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OPTIMAL CAPITAL ALOCATION IN THE REPLACEMENT OF AGING ASSETS OF POWER GENERATION PLANTS

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Aremas – Reliability, Risk & Economics

ABSTRACT

In today business environment, managers face the problem of finding the maximum return of investment in physical assets. One of main flexibility derives from the determination of the optimal time to replace existing assets in order to minimize total property cost. In the electricity sector because of (a) large number of assets, (b) high age of these assets, (c) lack of culture to carry out replacements for economic analysis and (d) tariff control of Brazilian Governmental Agency (ANEEL) adds additional pressure to control cost in order to increase return.

In this work, we present results of model to estimate the optimal time of replacement of individual assets and also the optimal time to replace groups of assets. The model includes variables such as (a) trends of maintenance costs of individual assets, (b) probabilistic models to comply with uncertainty in cost of failures, (c) cost of economic depreciation and savings from fiscal benefits, (d) cost of decommissioning. This model can fill a gap in the literature concerning the problem of replacement at the level of group of assets, which are not well explored, but whose solution is important for decision-makers dealing with real World problems in companies.

This model is applied for allocation of capital involving more than a thousand assets and results shows an improvement over the classic decision-making process of companies because of correct selection of assets and better scheduling replacements. Finally, the use of this model and methodology has contributed to increase return from better results of managerial decisions.

1. INTRODUCTION

One of the main tasks of plant and maintenance engineers is that associated with the replacement of existing assets, which are especially important in industries such as mining, petroleum, power generation, etc.

The basic replacement decision model is the one used to study individual asset such as a truck in a mining operation. The more complicated case is where the replacement must take into account the configuration of asset inside a larger production system.

The focus of this paper is the proposition of a new approach to evaluate the impacts of a strategy of assets replacement within a system considering variables over performance variables such as system total cost (which include OPEX and CAPX costs) and system downtime. The solution of this problem is not simple and also includes variables as: resale value of old assets, system total down time, opportunity cost of capital, and other. The main objective is to understand the trade-off between cost and availability according to the possible replacement strategies available. A numerical example of a Generation unit system is used to develop the discussion.

In order to fulfil the goals of the paper, the modeling known as Reliability Block Diagram (RBD) was employed together with the tool Monte Carlo simulation as discussed in section 2. Section 3 contains the results simulated and calculated. Section 4 presents the finals comments.

2. MODELING

The RBD of a Generation unit system is observed in Figure 1.

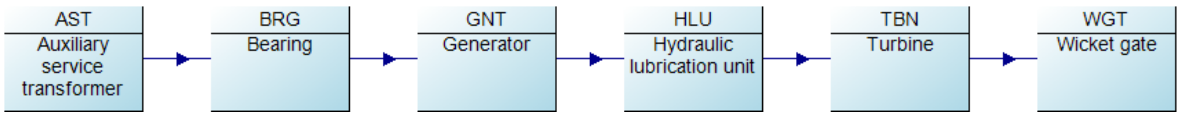

Figure 1 – Reliability Block Diagram Generation Unit System

Each asset from Generation unit system, represented by a block in Figure 1, can turn the system unavailable. In other words, the reliability configuration considered is in series.
Table 1 summarizes the time to failure modeling and the current age to each asset.

Table 1 – Time to failure modeling and current age of assets.

Asset		Time to failure modeling (Weibull distribution)		Current age (hours)
Code	Description	Eta (hours)	Beta	
AST	Auxiliary service transformer	56.940	1,8	87.600
BRG	Bearing	30.660	4,2	87.600
GNT	Generator	61.320	3,8	131.400
HLU	Hydraulic lubrication unit	78.840	3,2	87.600
TBN	Turbine	70.080	3,6	131.400
WGT	Wicket gate	43.800	1,4	43.800

According to Table 1, Auxiliary service transformer, for example, is indicated by the asset cod AST. This equipment has current age of 10 years of operation (87.600 hours) and time to failure modeled by a Weibull distribution with scale parameter (eta) equal to 56.940 hours and shape parameter (beta) equal to 1,8.
After the failure of each asset, a corrective maintenance must is performed. Table 2 contains the characteristic of the corrective maintenance task of each asset.

Table 2 – Maintenance corrective and asset replacement characteristic.

	Corrective maintenance			Asset replacement	
Asset code	Task duration (hours)	Cost (R$)	Age reduction factor	Task duration (hours)	Cost (R$)
AST	120	22.000	5%	24	120.000
BRG	72	7.000	85%	48	32.000
GNT	144	24.000	5%	72	160.000
HLU	96	35.000	5%	24	90.000
TBN	168	38.000	5%	96	210.000
WGT	120	15.000	5%	48	100.000

Considering again the Auxiliary service transformer (ASF), the task duration of the corrective maintenance is 120 hours, the cost of this task is R$ 22.000 and the age reduction factor is equal to 5%. To understand the last parameter presented, consider that after a maintenance task, the asset can return to a condition as good as new, as good as old or intermediate. To quantify this intermediate condition the following model can be used [1]:

$$I_d = I_a \cdot (1 - ARF) \tag{1}$$

where I_d is the considered age of the equipment after maintenance, I_a is the considered age before maintenance and ARF is the age reduction factor. The as good as new condition is represented by ARF = 100% and the as good as old condition is represented by ARF = 0%. The condition after the maintenance depends on the complexity of the asset, among others things.

Still in Table 2, the replacement of the Auxiliary service transformer, for example, has task duration equal to 24 hours and investment cost equal to R$ 120.000.

3. RESULTS

Based on parameters discussed in section 2, excluding current age (hours) and asset replacement characteristic, Figure 2 contains the maintenance cost profile simulated of each asset for a period of 20 years. Each profile is the result of the simulated mean maintenance cost considering 10.000 simulations and that the equipment is new in year zero.

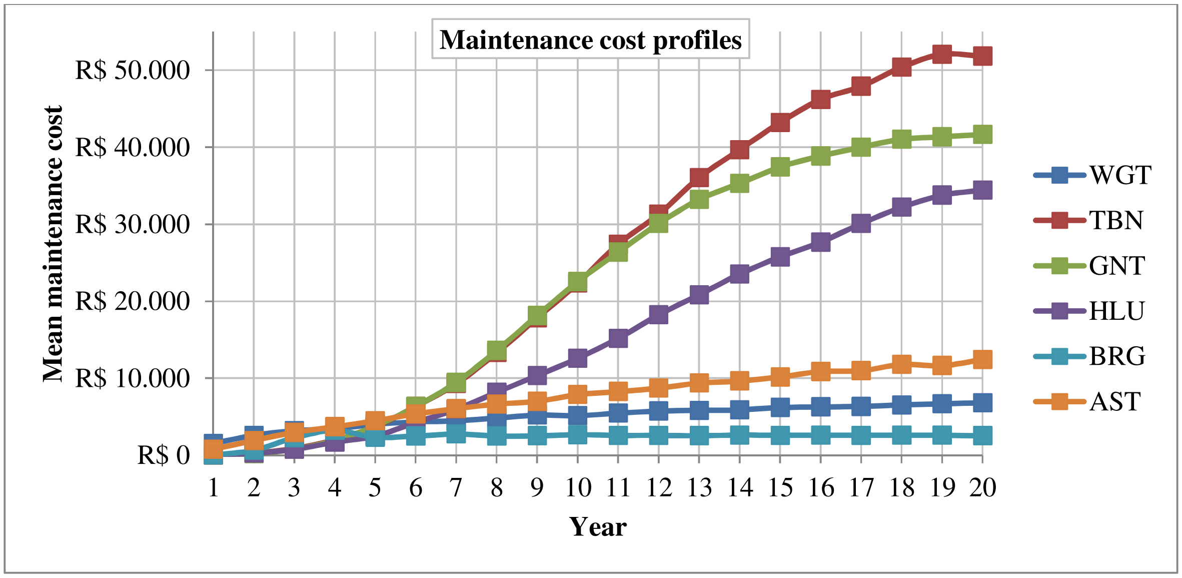

Figure 2 – Maintenance cost profiles

It´s easy to notice that the different assets have different maintenance cost profile. Considering only the year 20, the Turbine (TBN) has the highest simulated mean maintenance cost.

The maintenance cost profile affects directly the economic life of the asset, also known as the replacement age which results in minimum total cost ownership.

Considering opportunity cost of capital equal to 12% per year, fiscal depreciation equal to 10% during 10 years, income tax rate equal to 25% a year and economic depreciation of asset value of 10% a year, the total cost ownership versus the replacement age of each asset is presented in Figure 3 based on the modeling discussed in [2].

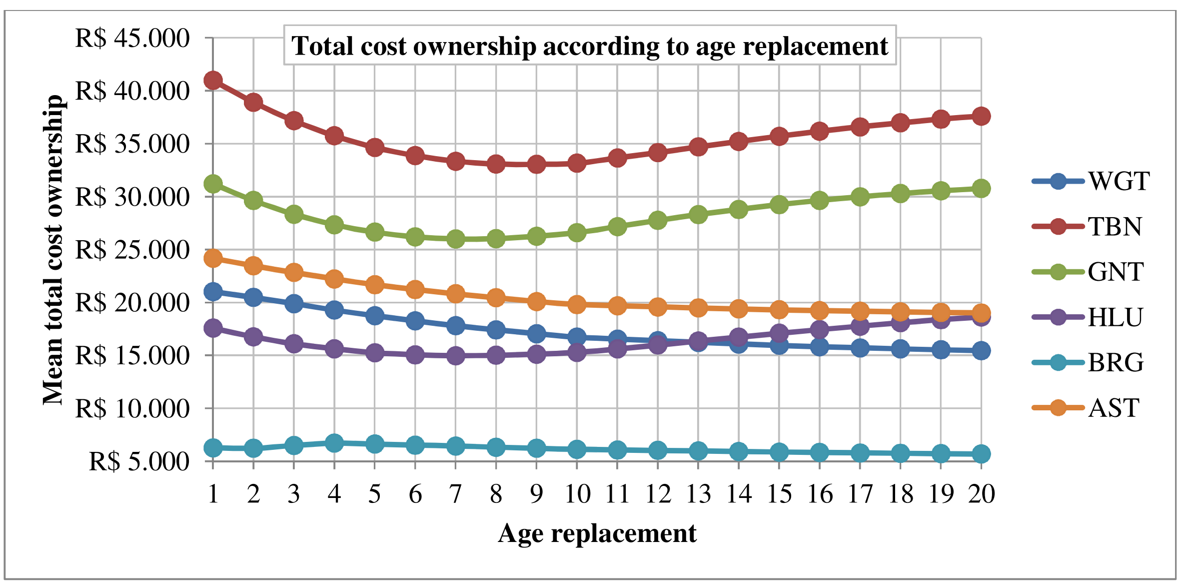

Figure 3 – Total cost ownership according to age replacement.

Figure 3 highlights that each asset has its own economic life. Turbine (TBN) and generator (GNT), for example, have economic life of 9 and 7 years, respectively. By other hand, to auxiliary service transformer (AST), for example, the asset replacement cannot decrease the total cost ownership, at least for a period of 20 years.

In reality, the problem faced by the companies is not only related about finding the economic life of each asset, but assessing the impact of different sets of asset replacement (strategies) in system performance.

To illustrate the question, considers the model discussed in section 2 simulated for 3 years. If no asset is replaced in the beginning of the period, the simulated mean total cost in present value, considering opportunity cost of capital equal to 12% per year, is equal to R$ 552.334 (as shown in Table 3).

Table 3 – Composition of the mean total cost simulated in present value.

Decision	OPEX in present value	CAPEX	Resale value	Total cost in present value
No asset replaced	R$ 552.334	R$ 0	R$ 0	R$ 552.334
All assets replaced	R$ 17.388	R$ 712.000	R$ 219.609	R$ 509.779
TBN replaced	R$ 330.696	R$ 210.000	R$ 43.237	R$ 497.459
GNT replaced	R$ 336.936	R$ 160.000	R$ 32.943	R$ 463.993
HLU replaced	R$ 494.056	R$ 90.000	R$ 31.381	R$ 552.675
HLU and GNT replaced	R$ 278.864	R$ 250.000	R$ 64.324	R$ 464.540
HLU and TBN replaced	R$ 272.100	R$ 300.000	R$ 64.324	R$ 507.776
GNT and TBN replaced	R$ 115.603	R$ 370.000	R$ 76.180	R$ 409.423
AST and WGT replaced	R$ 524.213	R$ 220.000	R$ 100.890	R$ 643.322

Table 3 indicates means values like, OPEX, CAPEX, resale value and total cost in present value according to different strategies of asset replacement. The total cost in present value to each strategy is composed of OPEX in present value, plus CAPEX and less resale value. The strategy of replacing only the generator and the turbine in the beginning of the period results in the minimum total cost. Not all possible strategies are present in this paper for a matter of simplification.

The total down time of the system is another important variable. In Figure 4 the plot indicates the mean total down time and mean total cost in present value to each strategy.

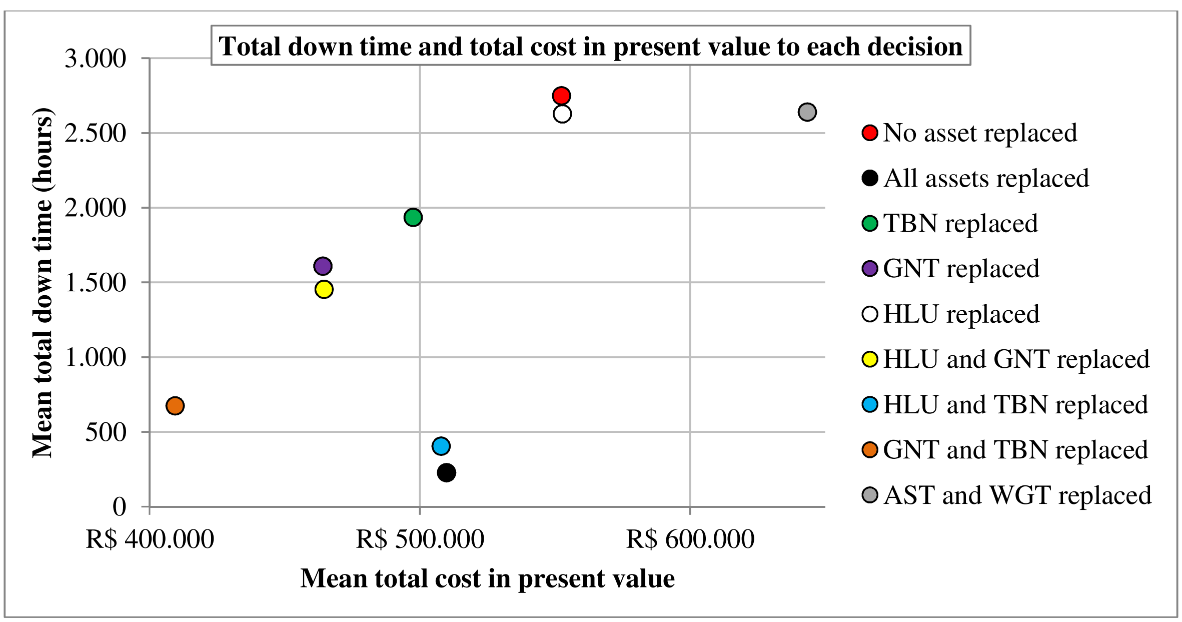

Figure 4 – Mean total down time and mean total cost in present value to each decision.

As already discussed, the strategy of replacing only generator and turbine in the beginning of the period results in the minimum total cost in present value. The choice for one strategy must rely on budget available to investment, expected maintenance cost and availability targets. So, if the companies do not tolerate total down time in hours to 3 years surpassing 500 hours, the strategy of replacing all assets can be a good option.

4. FINAL COMMENTS

Different strategies have different impacts in total cost and in total down time. Considering the existence of trade-offs between the two variables, an effective frontier can be created based on the simulated values for different replacement strategy, similarly to [3].

A big system contains a lot of asset, which results in a lot of combinations of replacement (strategies). This problem falls in the curse of the dimensionality, so, to big systems, the modelers must consider optimization algorithms in order to find a good solution.

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