = \sum_{j=1}^n \frac{CF_j}{(1+i_A)^j} - CA \end{array} \right. \quad (10)$$

MCMT with Reduction to Present Value (MCMT-RVP) and the ROI as a function of MTTR can be written as follows:

$$\left\{ \begin{array}{l} C_{n(MCMT-RVP)} = \min_{n \in \{1, 2, \dots, N\}} \frac{1}{n} \left( CA - \frac{V_n}{(1+i_A)^n} + \sum_{j=1}^n \left( \frac{(t * MTTR * \frac{CM_j}{d}) + CO_j}{(1+i_A)^j} \right) \right) \\ ROI = \sum_{j=1}^n \frac{CF_j}{(1+i_A)^j} - CA \end{array} \right. \quad (11)$$

Throughout the paper, the importance of monitoring the condition, its relationship with the MTTR and the importance of this KPI for the temporary replacement of a bus was highlighted. To show this relevance, an example of the influence of this reason is given, using the Uniform Annual Income Method. Table 1 and Figure 1 demonstrates the influence of MTTR on the bus replacement time. To simulate this influence, values of 5, 10, 20, 25, 30 and 35 days were used for MTTR.

Table 2 and Figure 2 shows the influence of MTTR on econometric models. An increase or decrease in MTTR over time varies the point of withdrawal from the equipment. The replacement point can vary by more than nine years. That is, the replacement time is five years, but if there is a decrease in MTTR, the replacement time increases to 14 years.

Additionally, it is relevant to analyse the influence of economic indicators for the evaluation of investments, such as ROI. To emphasize its importance, the influence of MTTR versus ROI on econometric models can be verified.

Table 1 – Influence of MTTR on RAU

Vehicles												RAU[€ Year n]					
Year j	CA [€]	φ [%]	i [%]	i <sub>A</sub>	i <sub>A</sub> [%]	MTTR <sub>1</sub>	MTTR <sub>2</sub>	MTTR <sub>3</sub>	MTTR <sub>4</sub>	MTTR <sub>5</sub>	MTTR <sub>6</sub>	RAU & MTTR <sub>1</sub>	RAU & MTTR <sub>2</sub>	RAU & MTTR <sub>3</sub>	RAU & MTTR <sub>4</sub>	RAU & MTTR <sub>5</sub>	RAU & MTTR <sub>6</sub>
0	110,66K	4%	4%	0,08	8%												
1		4%	4%	0,08	8%	5	10	20	25	30	35	25,99K	26,20K	26,61K	26,81K	27,02K	27,22K
2		4%	4%	0,08	8%	5	10	20	25	30	35	24,88K	25,18K	25,79K	26,09K	26,40K	26,70K
3		4%	4%	0,08	8%	5	10	20	25	30	35	23,94K	24,34K	25,14K	25,54K	25,95K	26,35K
4		4%	4%	0,08	8%	5	10	20	25	30	35	23,17K	23,67K	24,65K	25,15K	25,64K	26,13K
5		4%	4%	0,08	8%	5	10	20	25	30	35	22,54K	23,12K	24,29K	24,87K	25,46K	26,04K
6		4%	4%	0,08	8%	5	10	20	25	30	35	22,02K	22,69K	24,04K	24,71K	25,38K	26,05K
7		4%	4%	0,08	8%	5	10	20	25	30	35	21,61K	22,36K	23,88K	24,64K	25,39K	26,15K
8		4%	4%	0,08	8%	5	10	20	25	30	35	21,28K	22,12K	23,80K	24,64K	25,48K	26,32K
9		4%	4%	0,08	8%	5	10	20	25	30	35	21,03K	21,95K	23,79K	24,71K	25,63K	26,55K
10		4%	4%	0,08	8%	5	10	20	25	30	35	20,84K	21,84K	23,83K	24,83K	25,83K	26,83K
11		4%	4%	0,08	8%	5	10	20	25	30	35	20,70K	21,78K	23,92K	25,00K	26,07K	27,15K
12		4%	4%	0,08	8%	5	10	20	25	30	35	20,62K	21,76K	24,06K	25,20K	26,35K	27,49K
13		4%	4%	0,08	8%	5	10	20	25	30	35	20,57K	21,79K	24,22K	25,44K	26,65K	27,87K
14		4%	4%	0,08	8%	5	10	20	25	30	35	20,56K	21,84K	24,41K	25,69K	26,98K	28,26K
15		4%	4%	0,08	8%	5	10	20	25	30	35	20,57K	21,92K	24,62K	25,97K	27,32K	28,67K
16		4%	4%	0,08	8%	5	10	20	25	30	35	20,61K	22,02K	24,85K	26,26K	27,67K	29,09K
17		4%	4%	0,08	8%	5	10	20	25	30	35	20,67K	22,14K	25,09K	26,56K	28,04K	29,51K
18		4%	4%	0,08	8%	5	10	20	25	30	35	20,74K	22,28K	25,34K	26,87K	28,40K	29,94K
19		4%	4%	0,08	8%	5	10	20	25	30	35	20,83K	22,42K	25,60K	27,18K	28,77K	30,36K
20		4%	4%	0,08	8%	5	10	20	25	30	35	20,93K	22,57K	25,86K	27,50K	29,14K	30,79K
21	4%	4%	0,08	8%	5	10	20	25	30	35	21,04K	22,73K	26,12K	27,82K	29,51K	31,21K	

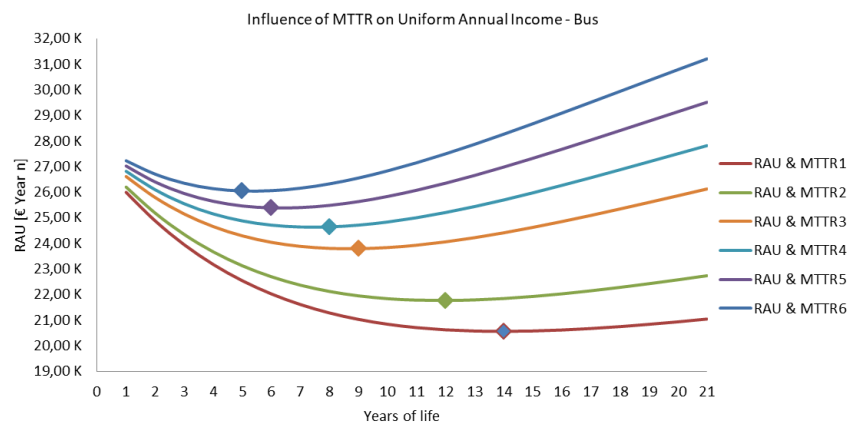


Fig. 1 – Influence of MTTR on RAU

Table 2 – Influence of MTTR on RAU+ROI

Vehicles									RAU [€ Year n]						
Year j	CA [€]	i <sub>A</sub> [%]	MTTR <sub>1</sub>	MTTR <sub>2</sub>	MTTR <sub>3</sub>	MTTR <sub>4</sub>	MTTR <sub>5</sub>	MTTR <sub>6</sub>	RAU & MTTR <sub>1</sub>	RAU & MTTR <sub>2</sub>	RAU & MTTR <sub>3</sub>	RAU & MTTR <sub>4</sub>	RAU & MTTR <sub>5</sub>	RAU & MTTR <sub>6</sub>	ROI
0	110,66K	8%													
1		8%	5	10	20	25	30	35	25,99K	26,20K	26,61K	26,81K	27,02K	27,22K	-87,51K
2		8%	5	10	20	25	30	35	24,88K	25,18K	25,79K	26,09K	26,40K	26,70K	-70,36K
3		8%	5	10	20	25	30	35	23,94K	24,34K	25,14K	25,54K	25,95K	26,35K	-54,57K
4		8%	5	10	20	25	30	35	23,17K	23,67K	24,65K	25,15K	25,64K	26,13K	-40,01K
5		8%	5	10	20	25	30	35	22,54K	23,12K	24,29K	24,87K	25,46K	26,04K	-26,61K
6		8%	5	10	20	25	30	35	22,02K	22,69K	24,04K	24,71K	25,38K	26,05K	-14,25K
7		8%	5	10	20	25	30	35	21,61K	22,36K	23,88K	24,64K	25,39K	26,15K	-2,88K
8		8%	5	10	20	25	30	35	21,28K	22,12K	23,80K	24,64K	25,48K	26,32K	7,61K
9		8%	5	10	20	25	30	35	21,03K	21,95K	23,79K	24,71K	25,63K	26,55K	17,26K
10		8%	5	10	20	25	30	35	20,84K	21,84K	23,83K	24,83K	25,83K	26,83K	26,15K
11		8%	5	10	20	25	30	35	20,70K	21,78K	23,92K	25,00K	26,07K	27,15K	34,35K
12		8%	5	10	20	25	30	35	20,62K	21,76K	24,06K	25,20K	26,35K	27,49K	41,89K
13		8%	5	10	20	25	30	35	20,57K	21,79K	24,22K	25,44K	26,65K	27,87K	48,84K
14		8%	5	10	20	25	30	35	20,56K	21,84K	24,41K	25,69K	26,98K	28,26K	55,24K
15		8%	5	10	20	25	30	35	20,57K	21,92K	24,62K	25,97K	27,32K	28,67K	61,14K
16		8%	5	10	20	25	30	35	20,61K	22,02K	24,85K	26,26K	27,67K	29,09K	66,56K
17		8%	5	10	20	25	30	35	20,67K	22,14K	25,09K	26,56K	28,04K	29,51K	71,56K
18		8%	5	10	20	25	30	35	20,74K	22,28K	25,34K	26,87K	28,40K	29,94K	76,17K
19		8%	5	10	20	25	30	35	20,83K	22,42K	25,60K	27,18K	28,77K	30,36K	80,41K
20		8%	5	10	20	25	30	35	20,93K	22,57K	25,86K	27,50K	29,14K	30,79K	84,31K
21	8%	5	10	20	25	30	35	21,04K	22,73K	26,12K	27,82K	29,51K	31,21K	87,91K	

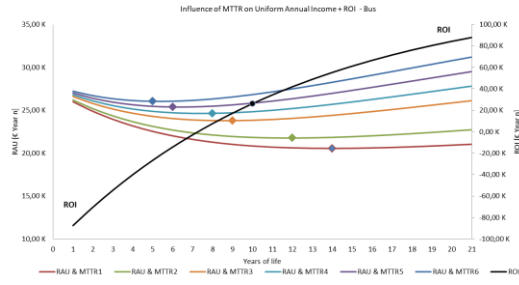


Fig. 2 – Influence of MTTR on RAU+ROI

If the uniform annual income curves are compared with the ROI, it appears that the lower the  $RAU_n$ , the greater the company's profit. Figure 3 focus on a five-day MTTR.

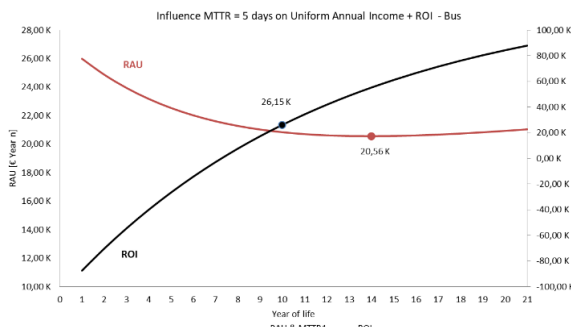


Fig. 3 – MTTR influence = 5 days in RAU + ROI

It can be noted that for an MTTR = 5 days, the replacement time is 14 years and the value of the Uniform Annual Income is € 20.56K. It can also be seen that in the 10th year the ROI value is € 26.15K. Therefore, the ROI is greater than the value of  $RAU_n$ ,

when the equipment starts to make a profit for the company. The period between the year in which the equipment starts to make a profit (year = 10) until the year in which the equipment is replaced corresponds to the year in which the RAU is minimal (year = 14), with a profit value of 103, 19 K €. The following example (Figure 4) uses data from the previous example, with the MTTR and  $RAU_n$  value, with the highest ROI value per year.

As the value of the ROI is higher each year, the bus starts to make a profit in four years with an ROI of € 55.41K. Then, from the period when the equipment starts to profit (year = 4) until the year when the equipment is replaced, when the Uniform Annual Income is minimal (= 14 years), the profit of the bus is 1905.76K €.

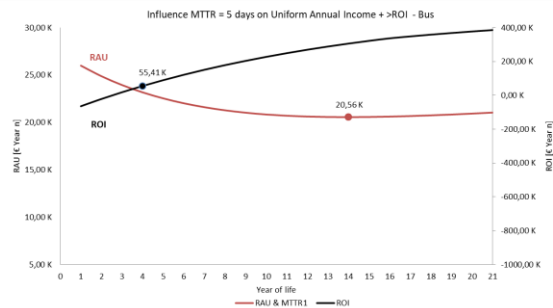


Fig. 4 – MTTR influence = 5 days in RAU + > ROI

Figure 5 presents the Model Integrated Reserve Fleet Assessment (MIRFA), which summarizes the global approach referred.

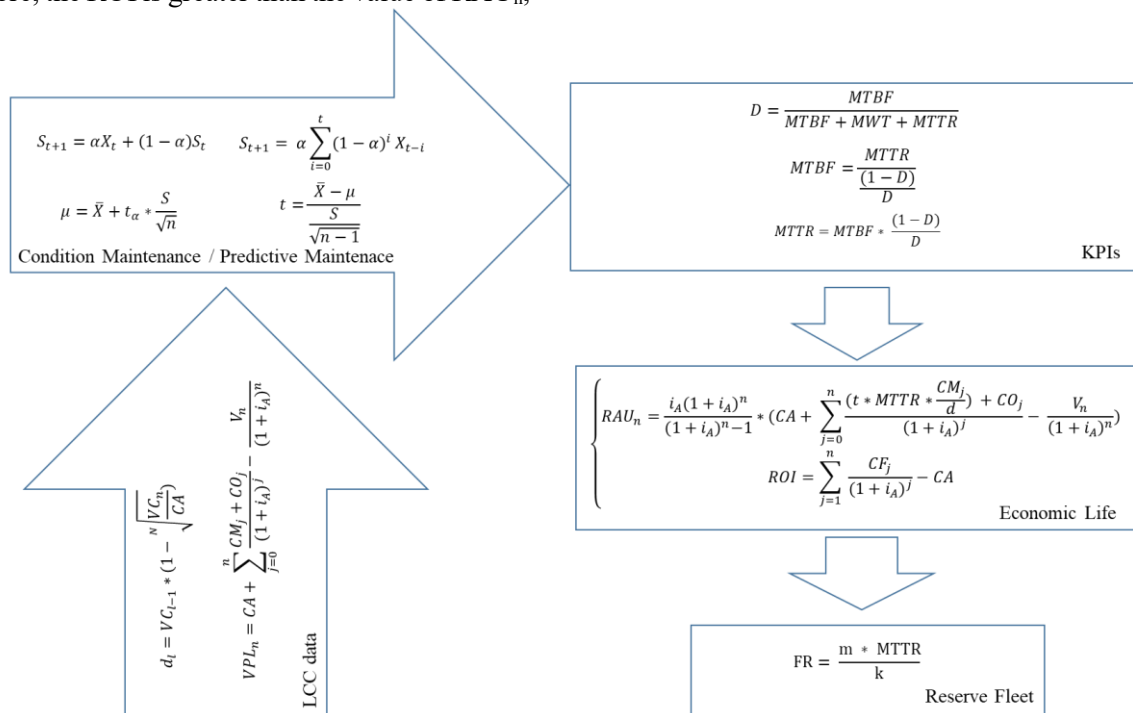


Fig. 5 - Model Integrated Reserve Fleet Assessment (MIRFA)

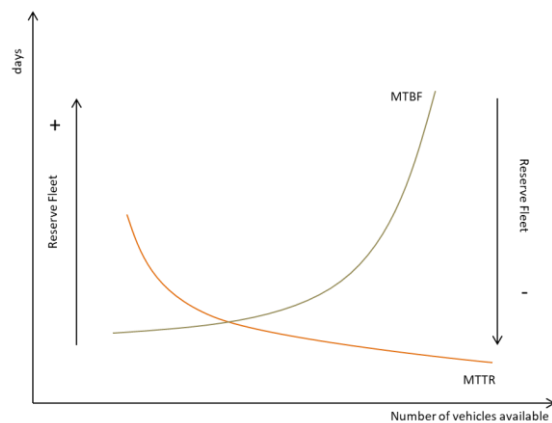


Fig. 6 – MTTR and MTBF versus Reserve Fleet

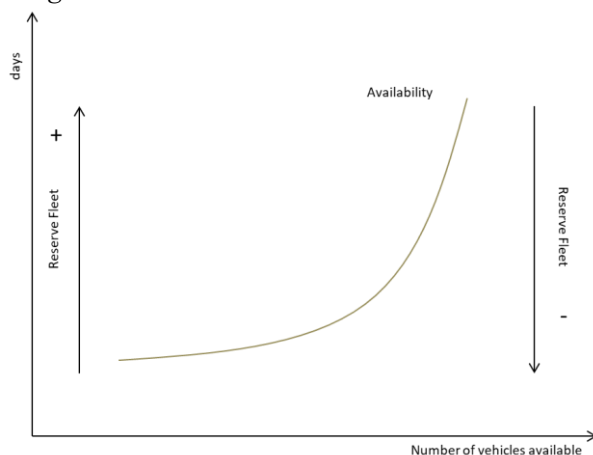


Fig. 7 – Availability versus Reserve Fleet

Figures 6-8 show that, when the MTTR decreases, the availability of the equipment increases. Although this conclusion seems obvious,

Table 3 – Availability versus MTTR

Availability (%)	MTBF_1	MTTR_1	MTBF_2	MTTR_2	MTBF_3	MTTR_3	MTBF_4	MTTR_4	MTBF_5	MTTR_5
80,0%	365	91	360	90	340	85	320	80	300	75
85,0%	365	64	360	64	340	60	320	56	300	53
90,0%	365	41	360	40	340	38	320	36	300	33
95,0%	365	19	360	19	340	18	320	17	300	16
96,0%	365	15	360	15	340	14	320	13	300	13
97,0%	365	11	360	11	340	11	320	10	300	9
98,0%	365	7	360	7	340	7	320	7	300	6
99,0%	365	4	360	4	340	3	320	3	300	3

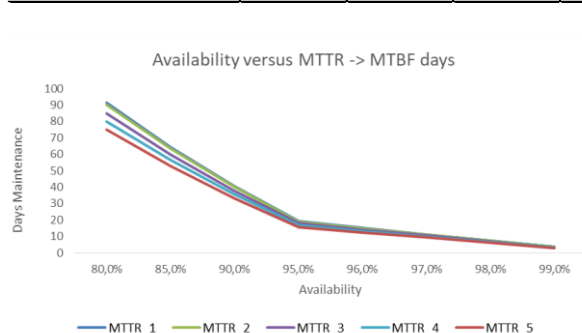


Fig. 9 – Availability graph versus MTTR -> MTBF

these Key Performance Indicators (KPI) are strategic. Thus, the decision maker can decide on the maintenance policy, namely the Condition Monitoring, including the analysis of oils.

Figure 8 illustrates how an increase of the MTBF and a decrease of the MTTR increases the availability of the bus, namely through a predictive maintenance policy. Table 1 and Figures 9 and 10 quantitatively illustrate this relationship. It is obviously important to demonstrate the effect of the interrelation of these indicators in the size of the reserve fleet. We emphasize that reliability's KPI is interlinked with the various indicators presented in the several calculation formulas and it plays a huge impact on the maintenance costs and the size of the reserve fleet.

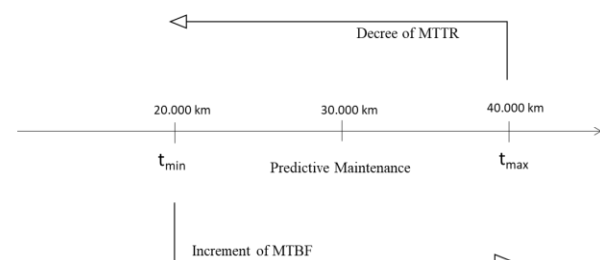


Fig. 8 – Predictive Maintenance versus MTTR/MTBF

Table 3 shows the Availability versus MTTR for a given MTBF, where the availability assumes the following values: 80%, 85%, 90%, 95%, 96%, 97%, 98%, and 99%.

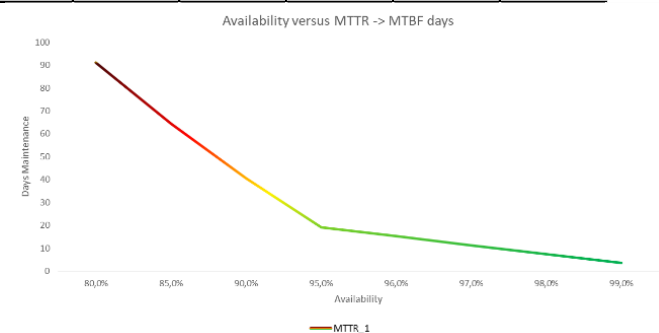


Fig. 10 – Availability graph versus MTTR -> MTBF

In general, it can be considered that, the more effective the maintenance function in an organization, the lower the equipment failure rate and the less time it takes to solve it. Thus, lower MTTR and higher MTBF values indicate that maintenance is performing well in support of productive operations. It can be seen from Figures 9 and 10 that, when the MTTR decreases, the bus's availability increases. In this sense, it is important to demonstrate the alignment of these indicators with the size of the reserve fleet in transport companies. Considering a real average of the MTTR of a transport company, the following data can be seen in Table 4:

- Availability (%) - Availability in percentage;
- Mean MTTR equal to 20 days for unplanned maintenance;
- Current Availability ( $D_{actual}$ ) - Availability resulting from the reality of a public transport company, with real MTTR and MTBF values;
- Recommended availability ( $D_{rec}$ ) - Availability recommended by the bus brands and oil suppliers to calculate the MTBF and MTTR values;
- Availability inherent to a Condition Maintenance policy - ( $D_{cbm}$ ) - Availability based on a conditioning maintenance policy and the MTBF and MTTR values.

Table 4 – Availability versus Type of Maintenance/KPI

Availability (%)	Unplanned Maintenance		Unplanned Maintenance + Planned Maintenance					
	Medium	MTTR	$D_{actual}$		$D_{rec}$		$D_{cbm}$	
			MTTR	MTBF	MTTR	MTBF	MTTR	MTBF
80,0%	20	25	100	23	92	21,5	86	
85,0%	20	25	142	23	130	21,5	122	
90,0%	20	25	225	23	207	21,5	194	
91,0%	20	25	253	23	233	21,5	217	
92,0%	20	25	288	23	265	21,5	247	
93,0%	20	25	332	23	306	21,5	286	
94,0%	20	25	392	23	360	21,5	337	
95,0%	20	25	475	23	437	21,5	409	
96,0%	20	25	600	23	552	21,5	516	
97,0%	20	25	808	23	744	21,5	695	
98,0%	20	25	1225	23	1127	21,5	1054	
99,0%	20	25	2475	23	2277	21,5	2129	

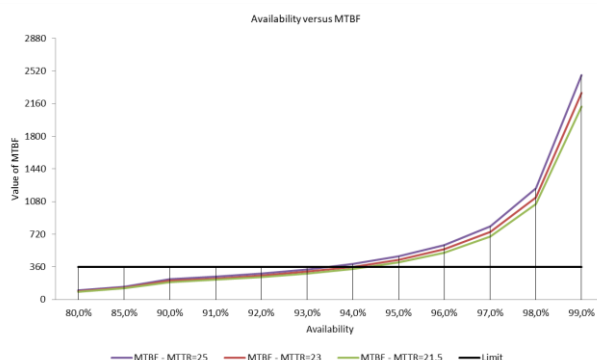


Fig. 11 – Graph of Availability versus MTBF -> MTTR

It can be seen from Table 4 and Figure 11 that Availability may vary by 1%, considering the reduction or increase of oil change intervals. When oil change intervals are reduced, there is a decrease of 1% in fleet availability, from 94% to 93%, with a limit of 365 days / year.

In this sequence, the Availability versus Production Requirement (buses necessary to carry out the careers) of the company under study is presented in Table 5 and in the radar map (Figure 12) throughout the year.

Table 5 – Availability versus reserve fleet buses

Months	Bus Fleet	Availability	Need	Maintenance	Reserve Fleet
January	115	97	90	18	7
February	115	94	90	21	4
March	115	96	90	19	6
April	115	97	90	18	7
May	115	97	90	18	7
June	115	96	90	19	6
July	115	93	90	22	3
August	115	93	90	22	3
September	115	96	90	19	6
October	115	97	90	18	7
November	115	99	90	16	9
December	115	97	90	18	7

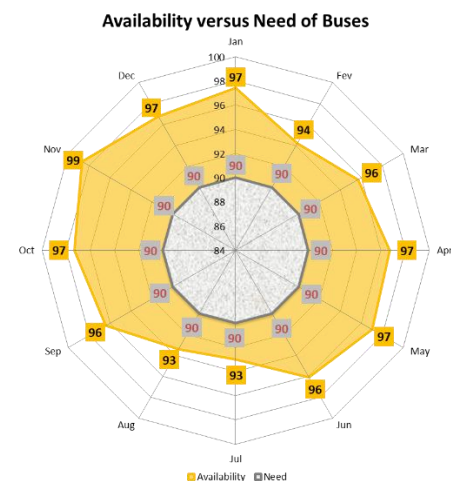


Fig. 12 – Availability Radar Map versus Bus need

In this sequence, the reserve fleet indexed to the MTTR values can now be calculated. Table 6 and Figure 13 show the variation of the size of the reserve fleet according to this indicator.

Table 6 – MTTR versus Reserve Fleet

MTTR	Bus Fleet [k]	Reserve Fleet [FR]	Interval [FR]
5	100	1,4	[1,2]
10	100	2,7	[2,3]
15	100	4,1	[4,5]
20	100	5,5	[5,6]
25	100	6,8	[6,7]
30	100	8,2	[8,9]

From Table 6, the formula (8) can be elaborated to determine the size of the Reserve Fleet:

$$FR = \frac{m * MTTR}{k} \quad (8)$$



Being,

$FR$  Reserve Fleet  
 $m$  Number of bus that constitute the fleet  
 $MTTR$  Mean Time To Repair  
 $k$  Number of days by year (365 days)

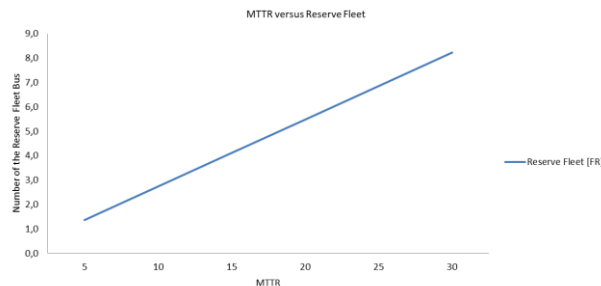


Fig. 13 – Graph of MTTR versus Reserve Fleet

According to Table 6 and Figure 13, the reserve fleet size increases with the MTTR increase. The lower this indicator, the lower the company's investment in a reserve fleet. The emphasis is placed on MTTR because of its high impact on management costs, especially indirect costs. Even a small increase in the value of the MTTR corresponds to an increase in the cost of the Reserve Fleet, due to the high cost of each bus, as mentioned previously.

Thus, it can be concluded that the reliability KPI's under discussion and the maintenance policies practiced by the passenger transport companies have a huge impact on the maintenance costs and the size of the Reserve Fleet.

Next, the calculation of the size of the Reserve Fleet for the company that served as support for this investigation is presented. Table 7 and Figure 14 show the results obtained in the present study.

Table 7 – MTTR versus Reserve Fleet – Company under study

MTTR [days]	Bus Fleet [k]	Reserve Fleet [FR]	Interval [FR]
5	115	2	[2,3]
10	115	3	[3,4]
15	115	5	[5,6]
20	115	6	[6,7]
25	115	8	[8,9]
30	115	9	[9,10]
35	115	11	[11,12]
40	115	13	[13,14]
45	115	14	[14,15]
50	115	16	[16,17]
55	115	17	[17,18]
60	115	19	[19,20]

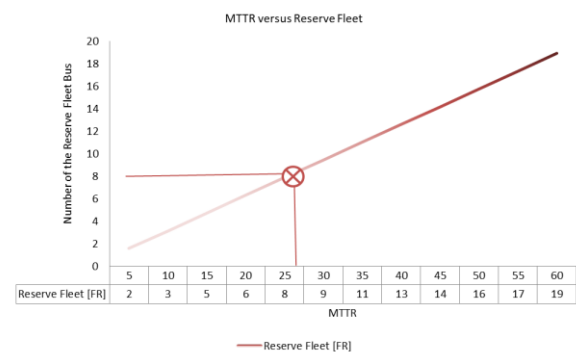


Fig. 14 – Graph of MTTR versus Reserve Fleet – Company under study

From the Graph of MTTR versus Reserve Fleet can be seen that, for a real MTTR of 25 days, in a fleet of 115 buses, a value of 8 units is obtained for the size of the reserve fleet.

Availability versus Need of Buses + Reserve Fleet

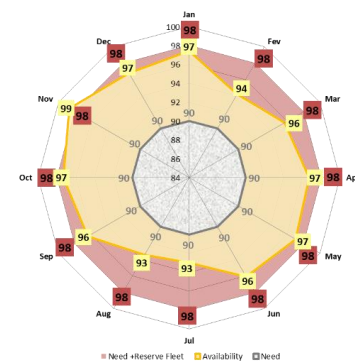


Fig. 15 – Radar map of the Availability versus necessity + Reserve Fleet

Through this model, calculations can be carried out to obtain the size of the reserve fleet for other companies of larger or smaller size, taking into account the number of buses that make up their fleets and the MTTR reliability indicator as presented will be presented next.

Table 8 – Bus Fleet versus Reserve Fleet

MTTR [days]	Bus Fleet [k]	Reserve Fleet [FR]	Interval [FR]
25	100	7	[7,8]
25	500	34	[34,35]
25	1000	68	[68,69]
25	1500	103	[103,104]
25	2000	137	[137,138]
25	2500	171	[171,172]
25	3000	205	[205,206]
25	3500	240	[240,241]
25	4000	274	[274,275]



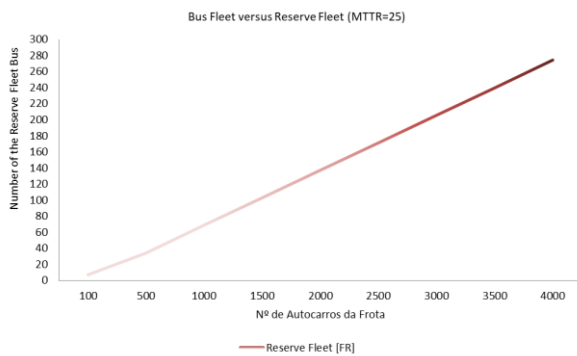


Fig. 16 – Graph of the Bus Fleet versus Reserve Fleet

Table 8 and Figure 16 show the size of the reserve fleet for several passenger transport companies, considering a constant value of 25 days for the MTTR, varying the size of the bus fleet and, consequently, this value related to the size of the company. Thus, the various values of the number of buses in the reserve fleet can be obtained depending on the size of the organization.

## 5 Results

The various approaches carried out throughout the paper, aiming at replacing buses and assessing the size of the reserve fleet, gave rise to the creation of a new integrated management model, which was called Model Integrated Reserve Fleet Assessment (MIRFA), as was illustrated in Figure 5, and that summarizes the global approach that was underlying the present paper.

The preceding approaches constitute a single model of analysis that allows determining the most rational period for replacing buses and, consequently, the reserve fleet, given that the first implies the second. It should be noted that the previous integrated approach is valid for new and used buses, considering the effect of monetary correction. Obviously, technological and environmental aspects are excluded from this analysis.

## 6 Conclusions

The paper focuses on economic models for determining the most rational moment for replacing buses in transport companies, indexed to the size of the reserve fleet. The overall result is centred on an integrating model to support the replacement of urban transport buses, but with the potential to extend to other types of equipment.

The main objectives of the research carried out were as follows: Rationalize the equipment / bus life cycle management; Streamline the time for replacing equipment / buses; Streamline the reserve fleet.

The economic aspects were guided by different indicators, such as the costs associated with the acquisition, maintenance, operation, cash flow, among others.

The paper was based on classic tools for determining the most rational time for replacing equipment but taking as reference the maintenance policies and their relationship with the Life Cycle Cost (LCC), applied to real data from an urban public transport company.

The paper also demonstrates that there is a variation in the more rational vehicle's replacement time, obtained by the several calculation methods used, namely, the Uniform Annual Income method, the Minimization of the Total Average Cost and the Minimization of the Total Average Cost with reduction to the present value.

It also demonstrates the influence of endogenous and exogenous variables, namely the rate of inflation, capitalization, the replacement value and the price of Diesel in determining the most rational moment for replacing buses.

Another aspect emphasized in the paper is related to the conditioning / predictive maintenance policies, given that they may be responsible for reducing the company's general expenses and increasing the operational availability of the equipment. This aspect is supported through the case of oil analysis, demonstrating that, the use of a conditioning / predictive maintenance policy influences the LCC and the size of the reserve fleet.

In this regard, some variables stand out, such as Soot, Viscosity and Iron content, which give relevant indications about the condition of Diesel engines. This same analysis can be extended to the remaining variables that allow the characterization of lubricating oils.

The paper also presents the relationship between the previous approach and the size of the reserve fleet in the urban passenger transport sector, demonstrating the relationship that exists between oil replacement intervals and the respective costs.

Finally, an integrating model of the preceding methodologies is presented in a global econometric model to support the decision to replace buses and calculate the size of the reserve fleet, which was called the Integrated Reserve Fleet Assessment Model (MIAFRA). In addition, it validates these methodologies using real data from a fleet of urban passenger buses.

The preceding approaches constitute a single model of analysis that allows determining the most rational period for replacing buses and, consequently, the reserve fleet, given that the first implies the second. It should be noted that the previous integrated approach is valid for new and used buses, taking into account the effect of monetary correction.

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