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POLICIES AND STRATEGIES FOR THE REFORM AND RENEWAL OF CONSTRUCTION EQUIPMENT

[1]Mamadou SAGNE, [2]Prof. Mouhamed Fadel Niang, [3]Elhadji Aliou DIOP, PhD

Electromechanical Engineer, Doctoral School for Sustainable Development and Society,
Iba Der Thiam University,
Thies, Senegal,
Professor and Researcher, Doctoral School for Sustainable Development and Society,
Iba Der Thiam University,
Thies, Senegal,
Researcher, Doctoral School for Sustainable Development and Society,
Iba Der Thiam University,
Thies, Senegal,

ABSTRACT: The issue of reform and renewal thus remains a reality that companies are forced to face, even in a situation marked by constraints such as competition, concern for profitability and the budget. In such a context, it is obviously difficult to establish precisely when it will be wiser to replace the equipment rather than continue to repair it. Moreover, a bad decision can have serious economic consequences for the company. This is the whole point of this article, the content of which is to propose a policy and a strategy that allows construction companies to minimize costs.

The works of certain authors inspire us so well that they can be validated in our approach or also be the subject of a proposal to improve their results. The synthesis of our study inevitably leads to a proposal for decision support for the reform of any equipment, in order to be able to optimize its profitability throughout its life cycle.

KEYWORDS: equipment – reform – optimization

INTRODUCTION

A construction equipment undergoes in its life a depreciation linked on the one hand to wear and on the other hand to time; which systematically implies that its lifespan is not infinite. It is also useful to remember that the acquisition of any equipment is an investment that the company must make profitable in the face of the various costs linked to its existence. Whatever the nature of the equipment, the equipment manager adopts a maintenance policy aimed at extending its useful life as much as possible by reducing its operating cost. However, at some point, this material must go out of the park instead of continuing to be maintained, and this one way or another.

We have seen in practice that most construction companies very often do not have reliable tools for determining when to decommission this equipment; and that in most cases they make use of their personal experiences.

Our model will aim to fill these gaps by presenting an effective decision-making tool for the reform and/or renewal of equipment. To do this, we are going to propose a policy of reform and renewal that responds to existing realities, after having presented a review of work relating to this problem. A replacement model is a method used to establish the sequence of equipment to be replaced (renewed/downgraded) according to a well-defined criterion.

In the literature review, we find several methods; the type of model to be used depends on criteria established in advance, the best known of which are based on the lifespan of the equipment and the repair costs [1]. Most of these models consider economic or financial criteria [2]. They are effective for any business that is aiming for a particular criterion. They are very precise and give equipment managers specific leads on specific problems related to renewal. Although they lead to very relevant results in terms of contributions to lowering costs or increasing profits, they do not take into account other variables involved, such as the environment and technology. The models of [3] had better take into account the realities of the company.

The objective is therefore to propose a planning and decision support model concerning the reform and renewal of the equipment fleet, by minimizing the overall economic costs and environmental impacts associated with its operation.

The first step will be to present the models for predicting the lifespan of equipment. Then we will make a collection of different models proposed to lead to the adoption of a management method for a policy of reform and renewal of equipment.

1. PREDICTIONS OF EQUIPMENT LIFETIMES

Estimating the life of the equipment is of great importance for the company. There can be two approaches to achieve this: one based on the technical characteristics of the equipment and the user himself and one based on the probabilities of renewal based on the observation of the physical life of the equipment. The advantage of the latter (approach) is on the one hand its analytical simplicity and on the other hand its flexibility. There are several models presented but the most common relating to construction equipment are:

- Weibull's law
- The Weibull law weighted by a Gamma law
- The Erlang-2 law weighted by a Gamma law

These models make it possible to estimate:

- For new equipment: the median lifespan, the average lifespan and the probable lifespan
- For second-hand equipment: the median residual life and the average residual life the probability of renewing this equipment (of a given age) at the end of a fixed time horizon.
- It can be recalled that a plethora of factors probably explains the lifespan of an equipment, considered as an essentially random phenomenon which can be represented by a law of probability

2. EQUIPMENT REFORM DECISION FACTORS

Throughout the life of the equipment, we ask ourselves several questions to know if the equipment is fully used, and if so, why replace it. These questions, if they are asked beforehand, can allow the company to avoid having too many units or inappropriate units in their equipment fleet.

Retirement/renewal decisions may vary due to several factors including fleet size and composition, maintenance costs, equipment obsolescence, physical deterioration, rental opportunities, sudden wear and failure of equipment [4].

2.1 The size and composition of the equipment fleet

The size and composition of the equipment park are closely linked to the demand expressed by the imperatives of the projects (or work sites). The determination of these notions is of great importance due to the direct impact on operating costs. Knowledge of the factors that influence demand and its projection over time is an asset for equipment managers in the process of choosing the type of equipment. Thus, too large a fleet leads to an increase in costs, even capital costs of assets; in the same way, a fleet that is too small causes external rental expenses necessary to ensure the level of service required. It is therefore important to adequately determine the size and composition of the fleet [5]. Several models have been proposed in the literature regarding the problems of the composition of the equipment fleet. [6] provides a useful decision support system for predicting demand, determining relevant criteria, developing and evaluating alternative fleet plans, and selecting the most profitable combination. Another model proposed by [7] deals with the optimal composition of a vehicle fleet.

2.2 Maintenance costs

We have already seen that some maintenance operations are limited while others are periodic and thorough. When the overall maintenance costs of a piece of equipment become excessive, the need for replacement arises. This problem is illustrated by [8] for whom companies reduce annual operating costs by deferring purchases and increasing the life cycle of equipment. The reduction in capital for renewal generally increases the cost of maintaining the fleet since the equipment remains in service for long periods in the fleet. Therefore, it is useful to use on the renewal planning to minimize the cost and manage the conflict between the replacement budget and the maintenance cost.

2.3 Hardware obsolescence

The obsolescence of equipment is the fact that it is outdated and therefore loses some of its use value due to technical (or technological) development alone, even if it is in perfect working order.

Several definitions have been found in the literature but in our research project, it is rather a question of obsolescence of use. It refers to the problem of deciding whether to keep equipment or replace it with more advanced technology. Indeed, in recent years this problem has been aggravated by the meteoric advance of technology faster than ever before. Thus, the driving force behind replacement decisions is likely to be obsolescence, rather than the physical deterioration of existing equipment [9]. A new design or improvement of existing equipment can make obsolete equipment economical [4].

The availability of improved equipment performing the same service with more economical means will justify the replacement of old equipment with new ones or even keeping them for other uses less than the current one. This translates into a better economic benefit. Hardware that is no longer in production can be considered obsolete. In the same way, equipment whose spare parts are becoming increasingly scarce can also become obsolete.

2.4 Possibilities of external leasing

The possibilities of external rental come up each time the demand for the site is greater than the availability in order to meet this need for the service to be rendered. In addition, the execution of specialized task can push the company to rent. Therefore, the possibilities of buying or renting equipment should be analyzed for individual cases. Figure 1 illustrates a procedure for determining the most cost-effective option. It is therefore advisable to buy equipment i for a given period n when the acquisition costs, $C_aC_{i,n}$ are lower than the rental costs, $Loc_{i,n}$

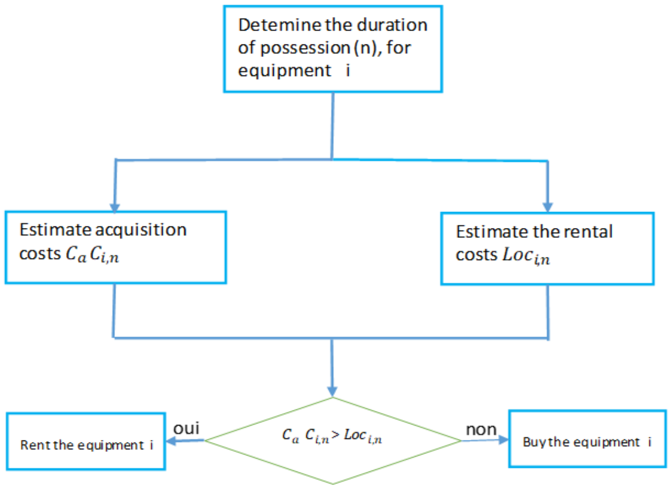

Figure 1. Simplified purchase or lease structure based on acquisition cost

2.5 Physical deterioration

Equipment may be prematurely taken out of service, scrapped due to gross damage, or mishandling. Moreover, when a piece of equipment is constantly deteriorating, it is much more interesting to predict its complete replacement. To determine whether the degradation behavior is constant or not, a reliability analysis is needed. An economic analysis will determine whether the replacement is feasible or not.

2.6 Equipment wear and sudden failures

In the life of the equipment, it happens that it suddenly breaks down even without deterioration over time. It is important to know in advance when the failure is likely to occur in order to initiate preventive action. This prediction of the time of failure can be made from the failure probability distribution of past experience. It is then a question of optimizing time, which minimizes the total cost that may be incurred; i.e. minimizing the sum of the costs of the equipment, the cost of replacement and the costs associated with the failure of this equipment: this is called preventive replacement.

3. EQUIPMENT DECOMMISSIONING HYPOTHESES

To properly study the problem of reforming or renewing equipment, we will agree on a certain number of hypotheses reflecting reality but also simplifying the analysis of this policy.

3.1 Technology

Some equipment candidates for replacement come with improved technology compared to that of the replaced equipment. Yet most commonly used models assume that technology remains constant over time. Which would lead to truly inappropriate and impertinent decisions if the technology changes [9]. Equipment that will be available in the future will be more efficient, reliable or productive than that currently on the market, due to tough competition among OEMs. This hypothesis naturally leads to the recognition of obsolescence, the difficulty of which lies in its qualification for the purposes of integration in the formulation of an optimal reform/renewal policy.

3.2 Planning horizon

This is the time interval taken into account in the formulation of the replacement policy. The horizon can be finite or infinite. In the first case, the project will have a fixed and predictable duration and thus the formulation of the renewal policy can be more realistic. In the second case (infinite horizon) the project will have an indefinite and unforeseeable duration. This is an assumption used when it is not possible to predict the end of the activity being analyzed.

3.3 Equipment life cost models

Many predictions could be made about revenues, costs and salvage value over the life of a piece of equipment. Revenues can for example be assumed increasing, costs not decreasing, etc. But the most prevalent assumption in the literature regarding retirement/renewal models assumes that annualized maintenance costs and annual operating costs do not decrease as equipment ages and salvage values are assumed not to decrease. increase with age [9]. The fact that use declines with age is an assumption that has been increasingly gaining ground in replacement models in recent times [1].

3.4 Availability of capital

In a replacement policy, it is important to know the limit of the availability of funds. Thus, it may be useful to introduce a model of the availability of capital and the cost of additional capital over time. The main sources of funds are depreciation, retained earnings, sales/leases, bank loans, etc.

3.5 Various other assumptions

Obviously, the list of hypotheses is not exhaustive; there is a great diversity of them that managers of equipment parks can consider in their renewal models.
In fact, the interest rate can be assumed to be non-zero in order to obtain the finite costs or the assumption on the future demand for services of the equipment fleet being considered known from forecasts made in the plans. In addition, the development of a model assuming a salvage value of the asset is different from one to develop assuming the non-existence of a salvage value.
These varieties can suggest a large number of different possibilities through the development of policies and models for the reform and/or renewal of equipment. But the importance remains in the fact that any model must represent a good approximation of reality.

4. APPROACH (OR PROCESS) TO REFORMING EQUIPMENT

Equipment reform decisions are one of the major challenges of construction companies where the result directly impacts the economic life of the fleet. In general, a reform plan is established according to a rehabilitation of the level of reliability of the fleet with the aim of maintaining the level of service required by the site(s). Obviously, this planning will tend to minimize unit costs and reconcile the capital budget with maintenance costs.
A quantified reform plan based on the rejuvenation of the stock has beneficial effects [4] such as:

- Give the company a means of controlling bank loans, capital expenditure and costs (in general)

- Establish and better control fleet maintenance indicators for the purpose of optimizing the useful life
  The long-term reform policy makes it possible to consider financial measures likely to promote renewal, to estimate their feasibility, to justify and explain the need for renewal, to measure the operating capacity of the fleet to manage flows profitability and finally, compares the impact of the different financing alternatives on renewal capacities. The reform approach overlaps to some extent with the stages of the equipment renewal process shown in Figure 2.

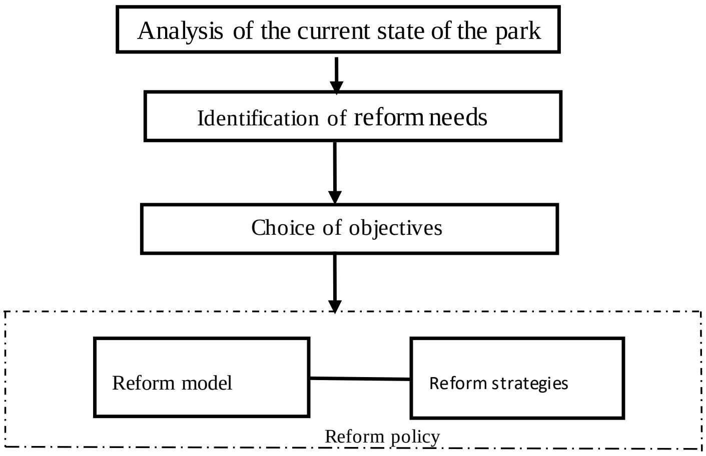

Figure 2: Steps in the hardware reform/renewal process

4.1 Analysis of the state of the equipment park

Above all, you must know your equipment well by objectively analyzing its condition. It is therefore the starting point of the reform process and reflects as faithfully as possible a real image of the park in terms of objectives, characteristics, environment, practices, means and constraints [10]. The condition of the fleet must come out of the technical inspection carried out under the best conditions by the internal departments of the company and/or the concessionaires or authorized structures. It will be sufficiently informed and will indicate:

- The make and model (type) of the equipment
- The serial number and the date of manufacture
- The current hour or odometer
- The type of use and the specific fuel consumption
- Financial data: acquisition values, total maintenance costs, current resale value, current cost price
- Performance indicators: efficiency, availability, reliability, utilization rate and other reform decision indicators

4.2 Determinants of reform needs

The analysis of the state of the fleet and the requests of the various construction sites (projects) in terms of equipment are the main elements on which the fleet manager relies in the implementation of replacement needs.
From a technical and economic point of view, various equipment indicators are determining factors for renewal needs.

4.3 Objectives of the reform of a material

Several renewal actions can be implemented. It can be conceived as renewal, the fact of undertaking major renovation/rehabilitation work, which restores the equipment to its original service potential.
The objective of a reform may be to reduce the number of units if the company seeks to maintain a balance between the capacity of the equipment fleet and the demand from the work sites (projects). On the other hand, the result of a reform and/or renewal can be the increase in the size of the market by this of its capacity [11].

4.4 Reform and Renewal Policy

Construction equipment in working order depreciates and causes higher and higher costs of ownership over time. For this equipment, the main fixed assets of construction companies, it is important to determine at what point in their life it would be necessary to decommission them, i.e. to carry out their reform for the interest of the company. The reform policy thus becomes an extremely delicate step in the sense that it constitutes the frame of reference to approach the crucial decisions relating to the criteria determining the material to be reformed, to the choice of the appropriate model and to the strategies of reform/renewal in general. Equipment fleet managers must then periodically identify candidate equipment for reform and equipment renewal (investment) taking into account budget constraints (limited). It is a question of aggregating many quantitative parameters within the framework of an optimal reform policy through an appropriate model, which becomes a valuable tool in the formulation of the objective aspects of the decision-making process [2].

The development of a policy for the reform and renewal of equipment in a construction company is strongly influenced by specific constraints, of which the availability of funds is one of the most striking; which explains the diversity of strategies for obtaining financial resources for the operation of such equipment. The possibilities for developing a renewal policy are thus as vast as they are diversified.

Equipment, for example, whose salvage value is assumed zero (non-existent), will have a different policy applied to it from that, which has it. In the same way, the renewal policy will change if it is a question of renewing a fleet of similar equipment instead of a fleet of different equipment [12]: we will then speak of individual or group replacement policy.

Individual replacement is characterized by this policy according to which renewal is carried out individually according to well-defined criteria. On the other hand, group replacement suggests the existence of a number of equipment of the same type at a non-negligible cost and which are responsible for their own failures; it will be here for economic reasons to replace them together as a preventive measure [4].

Some reform policies may result in long replacement times while others may be subject to regular delays. Thus, late replacement causes an increase in annual maintenance costs and a higher incidence of equipment downtime, while early replacement causes excessive capital expenditure [2]. When repair is no longer possible, replacement may become unavoidable. Postponing a reform/renewal of equipment (late replacement) can lead to a drop in the level of service and in the long term an economic disaster. However, it is possible that despite the logical and practical arguments to replace equipment at a certain precise moment in its life, some companies may delay it.
According to [4], apart from the economic replacement time, there are some reasons why the organization may prefer to delay the replacement of equipment such as:

- Current equipment is operational and of acceptable quality
- There is uncertainty associated with forecasting the expenditure of new technology, while the expenditure of current equipment is relatively certain
- Sunk costs psychologically influence replacement decisions
- The decision to replace the equipment is a stronger commitment for a period of time in the future than to do it at the present time
- Equipment managers tend to be conservative in decisions about replacing expensive equipment
- There may be a budgetary constraint for the purchase of new equipment, but none for the maintenance of existing equipment
- There may be uncertainty regarding future demand for the services of the equipment in question
- There is a passive attitude towards the fact that technological improvements in the future could make the equipment currently available obsolete
- There may be a reluctance to be a pioneer in adopting a new technology that causes the company to wait for further action from the competition instead of replacing it right away

Anyway, policies with regular replacements imply capital investments requiring an attitude of openness to the availability of replacement funds. It is in this spirit that a preventive replacement policy is inscribed.

Knowing that the policies can evolve from one company to another according to the intrinsic specificities, the objectives, the priorities, the needs and the constraints of exploitations (worksites and projects), the challenge of the persons in charge and directors of materials is, in practice, to find an optimal reform/replacement policy that responds in the best possible way to the particular conditions and the objectives set.

This optimal reform policy would be the one that gives the opportune moment of decommissioning/renewal of equipment and at the lowest possible cost. Timely replacement of equipment increases operator and user safety, ensures reliability, availability, best utilization rate, controls maintenance costs and enables asset management while also projecting a positive image of the company in relation to its customers (project owner or delegated project owner).

However, the big question that arises from the renewal policy is how to identify the equipment to be replaced among the other components of the fleet so that costs are minimized or in order to achieve any other objective. We will thus give pride of place to the different models of reform/renewal that make it possible to respond to this problem.

5. MODELS OF HARDWARE REFORM / RENEWAL

It was developed and applied several models of hardware reforms. Their differences are dictated by the objectives, the general orientations, the budgetary constraints and sometimes the environmental and socio-economic conditions of the company.

Construction companies (the subject of this research project) are primarily intended to build infrastructure by relying heavily on their equipment fleet, which constitutes the most important lever. From this moment, wanting to develop such a company comes down to making its main tool, namely its equipment, efficient. In addition, this constant concern to achieve the best results systematically rhymes with the search for a fleet of equipment subject to constant depreciation linked to its use and its maintenance qualities. It is then necessary to succeed in answering the nagging question of knowing: What and when to reform? The quest for answers to these questions will necessarily have to obey the search for an economically optimal solution for the company. The aim of the reform model will therefore be to select the equipment to be replaced and when, with the minimization of ownership costs.

While it is clear that today's hardware reform/renewal models can be supported by IT tools or software, the choice of a good model depends on established criteria, important determinants for a better reform.

5.1 Criteria for equipment reform

The definition of a reform/renewal policy is necessarily underpinned by a certain number of criteria. Construction companies can thus have the choice between using one criterion or a combination of several criteria. The most well-known criteria are:

- The optimal lifespan
- The limit of repair costs
- Technological change

5.1.1 The optimal lifespan

It is also called economic life and is between the date of commissioning and the opportune moment of reform of the equipment. Many studies have been developed to find the optimal lifespan of equipment. The most popular approaches based on optimal lifetime as a criterion are:

- Life cycle cost analysis (LCC)
- The average annual maintenance cost (C_{ma})
- The annual value method
- The replacement model of R. Cantù et al

5.1.1.1 Life cycle cost (LCC)

The life cycle cost of equipment (also called the global reference cost) is “the accumulation by successive years, of all the expenses relating to the possession of equipment” until its dismantling.

If the equipment provides quantifiable revenues (this is the case in the construction sector), then these can be associated with the analysis of the LCC. Most construction equipment has relatively long lives (more than 15 years); which implies updating the values so that the accumulation in constant monetary units is significant. The curves representing the LCC of a device generally look like figure 3.

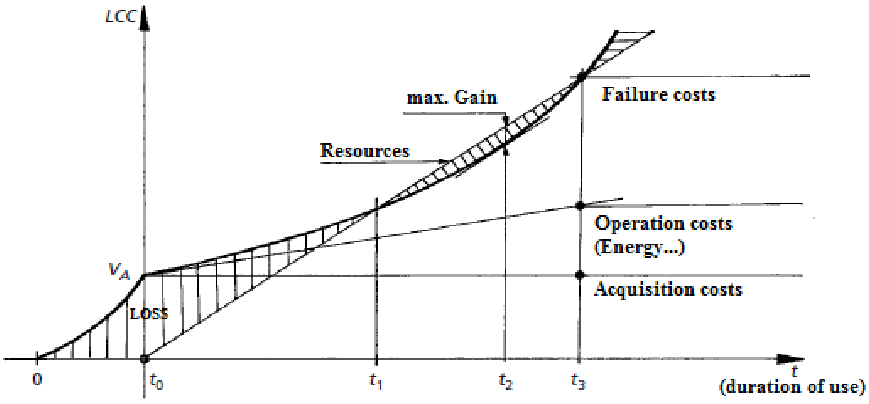

Figure 3: Life Cycle Cost Curve

In figure 3, note:

- 0: the date of the investment decision
- (0, t_0): Period of preliminary studies at the start of t_0, V_A being the sum of the costs linked to the investment
- (t_0, t_1): Operating period in deficit, as well as beyond t_3 when maintenance costs will increase inexorably
- (t_1, t_3): Profitable operating period; t_2 represents the period of economic optimization of the operation

Another graphical illustration, a possible variant of the representation of the LCC, can be constructed from differentiated axes for income and expenditure (figure 4).

$$LCC = V_A + D_F + C_D - R_V \quad (1)$$

Where

V_A: represents the initial investment, made up of the costs of preliminary studies (drafting of specifications, choice of supplier, ordering, integration of the equipment into the existing system), costs relating to the associated logistics, the cost equipment and its recipe. It is possible to correct V_A at end of life by adding the dismantling cost (if any).

R_V: represents the resale value of the equipment during the reform. It comes as a normal deduction from the acquisition value V_A

D_F: represents operating expenses (energy, consumables, labor related to normal operation, etc.)

C_D: represents the cumulative maintenance costs (direct and indirect)

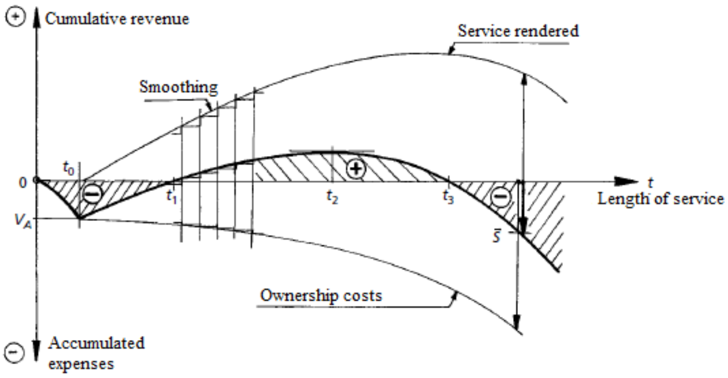

Figure 4: Profitability (Another illustration of the LCC)

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LCC = Γ or LCC (t) = Γ(t)
Then LCC (t) = Γ(t) = $V_A - R_V$ (t) + ψ(t) (2)
Knowing that R_V (t) = resale value
= V_A φ (t); φ (0) = 1 [φ (t): decreasing monotone]
Ψ (t) = cumulative cost of repairs and maintenance
ψ(0) = 0; ψ(t) = increasing monotone
Let then LCC (t) = $V_A - V_A$.φ (t) + ψ (t) (cost of the equipment for a duration t)
Figure 5 explains how it is possible to locate the period of reduced operating profitability, a period when the question of decommissioning/recycling must be asked, without necessarily knowing the revenues. All you have to do is add maintenance expenses per year. We find that the angle α decreases, then stabilizes in the area of point M, and then it will increase if exploitation occurs.
If the operation takes into account the resale value which decreases over time ($R_V = V_A$ φ(t)), then replacement should be considered earlier (figure 6)

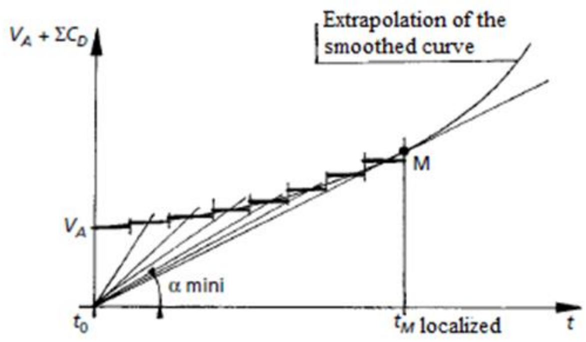

Figure 5: Determining the replacement period

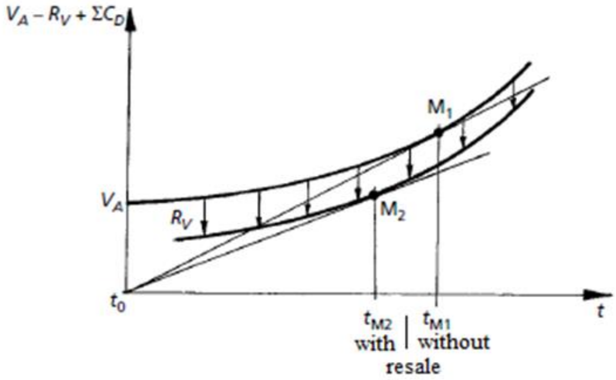

Figure 6: Determination of the replacement period (resale case)

Nb: The LCC analysis in this part is made assuming a constant silver rate.

5.1.1.2 The life cycle cost (LCC) taking into account the rate money

Let V_A be the acquisition value of equipment that has been scrapped and resold at a value $R_V = V_A$ φ(t) at time t. Due to wear and tear (not random here), the equipment must be subject to foreseeable maintenance and repair expenses. The maintenance and repair costs C1, C2,…, Ci,…Ct are considered at the end of each period i. We assume here that the periods are all of the same duration (and equal to one year); the economic horizon is assumed to be unlimited, and the renewed material always remains the same.
The reform period t_0 minimizing the discounted total cost Γ(t) is given by:

$$\Gamma(t) = [V_A + \alpha C_1 + \alpha^2 C_2 + \ldots + \alpha^t C_t - V_A \alpha^t \varphi(t)](1+\alpha^t+\ldots+\alpha^{nt}+\ldots) \quad (3)$$

With $\alpha = \frac{1}{1+i}$ where i = interest rate

$$1+ +\alpha^t+\ldots+\alpha^{nt}+\ldots = \frac{1}{1-\alpha^t}$$

By setting B (t) = $V_A + \alpha C_1 + \alpha^2 C_2 + \ldots + \alpha^t C_t - V_A \alpha^t \varphi(t$

It comes: $\Gamma(t) = B(t).\frac{1}{1-\alpha^t}$ (4)

Case of the maintenance cost varying discreetly:

The minimum of Γ(t) obtained using the following rule: "do not replace the equipment until the cost of maintenance and repair of the following period is greater than the weighted sum of the expenses already incurred”

$$C_{to+1} > \frac{V_A+\alpha C_1+\cdots+\alpha^{to} C_{to}}{\alpha+\alpha^2+\cdots+\alpha^{to}} \quad (5)$$

(The R_V resale value at the end of the operating period is not taken into account)

Case of maintenance cost varying continuously over time:

We have $\Gamma(t) = [V_A + \int_0^t c(u)e^{-iu}du]\frac{1}{1-e^{-it}}$ (with $e^{-it} = \alpha^t$) (6)

Where c(u)du represents the cost of maintenance during the period [u, x + du]
The discounted total cost is minimal for to such that:

$$c(t_o)(1- e^{-it_o})= i[V_A + \int_0^{t_0} c(u)e^{-iu}du] \quad (7)$$

5.1.1.3 Average annual maintenance cost (C_{ma})

At any time, a piece of equipment has:

- A V_A acquisition value
- An accumulation of recovery and maintenance costs ΣC_{E+R}
- A possible R_V resale value

Then, the average annual cost, the n[th] year is given by $C_{ma}(n) = \frac{V_A+\sum_1^n C_{E+R}-R_V}{n}$ (8)

If a renovation is made on the material, then

$$C_{ma}(n) = \frac{V_A+\sum_1^n C_{E+R}+C_{Rénovation}-R_V}{n} \quad (9)$$

If we consider the rate of money i, then

$$C_{ma}(n) = \frac{V_A\,(1+i)^n-R_V+\sum_1^n(C_{(E+R)(x)}+C_{Rénov(x)})(1+i)^{n-x}}{n} \quad (10)$$

The shape of the C_{ma} curve as a function of time is a "bathtub" curve, which passes through a minimum marking the economic life of the equipment (figure 7).
Indeed, if we call Γ(t) the cost of the equipment, then $\Gamma(t) = V_A - V_A.\varphi(t) + \psi(t)$
The average cost of use (per unit of time) is:

$$C_{mu}(t) = \gamma(t) = \frac{\Gamma(t)}{t} = \frac{1}{t}[V_A - V_A.\varphi(t) + \psi(t)] \quad (11)$$

γ(t) reaches its minimum for $\gamma'(t) = \frac{t\Gamma'(t)-\Gamma(t)}{t^2} = 0$

$$\text{Let } \Gamma'(t) = \frac{\Gamma(t)}{t} = \gamma(t) \quad (12)$$

Or again $V_A[1- \varphi(t) + t\varphi'(t)] + \psi(t) - t\psi'(t) = 0$ (13)

Figure 8 shows that the slope of the line (OM), tgα represents the average cost of use up to date t

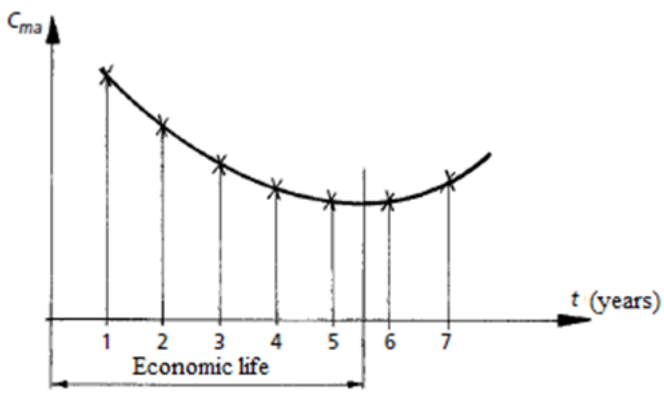

Figure 7: Shape of the C_{ma} curve as a function of time

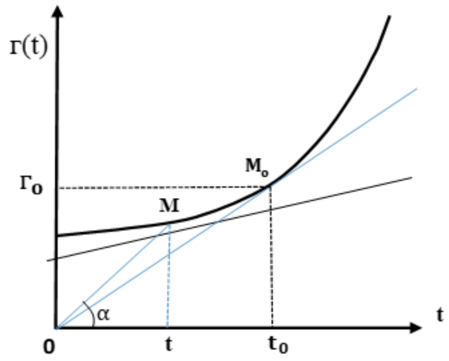

Figure 8: Marginal cost of equipment

The marginal cost at this date t is the slope of the tangent at M to the curve Γ(t). The equipment will be downgraded on date t0 for which the tangent to the curve passes through the origin.
Note: Determination of the admissible annual budget with the C_{ma} (figure 9)

By comparing each year, for a given piece of equipment, the sum of the failure costs recorded in the year with the C_{ma}. When these two values become equal, it is possible to extend the operation of the equipment provided that the direct and indirect expenses are controlled such that Cd is less than Cma: which gives the admissible budget of the equipment.
The average annual cost C_{ma} also finds its application in the equipment renewal policy (figure 10). Indeed, for equipment commissioned at t_0, we will consider at the end of the sixth year, three choice hypotheses:

- Extend the life of this equipment

- Renovate it
- Replace it identically

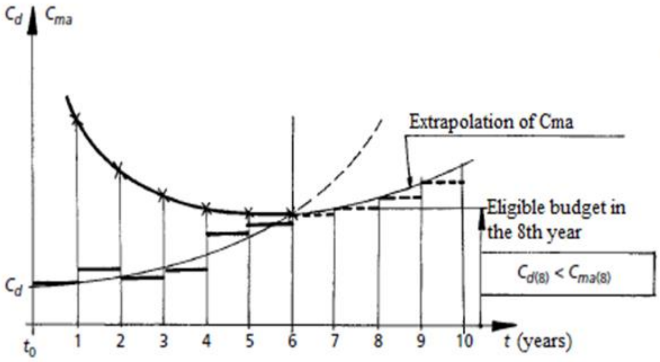

Figure 9: Eligible annual budget

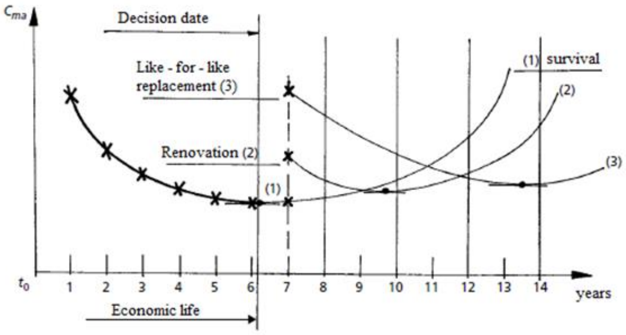

Figure 10: Equipment renewal

Extending the use of the equipment in the short term (7th and 8th year) is the economical solution. In the long term (beyond the 11th year), the solution is expensive. An identical renovation with new equipment would lead to a significant investment; but it remains the best solution from the twelfth year.

5.1.1.4 The annual value method

With this method developed by several authors such as [13], the economic lifetime of an item of equipment is the number of years n, during which the equivalent annual uniform cost (CAUE) [13] is a minimum, taking into account the most recent cost estimates over all possible years of asset lives. One methodology to approach this analysis is to acquire data from as many pieces of equipment (of the same type) as possible and obtain the averages for these expenses. To do this, a linear regression model can be used to determine for each component the costs expected over the number of years of life of the equipment. This way of approaching the problem considers the age of the hardware as the independent variable. Another linear regression can be used to determine the expected number of failures per period of year n. Again, the age of the equipment is taken as the independent variable. For the specific case of opportunity cost due to catastrophic failure, it can be calculated based on the probability of catastrophic failure. If we consider that the age of equipment follows a normal distribution with a given mean and standard deviation, the cumulative probability of catastrophic failure will increase with age.

To find the minimum useful life cost, one increases the useful life value, called k, from 1 to the maximum expected value for the asset N, i.e., k = 1,2, 3, …N

For each value of k, the $CAUE_k$ value is calculated using the following formula from [13]:

$$CAUE_k = P\,(A|P, i\%,k) - Vs_k(A|F, i\%,k) + \left[\sum_{j=1}^{k} CAO_j\,(P|F, i\%, j)\right](A|P, i\%, k) \qquad (14)$$

Where V_{sk}: salvage value if the asset is retained for k years

CAO_j : annual operating cost during year j (j = 1, 2, ...,k)

The following must be transformed into annual values for each number of years, the equipment is studied, for an interest rate i:

- The cost of acquiring the equipment
- Operation and maintenance costs (major maintenance cost, opportunity cost, opportunity cost for catastrophic failure)
- The salvage value at year n
- The salvage value at the end

These expenditures in annual value will then be added together to obtain a value of the CAO annual operating cost for each year. The annual capital recovery value must then be added to the CAO to obtain the Economic Service Life (ESL). The optimal replacement time would be when the ESL is at a minimum.

NB: Any cost that does not change with the age of the equipment (such as the cost of labor in certain special cases) should not be included in the calculation.

5.1.1.5 The replacement method of R. Cantù et al [14]

Contrary to many works encountered in the literature ([15] and [16]) where studies of replacement and reform of equipment use the year as a period, Ricardo Cantù and his collaborators find that the month is the most appropriate ([17] and [18]). Indeed, using the year as a period could be too broad for some, such as the category "small construction equipment" for example.

The mathematical model was built on the work of [18] who proposed an approach based on a solid theory of investment. This model supports decision making on replacement age, but can also be used to make a decision where the options are either to replace, repair, or choose from different machine options. Working capital and risk premiums are included in the model proposed by [14]; this model will help determine the optimal replacement period, as the following equation describes:

$$n = Max\{MCRF_n.[H_0 - \sum_{i=1}^{k} PP_i\ P(i) + (MV_n - TX_n - LB_k) + \sum_{i=1}^{n} NOPAT_i.P(i)]\} \quad (15)$$

With: n = Optimal replacement period (months); $1 \leq n \leq N$
$MCRF_n$ = Monthly Capital Recovery Factor
H_0 = Initial investment during period zero
K = Number of loan installments
PP_i = Principal repayment in period i
P(i) = Monthly discount factor
MV_n = Expected market value of the asset in period n
LB_k = Loan balance at the end of period k
$NOPAT_i$ = Net operating income after tax for period i

Remark:

In this model, the company buys the equipment using a mix of debt and equity. Debt will be assumed to have an annual percentage interest rate, while equity will be hedged using an expected minimum acceptable rate of return. Thus, the model below is designed to determine a period during which the replacement maximizes the benefits generated by the equipment.

5.1.2 Repair cost limit

The repair cost limit is a limit on the amount of money that can be spent on repairing equipment at a particular job [1]. It depends on the type, age and, in some cases, the geographical location of the machine. Equipment whose repair work exceeds the specified total repair cost is not repaired but is taken out of service. Thus, the repair limit provides an economical replacement policy that ensures that equipment that continuously exceeds this cost is taken out of service [19].

These authors (Drinkwater and Hastings) determine the optimal repair limit using two methods. The first uses an equation that finds the optimum by successive approximations. The second method is based on frequency distributions for repair costs and repair visits. They show that the cost limit criterion has advantages over the lifetime limit criterion. And it should be noted that it is assumed that the equipment is replaced because of the repair costs which increase with age, and it is not taken into consideration the case where the repair cost is a function of two variables independent (example: age and machine hour).

Given a piece of equipment at age t that needs repair, the following variables are defined:

C_r: repair cost
$C_{rf}(t)$: expected total cost of future repairs
$V_{ra}(t)$: Expected remaining life for the equipment

If we consider repairing the equipment, the future cost per year will be: $\frac{C_r + C_{rf}(t)}{V_{ra}(t)}$ (16)

If we decide to reform the equipment, the expected future cost per year will be θ, defined by:

$$\theta_t = \frac{y}{t} \quad (17)$$

Where y corresponds to the cumulative cost of equipment of age t

For a decision in favor of repair, then we will have $\frac{C_r + C_{rf}(t)}{V_{ra}(t)} < \theta$ (18)

For a decision in favor of an expected equipment reform, the critical value of C_r occurs when:

$$\frac{C_{r0}+C_{rf}(t)}{V_{ra}(t)} = \theta \qquad (19)$$

Where:
$C_{r0}(t)$: the cost limit for repairing an item of equipment at time **t**. This limit is therefore defined by the following repair limit equation:

$$C_{r0} = \theta \bullet V_{ra}(t) - C_{rf}(t) \qquad (20)$$

For a fleet of n equipment, the average cost per equipment per year, for the entire fleet, made up of n equipment will be:

$$\theta = \frac{y_1+y_2+y_3+\cdots+y_n}{t_1+t_2+t_3+\cdots+t_n}$$

Where y_i is the cumulative cost of equipment i and t_i the age of equipment i (i =1,2,3,…,n)
Equations (20) and (21) give from simulation a cost equation, which is minimized to find the optimal repair limits.

5.1.3 Technological evolution

In practice, a new technology is evaluated either in terms of the increase in income it brings or the reduction in the costs of acquiring and operating the new technology. Most of these models assume that technology improves deterministically (in terms of costs and revenues) and the timing of technological improvements is known in advance [9]. The study carried out by the latter considers the problem of choosing between keeping equipment or replacing it with more advanced technology available on the market. However, this is a complicated issue because further improvements in technology may occur in the future and these improvements may affect the current decision. Their work takes into account the case where the replacement of equipment considers non-stationary variables over time such as technological forecasts, revenues and costs.
By also integrating, the salvage value in their work [9] proposed a method for calculating the optimal equipment replacement decision for the treatment of these variables.

5.2 Results: Reform/replacement models

In most of the models found in the literature and proposed to companies, the criteria for reform/replacement are mainly of an economic nature; very few use environmental or technological criteria. Obviously, construction equipment (subject of this research project) cannot be isolated from this generality even if the environment and technological progress must be better taken into account in the choices (decisions) of reform and/or renewal.
It is useful to remember that in any construction company, the department in charge of equipment is responsible for the "health" of each piece of equipment throughout its useful life cycle, from acceptance through to its aging period and downgrading. He is also responsible for controlling the expenses relating to the possession of each piece of equipment. This is how a certain number of questions will successively arise and may influence the reform policy:

- What is the expected durability of the equipment?
- When does this hardware provide maximum operating gain?
- When maintenance actions should be stopped by stopping "therapeutic relentlessness" on this equipment?
- When should it be reformed (downgraded)?
- What is the resale value of the equipment? Alternatively, conversely, what is the cost of scrapping or dismantling?
- Should it be replaced identically or with new generation equipment?
- Should it be renovated?

These questions are essential for the equipment manager when it comes to addressing the technical and economic dimension of the reform models to be proposed. We have already seen that, of all the criteria discussed, the optimal lifespan is the most used in the literature. Which is completely understandable since the vocation of a company is above all to obtain profit. This is (of):

- The minimization of the life cycle cost (LCC) taking into account the evolution of the silver rate for classic construction equipment (> 10 years). In this case, it is a question of summoning equations (5) and (7), respectively:

$$C_{to+1} > \frac{V_A+\alpha C_1+\cdots+\alpha^{to}C_{to}}{\alpha+\alpha^2+\cdots+\alpha^{to}} \quad \text{and} \quad c(t_o)\bullet(1- e^{-it_o}) = i\bullet[V_A + \int_0^{t_0} c(u)e^{-iu}du]$$

t_o being the optimal instant of equipment reform.

- Minimization of the average annual maintenance cost (C_{ma}) by using equations (12) and (13)
- The annual value method developed by [13] with the equivalent uniform annual cost (CAUE) minimization. The equation (14) known as the Blank and Tarquin formula makes it possible to obtain the economic service life (ESL) which, minimized, leads to the optimal replacement time.
- From the replacement model of R. Cantù where the month is used as the period in the studies unlike the others which use the year. The advantage of the work of [14] is its easy adaptation to equipment with relatively short lifetimes such as small equipment. Equation (15) is invoked to illustrate this method. The repair cost limit is also an interesting criterion used by [19] to propose a fairly practical method. The latter succeeded in proving the advantages of their method with respect to the criterion of the limit of life. Indeed, the equipment is downgraded because of the repair costs, which increase considerably with age. Relations (17), (18) and (19) summarize this method. We have respectively:

$\theta_t = \frac{y}{t}$ where y = cumulative cost of equipment of age t

$\frac{C_r + C_{rf}(t)}{V_{ra}(t)} < \theta$: decision in favor of compensation

$\frac{C_{r0} + C_{rf}(t)}{V_{ra}(t)} = \theta$: decision favorable to the reform and $C_{ro}(t)$ representing the equipment repair limit at time **t**

Technological evolution weighs less in decommissioning/replacement decisions. It is a criterion which, if taken into account, is because it influences the performance of the equipment. In this case, it is difficult not to link the replacement to the economic aspect of the decision-making.

This reflection is also valid for the environmental criterion of the reform decision. Indeed, the company is pushed to the decision of replacement for "environmental" reasons when its profit is threatened by possible surcharges, as is the case in certain current projects.

We can see that the decision to decommission equipment, to replace it or to maintain it depends on many criteria in practice, even if we can notice a predominance of the economic criterion. It is therefore necessary to propose a multi-criteria assessment grid making it possible to aggregate the various possibilities and to proceed to a classification of the equipment candidates for the reform as well as the weighting of the said criteria (see table 1).

Table 1: Definitions of reform decision criteria and weighting system

N°	Critères	Définitions	Systèmes de pondération des critères
1	the age of the equipment	the number of years of existence of the material since its manufacture	1 point / year of service
2	hour meter or kilometrage	the actual use of the equipment expressed in hours or kilometers	1 point every 1000H
			1 point every 50.000Km
3	service severity	the degree and service of the tasks given to the equipment in relation to the test, the environnemental agression, etc.	1 point for moderate severity
			2 points for confirmed severity
			6 points for extreme severity
4	reliability	Basically, it is measured by the frequency of breakdowns or failures occurring on the equipment for a given period (example: the month)	1 point for ONE garage intervention / month
			3 points for each garage intervention if number of garage interventions/month exceeds 2
5	Average utilization rate	As its name suggests, it characterizes the percentage of use of the equipment in relation to its potential	0 point for T.U > 70%
			2 points for 50% < T.U < 70%
			6 points for T.U < 50%
6	Equipment efficiency	A performance indicator and can be calculated by thea formula: E= (HM+HD)/(HM+HP+HD) where HM: running time, HD: Availability time, HP: Breakdown time	0 point for Eff > 85%
			2 points for 60% < Eff < 85%
			8 points for Eff < 60%
7	Financial profitability of the equipment	An indicator of economic (financial) profitability of the equipment. It is measured by considering that the equipment constitutes an investment which, despite its operating and maintenance costs, generates revenue through rental (albeit internal)	0 points as long as the equipment is profitable
			10 points as soon as the material is no longer profitable
8	Total maintenance cost	All of the maintenance costs of the equipment compared to the cost of the initial investment of the equipment. This is a criterion for limiting maintenance costs	1 point for Maintenance costs < 20% of equipment acquisition cost
			3 points for 20% Acquisition cost < Maintenance costs < 70% acquisition cost
			10 points for maintenance costs > Acquisition cost
9	Technological obsolescence	Indicator of the state of the equipment compared to modernity and particularly to the latest technological advances concerning it	0 points if the equipment is latest generation
			2 points if the equipment is of the penultimate generation
			4 points if older older generation
10	Availability in PDR	Indicator that determines the reliability and also the profitability of the equipment	1 point for each immobilization for non-availability of PDR in the month
11	After-sales service availability	Some equipment has no after-sales service and is immobilized in the event of certain failures	1 point for each immobilization for unavailability of after-sales service during the month

To advance in the decision-making process, points are assigned to the various factors according to their impact and their importance on the weight of the choice. From Table 1, we propose an elaborate selection grid in Table 2 below.
The development of the reform decision-making process is rather a selective perspective in a multifaceted park. In practice, this facilitates the task of the equipment manager in his regular control obligations.

Table 2: Grid for assessing reform needs

N°	POINTE RANGE		COMMENTS
	Classic equipment	Small equipment	
1	> 90	> 65	Immediate reform of equipment
2	65 - 90	45 - 65	Reform to consider in the short term
3	45 - 65	30 - 45	Reform candidate: study to be refined
4	25 - 45	15 - 30	Equipment still usable
5	< 25	< 25	Equipment not concerned by the reform

Based on the evaluation grid (Table 2), the equipment manager draws up a short list in which all the energies necessary for the implementation of the equipment reform/replacement policy and strategy are concentrated.

6. CONCLUSION

The management of construction equipment imposes a permanent optimization of its levers such as the reform and renewal of the fleet. Companies would benefit from giving pride of place to the reform policy since it helps to improve the performance of equipment. This article has therefore been the opportunity to highlight different strategies that help in the best decision-making as to the outcome of any equipment that has operated for a given period. In the process, we have highlighted the determining factors of a reform policy, the conditions for decommissioning equipment and finally the proposal for a reform model that optimizes the performance of the equipment fleet.

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