A PROBABILISTIC MODEL FOR THE MANAGEMENT OF A TRAM FLEET

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1 INTRODUCTION

The maintenance of transport vehicles represents an important aspect of the operating costs of a TPL (local public transport) company. This work analizes the programmed and corrective maintenance procedures of a recent tram fleet.
Starting from machine shop's data, after a careful technical and economic analysis, a set of two models has been developed in order to forecast and point out time and operating cost of the examined stock, using the RAM parameters' characteristics: a probabilistic model for the anomaly management in line and for the analysis of shops' maintenance operations, and a model for the calculation of LCC (Life Cycle Cost).
The procedure has been applied to a TPL company obtaining satisfactory results consistent, under an economic point of view, with balance data and, under a reliability point of view, consistent with the purchasing specifications.

2 RAM PARAMETERS

In the current maintenance management, the ensemble of reliability, availability and maintenability performances represents an important role [1]; methods and studies concerning the maintenance support always aimed to know, with precision and objectivity, how components really work. In order to have a parametric study, of general validity, parameters capable to point out the physical, operating and performance characteristics of the selected components have been used. As a consequence came out the so-called RAM parameters (Reliability, Availability, Maintenability) that include, represent and make a synthesis of more general concepts, specially in the current system management; in particular [2]:

- Reliability is the probability of an item operating for a given amount of time without failure, in specified environment and with a desired confidence.
- Availability is the probability that an item will be able to function at the required conditions (up time/total time).
- Maintainability is the probability that a failed unit will be repaired in a given time.

3 THE WEIBULL FUNCTION

Weibull's distribution is one of the most common used distributions in reliability engineering [3], [4]. This distribution is widely used due to its versatility and to the fact that the Weibull probability density function (pdf) can assume different shapes based on the parameters' values. The most general form of the Weibull distribution is the three-parameter form:

$$f(t) = \frac{\beta}{\eta} * (\frac{t-\gamma}{\eta})^{\beta-1} * e^{-(\frac{t-\gamma}{\eta})^{\beta}} \tag{1}$$

with $f(T) \geq 0$, $T \geq 0$ o γ, $\beta > 0$, $\eta > 0$, $-\infty < \gamma < \infty$, where β, η e γ are respectively the shape, scale and position parameters. In figure 1 a graphic showing the β effect upon the failure rate function is represented:

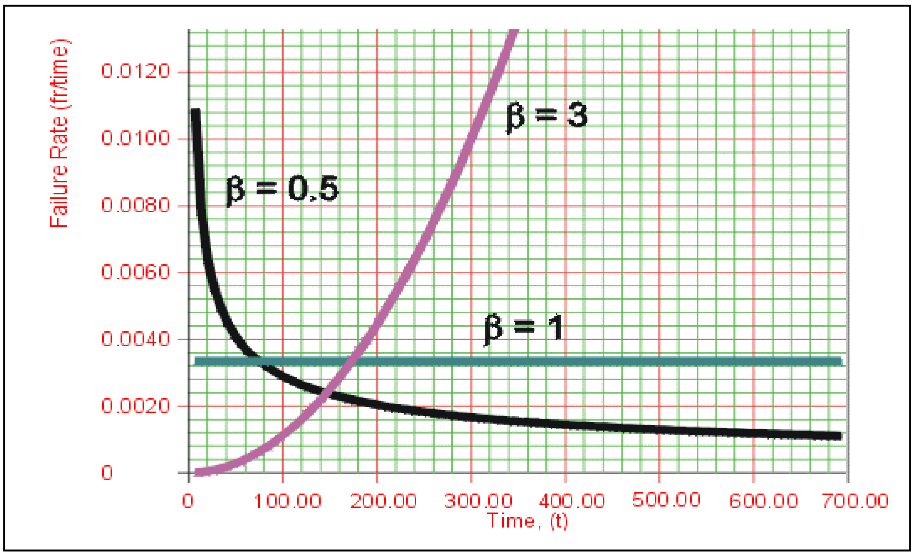

Figure 1. β effect upon the failure rate function

The curve with β<1 exhibits a failure rate that decreases with the time, the curve with β=1 has a constant failure rate (consistent to the exponential distribution) and the curve β>1 has a failure rate that decreases with time. All three life stages of the "bathtub curve" can be modelled with the Weibull distribution just varying the values of β.

4 THE MAINTENANCE MANAGEMENT MODEL

In the general model's formulation, due to economic and management reasons, two different diagrams has been built; the first one concernes the anomaly management during vehicle's service, the second one is specific for the analysis of shop operations' procedures. For each diagram, the choice of one procedure instead of another is based on the failure's gravity. In management service phase (fig. 2), this choice allows to evaluate and plan vehicle's assistance or substitution depending on the means availability. During the shop operations (fig. 3), the selection of the problem's importance allows to cut down the work of the team responsible for the major failures that, of course, conditions tram's availability. It also allows to simulate a possible vehicles' warranty situation. Besides, in figure 3, another procedure, that runs in parallel to the others, has been added to represent the programmed maintenance. Figure 2 and 3 show the develop block diagram of the service and shop models.

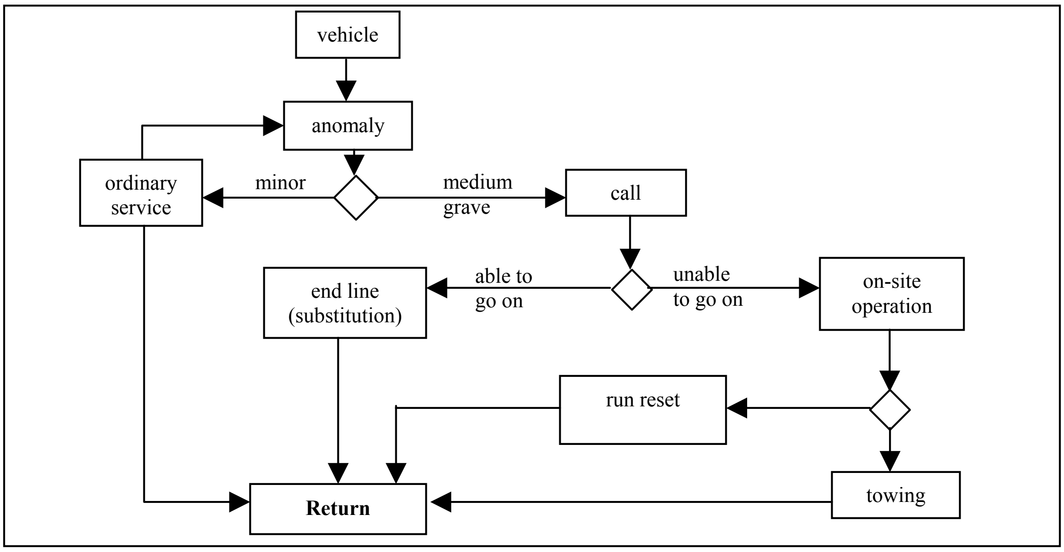

Figure 2. Management service phase

It can be noted that in both cases of anomaly and call, the choise is based on the event's gravity. Concerning to shop's operations (figure 3) it can be noted that an eventual repair under warranty is considered as a medium-grave importance operation

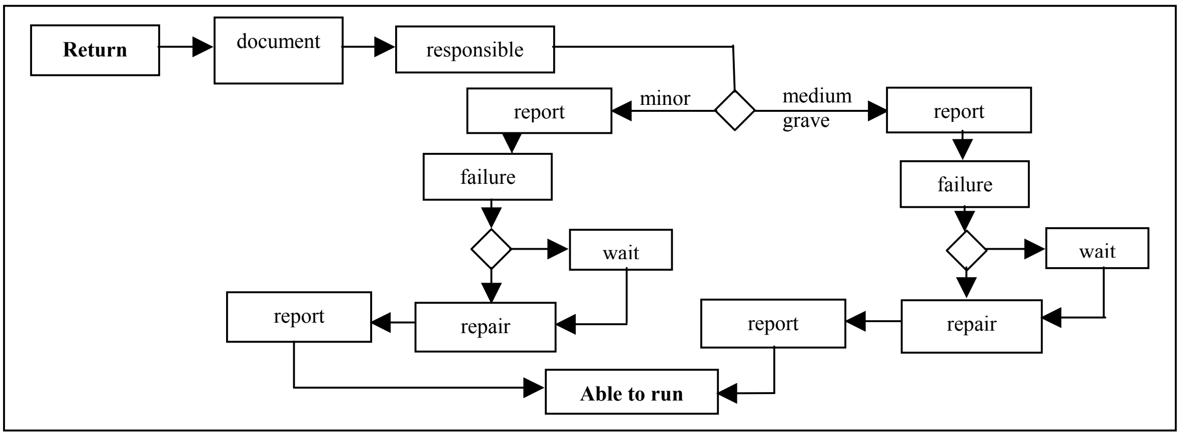

Figure 3. Shop operations diagram

5 AN ANALYSIS MODEL FOR LIFE CYCLE COST (LCC) ESTIMATION

In the choise of the most significant and more capable evaluating parameters to describe the different situations in which a tram can find itself, the labour costs for one man - hour of work and the annual specific distance (km) covered have been chosen. In fact these are two elements that can change shifting from one urban reality to another, while all others remain unchanged but for a little percent differences that can be characterized by proper corrective factors. In that way all expressions will be function of the two above mentioned parameters and the costs determination will be obtained when the technical characteristics and the maintenance periods are known through the β_i comparison parameters between the costs of more difficult determination and the reference ones (C_{mdo-p}).

In the following the expressions for labour and materials costs of failure's maintenance are reported.

$$C_{mdo-im} = \sum_{j=1}^{m} (h_{j-im} * n_{j-im} * Mdo_j) \quad (2)$$

Concerning to the costs of the necessary materials to these operations, they can be compared with labour costs through the β_{im} factor with the following equation:

$$C_{mat-im} = \beta_{im} * C_{mdo-im} \quad (3)$$

with:

C_{mdo-im}: labour cost of the minor operations during the whole lifetime;

C_{mat-im}: materials cost of the minor operations during the whole lifetime;

$MTBF_{im}$: mean distance (in kilometers) between minor failures;

$n_{j-im} = \frac{S_j}{MTBF_{im}}$: number of minor repairing operations in one year;

h_{j-im}: yearly hours/man, on average, necessaries to execute a minor maintenance operation.

6 ANALISYS OF RAM PARAMETERS' PERFORMANCES OF TRAM FIAT 9100

Committed by the Rome's transport company (A.T.A.C. S.p.A.) [5] with the intention of increasing and improving the city's urban transports, this new tram with partially lowered floor takes advantage of the accumulated experience of the vehicle realized for ATM's Turin running from 1989. Both the design and the construction have been conceived to have low operating costs and easy maintenance, thanks to the use of standard modular components. This tram, see figure 4, whose styling has been supervised by Giugiaro Design, adopts structural and formal interior solutions that combine confort and brightness, in addition to a pleasant and modern appearance.

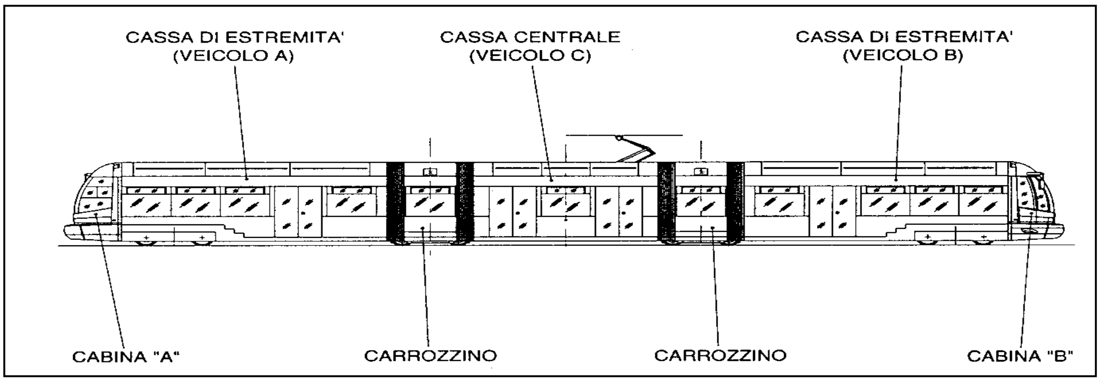

Figure 4. Carriage

In order to combine reliability, availability and maintenability performances of the tram Fiat 9100, it has been necessary to build suitable databases according to the performances to be evaluated [5]. For this purpose, it has been necessary to evaluate the failures of tram in ATAC shop. In order to have trustworthy results tram from 9101 to 9112 have been considered: these ones represent, in fact, the first lot of tram started begun running in April 1999. The period considered in this work is April 99-June 2001 and it has been divided in six blocks, each one of four months and the last one of three months. In figure 5 the obtained results have been reported:

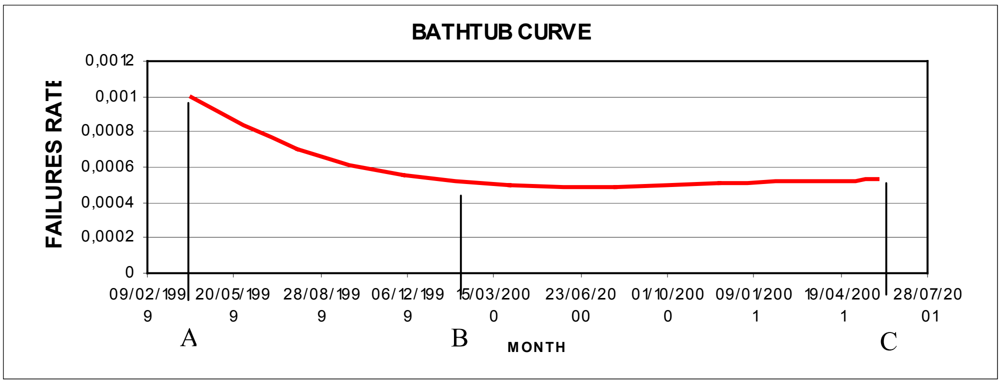

Figure 5. Bathtub curve

In figure 5 the lines pointed out in figure 1 relatively to early mortality (AB line) and operating life (BC) are easily recognizable.

The computation of the basic reliability's MTBF (Mean Time Between Failures [6] has been carried out considering all failures that occurred under warranty operations. The MTBF value indicated in Fiat specifications is one failure in 1050 km with a mean speed of 12 km/h. The computed MTBF result is 1436 km that can be compared with the contract declared value.

Regarding the operating reliability's MTBF value [6] computed by Fiat, it is equal to 2520 km at a mean speed of 12 km/h. In base of shop's information, the analysis has given a MTBF's value equal to 2461 km, comparable to the value proposed by Fiat.

The tram's availability has been calcoulated considering the number of tram operative in the morning before its running. In this way, the method considers the only vehicles able to carry out the service; vehicles under preventive maintenance are not considered in the calcolous since its unreliability is known in advance. The obtained availability's mean value for the year 2000 has been equal to 85,5%.

7 LCC ESTIMATE FOR THE TRAM FIAT 9100

The amount of costs described in this paragraph has been evaluated through the model introduced in paragraph 4. The input data assumed for the study have been:

- annual mean distance: 60000 km (constant throughout the years);

- 2001 materials' repairing costs;
- initial LTR cost: 1807600,00 €;
- lifetime: 30 years;
- rate of materials' costs increase: i_c=0,03;
- rate of staff's costs increase: i_p=0,02

Concerning maintenance costs, as regards the total costs, the programmed maintenance weights on for a 36% while the failure maintenance weights on for a 64%. On the whole lifetime, the considered costs' terms have shown the following percent rate:

- maintenance: 36,6%;
- energy consumes: 41,2%;
- amortization: 14,2%;
- insurance: 5,2%;
- incidents: 2,4%.

The effect of the management costs of the tram fleet considered, as regard all A.T.A.C. S.p.A. vehicles, has also been calcoulated.

A.T.A.C. S.p.A. vehicles costs	**Amount (€)**	**LTR Fiat 9100 costs**	**Amount (€)**
Amortization	25182440,00	Amortization	1601016,00
Energy consumes	37226213,00	Energy consumes	4751404,00
Maintenance	83758980,00	Maintenance	3976718,00
Insurance	19160551,00	Insurance	619748,00

Figure 6. Comparison between Fiat 9100 costs and A.T.A.C. S.p.A. vehicles costs

8 CONCLUSIONS

In this work set of statistical and economic models of general validity has been developed, in order to characterize the reliability's performances and maintenance costs of an particular transit vehicle like the tram. Two diagrams about in line and shop operations management have been realized, supplying the necessary references for database creation, and a mathematical model for the analysis of "rolling", amortization and drivers costs has been carried out. The importance of this study is the applicability of all models to an important and complex case study in Rome, in order to evaluate reliability and economic performances of the tram Fiat 9100 in the current period between the old management procedures and the new rules due to TPL reform,.

REFERENCES

[1] Palazzini C., (1996), *"RAM: un approccio pratico"*.

[2] www.weibull.com, (2001), *"Reliability glossary"*.

[3] D'Alessio T., Meucci G., Somma R., (1987), *"I metodi dell'affidabilità. Teorie, strumenti ed applicazioni per l'analisi dell'affidabilità di componenti e sistemi"*, Franco Angeli Milano.

[4] www.weibull.com, (1997), *"Reliability growth reference"*.

[5] A.T.A.C. Agenzia Trasporti Autoferrotranvieri del Comune di Roma, (giugno 1995), *"Capitolato tecnico speciale per la fornitura di motrici tranviarie articolate, a pavimento ribassato, da adibire al servizio passeggeri sulla rete di Roma"*, documento interno.

[6] Fiat Ferroviaria, gennaio 2000 *"Metodologia di rilevamento degli indici RAMS LTR Roma 72550"*.

[7] Cirillo F., (1997),*"Progetto di sistemi meccanici",* Mc Graw-Hill Milano.

[8] Decambre P., (marzo 2000), *"Les nouvelles methods de maintenance du matériel roulant ferroviaire à la RATP"*, Revue Générale des Chemins de Fer, pp. 39 – 47, Delville.

[9] ATM Area Affari Generali, *"Costi del ciclo di vita per autobus per servizio pubblico: criteri di valutazione per gare d'appalto"*.