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A QUEUE MODEL TO MONITOR THE CONVERSION FROM ICEV TO EV, HEVAND DV IN A SCARCE OIL ENVIRONMENT

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Abstract. Grounded on the M|G|∞ queue system, we build a model to analyze a situation in which ICEV-**I**nternal **C**ombustion **E**ngine **V**ehicles, moved only by the action of an internal combustion engine, get idle, in a scarce conventional energy ambience, and are either recycled, turning either EV-**E**lectric **V**ehicles or HEV-**H**ybrid **E**lectric **V**ehicles, or dismantled becoming DV-**D**ismantled **V**ehicles. We model the three situations: EV, HEV and DV with the same purpose. The model allows concluding that when the rhythm ICEV become EV, HEV and DV is greater than the rate at which they become idle the system has a tendency to balance. In addition, we perform a cost-benefit analysis.

Keywords. ICEV, EV, HEV, DV, M|G|∞, hazard rate function.

Mathematics Subject Classification: Primary 60G99; Secondary 91F99.

1 Introduction

Humanity has come to the beginning of a new stage of development. Things have begun to change about environmental and ecological attitudes and about criteria and conditions for business. Now companies and governments seem to be concerned about the environmental changes. Very important changes in the way of living and in the balances of the planet are coming up fast. We explore conventional sources of energy at a very fast rate and they will be exhausted in a near future, maybe within just a few decades.

World steps far to a new era of energy. Many of the non-renewable resources are over-exploited and conventional sources of energy such as oil, gas and coal, that have been determinant as fuel's civilization in the last centuries, will collapse soon. Possibly firstly oil, then gas and lastly coal. New opportunities for business are becoming visible and began to be experienced all over the world associated to the new sources of energy

General problems of environment have emerged from the bad use of this kind of resources. Demand for inputs by industry companies has seriously increased for more than the two last centuries to satisfy all the demand that has resulted either from the strong increasing of human global population or from the increasing level of life for an important part of the world population. People must overcome all wastes made for many decades and it should be know how to convert old equipment in useful devices, when possible. New and many kinds of problems will occur and it is important to know how quickly general changes may happen, while today societies develop new sources of energy in order to create a new economy and a reorganized society.

The aim of this paper is to show that ICEV, which work based on oil, may have an alternative use when this conventional source of energy collapses; or simply they may become dismantled.

In the model shown, using infinite servers' queues, we admit that too many ICEV will become idle if conventional energy misses or even when conventional energy becomes replaced by a renewable one.

ICEV dismantle or recycling will become very usual because there will not be a way to get them functional with conventional oil, since the moment it is depleted.

We shall state that it is essentially relevant the cadence at which we will perform the recycling and dismantling actions, being important in this analysis the hazard rate function of the service time:

$$h(t) = \frac{g(t)}{1 - G(t)} \quad (1.1),$$

where $G(t)$ is the *df* and $g(t)$ the *pdf* . The mean service time is designated α.

This work is commited to a goal of primary importance: to contribute to the sustainability of the standard of living of humankind, compatible with a properly preserved natural environment, here are some more in this path: Andrade et al. (2012), Ferreira (2014), Ferreira and Matos (2018), Ferreira et al. (2008, 2012, 2014, 2016), Filipe et al. (2012), Matos and Ferreira (2005) and Selvarasu et al. (2009).

2 The Model

In what concerns the present study, the costumers are the ICEV that become idle. The arrivals rate, designated λ, is the rate at which the ICEV become idle. The service time for each one is the time that goes from the instant they get idle until the instant they are either recycled or dismantled. Also important is the traffic intensity defined as $\rho = \lambda\alpha$.

The rate at which the services end is $h(t)$. For the situation under study in this paper, is the rate at which the motorcars are either recycled, turning either EV or HEV, or dismantled, turning DV.

Denoting $p_{1'0}(t) = G(t)e^{-\lambda\int_0^t[1-G(v)]dv}$, the probability the M|G|∞ queue has no costumers at instant *t*, being the time origin an instant at which a costumer arrives at the system finding it empty (symbolized by the $1'$), see, for instance, Ferreira (1991),

Proposition 2.1

If $G(t) < 1, t > 0$ continuous and differentiable and

$$h(t) \geq \lambda, t > 0 \quad (2.1)$$

$p_{1'0}(t)$ is non- decreasing.

Dem.: It is enough to note that $\frac{d}{dt}\, p_{1'0}(t) = e^{-\lambda\int_0^t[1-G(v)]dv}\big(1 - G(t)\big)\big(h(t) - \lambda G(t)\big)$.■

Obs.:

-If the rate at which the services end is greater or equal than the costumers 'arrivals rate

$p_{1'0}(t)$ is non-decreasing.

-For the M|M|∞ system, exponential service times, $h(t) = {}^{1}\!/_{\alpha}$ and (2.1) is equivalent to

$$\rho \leq 1 \ (2.2).$$

Either Equation (2.1) evidences that if the recycling or the dismantling rate is greater or equal than the rate at which the motorcars become idle, the probability that the system is empty at instant t, meaning it that there is no idle ICEV, does not decrease with t. Therefore, the system has a tendency to balance as far as time goes on.

Denoting now $\mu(1', t) = 1 - G(t) + \lambda\int_0^t[1 - G(v)]\,dv$ the mean number of customers in the M|G|∞ queue at instant *t*, being the time origin an instant at which a costumer arrives at the system finding it empty (symbolized by the $1'$), see, for instance, (Ferreira and Filipe, 2017)

Proposition 2.2

If $G(t) < 1, t > 0$ continuous and differentiable and

$$h(t) \leq \lambda, t > 0 \quad (2.3)$$

$\mu(1', t)$ is non- decreasing.

Dem.: It is enough to note that $\frac{d}{dt}\mu(1', t) = \big(1 - G(t)\big)\big(\lambda - h(t)\big)$.■

Obs.:

-If the rate at which the services end is lesser or equal than the customer's arrivals rate, $\mu(1', t)$ is non- decreasing.

-For the M|M|∞ system $h(t) = {}^{1}/_{\alpha}$ and (2.3) is equivalent to

$$\rho \geq 1 \text{ (2.4).}$$

Either equation (2.3) evidences that if the recycling or the dismantling rate is lesser or equal than the rate at which the ICEV become idle, the mean number of ICEV in the system does not decrease with time. This means that the system has a propensity to become unbalanced as far as time goes on. Note that for exponential service times, in both criteria considered, the condition $\rho \leq 1$ guarantees the system balance

3 Cost-Benefit Analysis

To perform an economic analysis, based on the model presented behind, consider additionally *p* as the probability, or percentage, of the ICEV arrivals designed to the recycling being consequently 1-*p* the same to the dismantling. In addition, be *q* the percentage or probability of ICEV designed for recycling that turn EV; 1-*q* will be the same for ICEV designed for recycling that turn HEV. Call $h_i(t), c_i(t)$ and $b_i(t), i = EV, HEV, DV$ the hazard rate function, the mean cost and the mean benefit, respectively for a ICEV turn either EV or HEV or DV, at instant *t*. So the total cost per unit of time, at instant *t*, for motor cars recycling and dismantling is:

$$C(t) = \lambda[pqc_{EV}(t) + p(1-q)c_{HEV}(t) + (1-p)c_{DV}(t)] \text{ (3.1)}$$

and the total benefit per unit of time, at instant *t*, resulting from recycling and dismantling

$$B(t) = b_{EV}(t)h_{EV}(t) + b_{HEV}(t)h_{HEV}(t) + b_{DV}(t)h_{DV}(t) \text{ (3.2).}$$

From an economic point of view, extreme, it must be $B(t) > C(t)$ for any t. So results that it is interesting recycling, turning ICEV in EV, if

$$b_{EV}(t) > \max\left\{\frac{\lambda[pqc_{EV}(t) + p(1-q)c_{HEV}(t) + (1-p)c_{DV}(t)]}{h_{EV}(t)} - \frac{b_{HEV}(t)h_{HEV}(t) + b_{DV}(t)h_{DV}(t)}{h_{EV}(t)}, 0\right\} \text{ (3.3).}$$

If $G_{EV}(t), G_{HEV}(t)$ and $G_{DV}(t)$ are all exponential, with means α_{EV}, α_{HEV} and α_{DV}, respectively, (3.3) becomes

$$b_{EV}(t) > \max\left\{[pqc_{EV}(t) + p(1-q)c_{HEV}(t) + (1-p)c_{DV}(t)]\rho_{EV} - \frac{\alpha_{EV}}{\alpha_{HEV}}\, b_{HEV}(t) - \frac{\alpha_{EV}}{\alpha_{DV}}\, b_{DV}(t), 0\right\} \quad (3.4),$$

with $\rho_{EV} = \lambda\alpha_{EV}$.

It is interesting recycling, turning ICEV in HEV, if

$$b_{HEV}(t) > \max\left\{\frac{\lambda[pqc_{EV}(t) + p(1-q)c_{HEV}(t) + (1-p)c_{DV}(t)]}{h_{HEV}(t)} - \frac{b_{EV}(t)h_{EV}(t) + b_{DV}(t)h_{DV}(t)}{h_{HEV}(t)}, 0\right\} \quad (3.5).$$

If $G_{EV}(t), G_{HEV}(t)$ and $G_{DV}(t)$ are all exponential, with means α_{EV}, α_{HEV} and α_{DV}, respectively, (3.5) becomes

$$b_{HEV}(t) > \max\left\{[pqc_{EV}(t) + p(1-q)c_{HEV}(t) + (1-p)c_{DV}(t)]\rho_{HEV} - \frac{\alpha_{HEV}}{\alpha_{EV}}\, b_{EV}(t) - \frac{\alpha_{HEV}}{\alpha_{DV}}\, b_{DV}(t), 0\right\} \quad (3.6),$$

with $\rho_{HEV} = \lambda\alpha_{HEV}$.

It is interesting dismantling, turning ICEV in DV, if

$$b_{DV}(t) > \max\left\{\frac{\lambda[pqc_{EV}(t) + p(1-q)c_{HEV}(t) + (1-p)c_{DV}(t)]}{h_{DV}(t)} - \frac{b_{EV}(t)h_{EV}(t) + b_{DV}(t)h_{HEV}(t)}{h_{DV}(t)}, 0\right\} \quad (3.7).$$

If $G_{EV}(t), G_{HEV}(t)$ and $G_{DV}(t)$ are all exponential, with means α_{EV}, α_{HEV} and α_{DV}, respectively, (3.7) becomes

$$b_{DV}(t) > \max\left\{[pqc_{EV}(t) + p(1-q)c_{HEV}(t) + (1-p)c_{DV}(t)]\rho_{DV} - \frac{\alpha_{DV}}{\alpha_{EV}}\, b_{EV}(t) - \frac{\alpha_{DV}}{\alpha_{HEV}}\, b_{HEV}(t), 0\right\} \quad (3.8),$$

with $\rho_{DV} = \lambda\alpha_{DV}$.

In a more global approach, more realistic and not so extreme, consider a period of time T. Then it must be $\int_0^T B(t)dt > \int_0^T C(t)dt$. It is not so simple to deal analytically with this expression as in the former situation. But, considering $b_{EV}(t), b_{HEV}(t)$ and $b_{DV}(t)$ constant in $[0,T]$ with values b_{EV}, b_{HEV} and b_{DV} , respectively, it is obtained:

- Recycling, turning ICEV in EV, is interesting, if

$$b_{EV} > \max\left\{\frac{\lambda[pqC_{EV}^T + p(1-q)C_{HEV}^T + (1-p)C_{DV}^T]}{\ln\frac{1-G_{EV}(0)}{1-G_{EV}(T)}} - \frac{b_{HEV}\, ln\frac{1-G_{HEV}(0)}{1-G_{HEV}(T)} + b_{DV}\, ln\frac{1-G_{DV}(0)}{1-G_{DV}(T)}}{ln\frac{1-G_{EV}(0)}{1-G_{EV}(T)}}, 0\right\} \quad (3.9)$$

- Recycling, turning ICEV in HEV, is interesting if

$$b_{HEV} > \max\left\{\frac{\lambda[pqC_{EV}^T + p(1-q)C_{HEV}^T + (1-p)C_{DV}^T]}{\ln\frac{1-G_{HEV}(0)}{1-G_{HEV}(T)}} - \frac{b_{EV}\, ln\frac{1-G_{EV}(0)}{1-G_{EV}(T)} + b_{DV}\, ln\frac{1-G_{DV}(0)}{1-G_{DV}(T)}}{ln\frac{1-G_{HEV}(0)}{1-G_{HEV}(T)}}, 0\right\} \quad (3.10)$$

- Dismantling is interesting if

$$b_{DV} > \max\left\{\frac{\lambda[pqC_{EV}^T + p(1-q)C_{HEV}^T + (1-p)C_{DV}^T]}{\ln\frac{1-G_{DV}(0)}{1-G_{DV}(T)}} - \frac{b_{EV}\, ln\frac{1-G_{EV}(0)}{1-G_{EV}(T)} + b_{DV}\, ln\frac{1-G_{HEV}(0)}{1-G_{HEV}(T)}}{ln\frac{1-G_{DV}(0)}{1-G_{DV}(T)}}, 0\right\} \quad (3.11)$$

where $C_i^T = \int_0^T c_i(t)dt, i = EV, HEV, DV.$

But if moreover $G_{EV}(t), G_{HEV}(t)$ and $G_{DV}(t)$ are all exponential, with means α_{EV}, α_{HEV} and α_{DV}, respectively, (3.9), (3.10) and (3.11) become:

- Recycling, turning ICEV in EV, is interesting, if

$$b_{EV} > \max\left\{\frac{\rho_{EV}[pqC_{EV}^T + p(1-q)C_{HEV}^T + (1-p)C_{DV}^T]}{T} - b_{HEV}\frac{\alpha_{EV}}{\alpha_{HEV}} - b_{DV}\frac{\alpha_{EV}}{\alpha_{DV}}, 0\right\} \quad (3.12)$$

- Recycling, turning ICEV in HEV, is interesting if

$$b_{HEV} > \max\left\{\frac{\rho_{HEV}[pqC_{EV}^T + p(1-q)C_{HEV}^T + (1-p)C_{DV}^T]}{T} - b_{EV}\frac{\alpha_{HEV}}{\alpha_{EV}} - b_{DV}\frac{\alpha_{HEV}}{\alpha_{DV}}, 0\right\} \quad (3.13)$$

- Dismantling is interesting if

$$b_{DV} > \max\left\{\frac{\rho_{DV}[pqC_{EV}^T + p(1-q)C_{HEV}^T + (1-p)C_{DV}^T]}{T} - b_{EV}\frac{\alpha_{DV}}{\alpha_{EV}} - b_{HEV}\frac{\alpha_{DV}}{\alpha_{HEV}}, 0\right\} \quad (3.14).$$

5 Conclusions

To apply this model, and get useful conclusions, it is important to check if customers' arrivals occur according to a Poisson process. In this kind of problem, this is pacific, in general, due to the huge quantity of ICEV's, which owners certainly will look for these services. It is essential to estimate λ and *h(t)* to get conclusive particular results about the system after the available data. A correct estimate of λ will depend also on the arrivals process to be Poisson in real. Moreover, certainly the way is to decide for a mean λ estimate for a given period since it is easy to admit that the arrivals rate will depend on time. In addition, it is correct to admit that with very large populations, such as the ones dealt in these situations, the estimation of $h(t)$ is in general technically complicated. Then the best to do is to estimate directly $h(t)$ instead of estimating first the service time distribution followed by the consequent computation of $h(t)$.For exponential service times all this is particularly easy since in this case $h(t)$ does not depend on *t*.

From Cost-Benefit analysis performed standing on this model, it is concluded that there are minimum benefits above which, from an economic point of view, both dismantling and recycling are interesting. Moreover, the most interesting is the one for which this minimum benefit is the least. That is, in a broader perspective it is more efficient the activity that corresponds to a lower level for the minimum interesting benefit.

The model here presented contributes for a better understanding of this kind of problems. With eventual modifications, to study for example some other social economic and financial problems such as unemployment, health, pensions' funds, investment projects or repair systems the model is also applicable.

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