AUTOMOTIVE FAILURE ANALYSIS DURING LIFETIME BASED ON WARRANTY DATA

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Abstract. *In this paper case studies regarding automotive failures in two different countries Brazil and Argentina are analyzed. All repairs were performed during warranty period of heavy duties trucks at authorized dealerships. Thus, warranty data was the source of information on the behavior of components in service. Failures of several mechanical components were compared and analyzed. The reliabilities and failure rates of the vehicles in both countries were determined and compared. Weibull model was used to determine the reliability of the vehicles. The failure rate was smaller in Argentina than in Brazil. The reliability behavior of the vehicles in both countries was similar with differences in individual components: Drive trains and electric systems failures were the most responsible for breakdown in service in both countries. The shat failures in Argentina were higher than in Brazil. All these issues are responsible for the low reliabilities and high failure rates. The clearest evidence of this paper is that the assessment of in-service failures requires a careful examination of reliability and failure rates of individual mechanical component. The sharp decrease of reliability with increasing life indicates that these vehicles need premature maintenances. Thus, maintenance policies have to be implemented with the aim of reducing premature failures.*
Keywords*: Reliability, automotive failures, mechanical components, failure rates.*

1. INTRODUCTION

The ability of individual automotive components to tolerate accidental failures without compromise the vehicle is important when they operate under arduous conditions. The performance rates of system elements should be taken into account as well as the level of demand when the entire system's survivability is estimated. Numerous studies have been made to analyze failures of individual mechanical components. However, a global analysis of automotive component failures is imperative to determine the reliability of the vehicles.

Within the automotive industry, the past experience regarding component failure assessments has been well studied (Heuler and Birk, 2002, Eryürek *et al*, 2007, Bayrakceken *et al*, 2006, Heyes, 1998 and Wang and Wang, 2005). Several authors had studied on the failures of individual mechanical components as crankshafts (Wang and Wang, 2005), suspensions springs (Eryürek *et al*, 2007), drive shaft and universal joint (Bayrakceken *et al.)*, etc. In some cases, a consequence of these in-service failures result in the recall of all affected vehicles with costs and bad publicity (Heyes, 1998). Others authors have spent effort in developing suitable tools for statistical analysis and reliability evaluation of component failures (Nelson, 1990 and Zao *et al*., 2007). Reliability engineering is essential during design of multi-component systems, as in the case of automotive vehicles. Surveys on reliability optimization and experimental results have been published Zao *et al*., 2007, Kwo *et al*., 2001 and Yalaoui *et al*., 2005). Zequeira and Bérenenguer, (2006) have published a study on preventive maintenance with two categories of competing failure modes. A method for the reliability analysis of a vehicle body-door subsystem with respect to the door closing was presented by Zou *et al*., 2002. In this paper, a generalized approach for reliability estimation was developed, and it is illustrated for application in specific components.

A simplified method to determine the influence of improving life and warranty costs was published by Rai and Singh, (2002). According to these authors, the reliability of database is essential for quality improvement. A case study regarding the reliability of some automotive components based on field failure warranty data was presented by Attardi *et al*., 2005. An application of a mixed-Weibull regression model of two components of the gear-box of automobiles was presented in this paper. An integrated database and expert system has been developed for identifying and for assisting the analysis the failure mechanism of mechanical components (Warren *et al*., 1999a and Warren *et al*., 1999b. This system comprises database, case maintenance and test-recommendations facilities.

Accurate determination of cause of component failures requires identification of failure modes of several vehicle parts. In this paper case studies regarding automotive failure warranty data is analyzed. All repairs performed during this warranty period at authorized dealerships were recorded in a database. Thus, warranty data was the source of information on the behavior of components in service. A methodology was developed to analyze the reliability and failure rate of a same vehicle type in two different countries: Brazil and Argentina.

2. EXPERIMENTAL PROCEDURE

2.1 Data Acquisition

This study was performed using heavy duties trucks vehicles, which are commercialized in two different markets: Brazil and Argentina. These vehicles were exactly the same model on both countries, with load capacity of 45 ton (≈ 4.59 kN) and power of 272 kW (370 CV). The vehicles were analyzed during their warranty period, which corresponds to one year or 100,000 km in both countries. A sample of 1,606 vehicles in Brazil and 2,395 vehicles in Argentina were used to collect failure data during their warranty time. All data were collected between November 01, 2004 and November 01, 2005. For this reference period, available information from the warranty database are: local of maintenance, total number of kilometers traveled, chassis number and failed components. Moreover, the number of vehicles with no claims during this period was also provided.

2.2 Methodology

In this work the data for failures as a function of kilometers traveled were modeled using Weibull distribution. The vehicle was divided in two sub-systems as shown in the flow chart in Fig. 1. The subsystem constituted by brakes, shafts, drive trains and gearbox were associated in series, while the elements of the second subsystem (Chassis and body, engine, injection and electric systems) were associated in parallel. Both subsystems were associated in series. The first subsystem is constituted of safe critical items, which failures can result in loss of control of the vehicle.

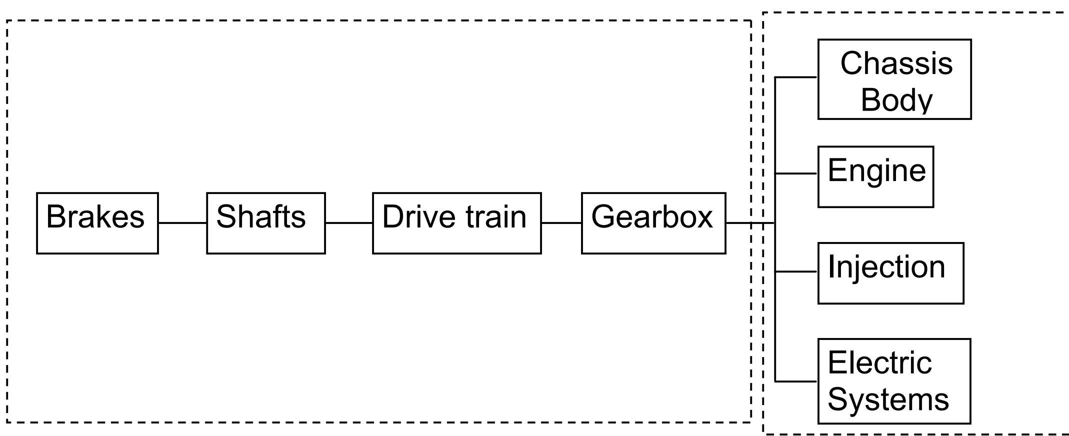

Figure 1. Flow chart of the vehicle subsystems

The probability density function f(t) was calculated using the Weibull model (Hahn and Shapiro, 1967 and Fisher and Fisher, 2000), according to Eq. (1)

$$f(t) = \left[\frac{\beta}{\eta-\delta}\left(\frac{t-\delta}{\eta-\delta}\right)^{\beta-1}\right]\exp\left[-\left(\frac{t-\delta}{\eta-\delta}\right)^{\beta}\right], t \geq 0 \tag{1}$$

where β is the Weibull shaper parameter, δ is the minimum life (or location parameter) and η is the scale parameter (characteristic life). The reliability R(t) is given by the Eq. (2)

$$R(t) = \exp\left[-\left(\frac{t}{\eta}\right)\right]^{\beta} \tag{2}$$

In this equation t is the time to failure and η (characteristic life parameter) is equal to n times 0.632 (that is η = n x 0.632). Thus, this value of η is the sequential indication of the life (in kilometer) that corresponds to 63.2% of total sample.

The failure probability (P(x)) of each mechanical subsystem for a given kilometer was calculated using the Equation

$$P(x) = \frac{RM(x) - 0.3}{n + 0.4} \tag{3}$$

RM(x) is the Weibull location parameter, that is, the failure position of the sub-system in kilometer related to the expected life [16,17]. This location parameter represents an initial period during which no failures can take place, that is, the minimum life parameter [16]. n is vehicle sample, that is, the number of analyzed vehicles (1,606 vehicles in Brazil and 2,395 vehicles in Argentina). The numbers (0.3 and 0.4) in Eq. (3) adjust the results for the censored units.

The failure rates of Weibull model (λ) were determined by using the Eq. (4)

$$\lambda = \frac{\beta}{\eta - \delta}\left(\frac{t - \delta}{\eta - \delta}\right)^{\beta - 1}, t \geq 0 \tag{4}$$

Then, the estimates P(x) were plotted against the life in kilometer on a Weibull paper (in logarithm scales). The angular coefficient of the fitted experimental data was the Weibull shaper parameter (β).

According to Fig. 1, the reliability of the vehicle (R) is calculated multiplying the reliabilities of series (R_S) by parallel subsystems (R_P), that is:

$$R = R_S \, . R_P \tag{5}$$

The reliabilities of the components associated in series and in parallel are given by equations (6) and (7), respectively:

$$R_S = R_B R_{SH} R_{DT} R_{GB} \tag{6}$$

$$R_P = 1 - (1 - R_{CB})(1 - R_{EN})(1 - R_{IN})(1 - R_{ES}) \tag{7}$$

where R_B, R_{SH}, R_{DT}, R_{GB}, R_{CB}, R_{EN}, R_{IN}, and R_{ES} are the reliabilities of the brakes, shafts, drive train, gearbox, chassis, engine, injection and electric systems, respectively.

3. RESULTS

Based on the analysis of collected failure data of the vehicles during their warranty period, the distribution of component failures are shown in figures 2 and 3, for Brazil and Argentina, respectively. It can be seen from these figures that drive trains failures were the most common, followed by electric systems, in both countries. The most discrepancy was observed in shaft failures with 2% in Brazil and 11% in Argentina.

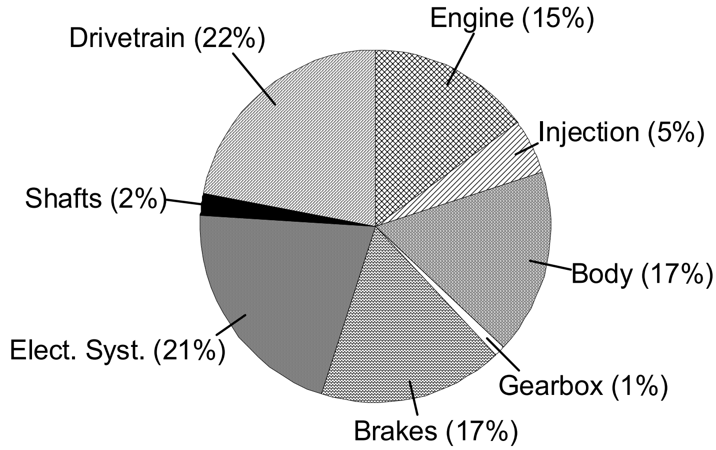

Figure 2. Distribution of component failures – Brazil

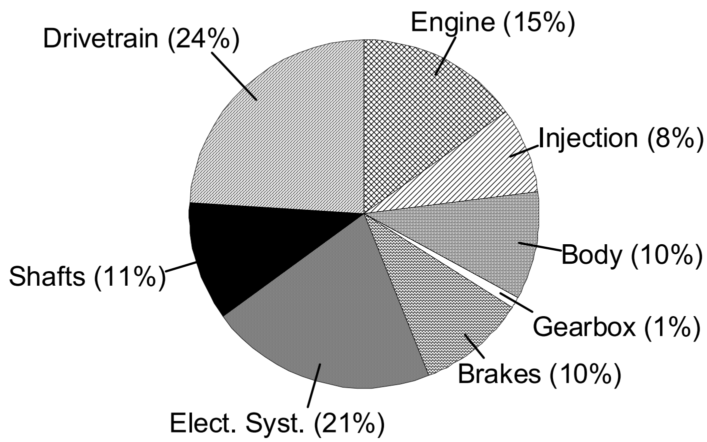

Figure 3. Distribution of component failures – Argentina

A common problem in comparing different countries is that the vehicles have been exposed to distinct culture, roads and environments. Thus, a better comparison of failures between both countries can be done if failure rates are used. These rates were calculated dividing the absolute failure numbers and frequency by the total number of analyzed vehicles (1,606 vehicles in Brazil and 2,395 in Argentina). These failure rates are shown in Fig. 4. The failure rates are greater in Brazil than in Argentina. Since the behavior of failure rate can be used to characterize the system degradation, the results of Fig. 4 demonstrate that the Brazilian conditions are more arduous than those in Argentina. Moreover, the failure rates during the life of the vehicles are almost constant in Argentina, and show large peaks for each 15,000 km in Brazil. These peaks correspond to the obligatory preventive stops maintenance recommended by the manufacturer in Brazil.

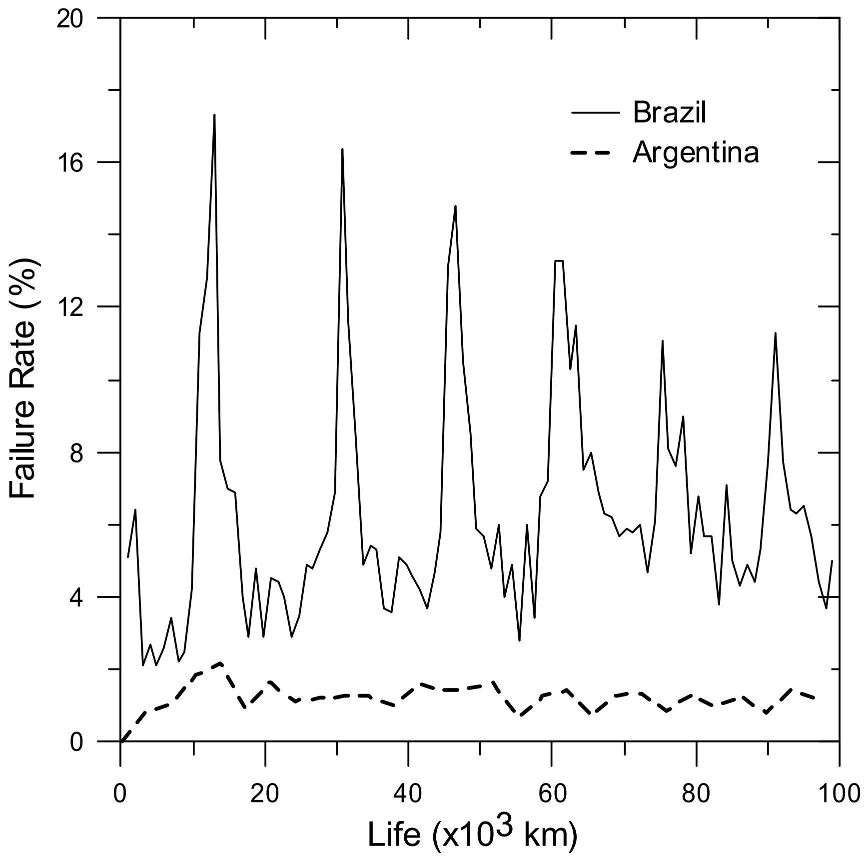

Figure 4. Comparison between failure rates in Brazil and in Argentina

The Weibull model was used to determine the reliability of the vehicle, according to item 2.2. For each mechanical component (Fig. 1) the failure probability curve was drawn using the maintenance database. The values of Weibull shaper parameters were compared with the failure analysis or the components. As examples, the failure probabilities for shafts in Brazil and in Argentina are shown in figures 5 and 6, respectively. The Weibull shaper parameters are $\beta = 0.765$ in Brazil and 1.724 in Argentina.

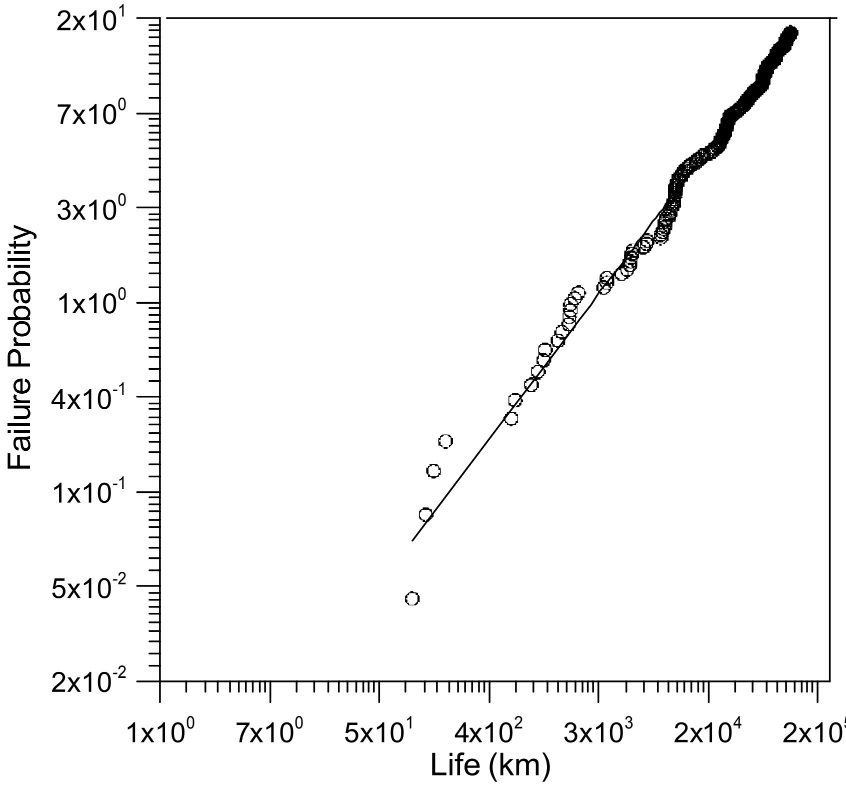

Figure 5. Failure probabilities shafts in Brazil

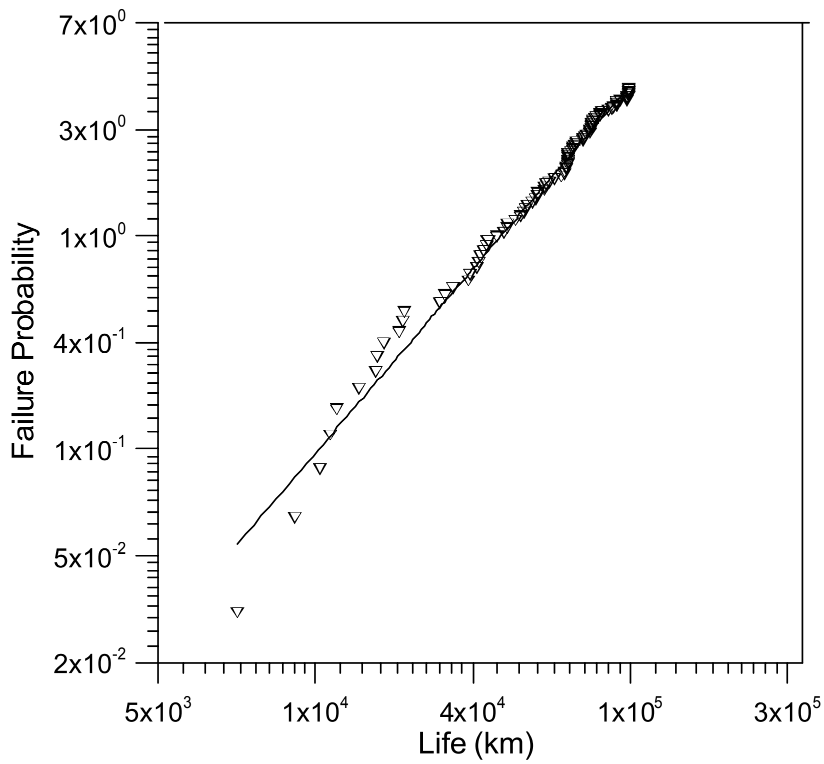

Figure 6. Failure probabilities in Argentina

The values of the Weibull shaper parameters of all mechanical components are summarized in Table 1. Shaper parameter smaller than unity ($\beta < 1$) means that after an initial large value, the failure rate decreases with life. These failure types are associated with manufacturing or design, assembly, raw material and abuse. On the contrary, shape parameter between one and two ($1 < \beta < 2$) means that the failure rate increases with increasing life service, initially rapid and then gradually. These failures were associated with wear, corrosion and fatigue.

Table 1. Weibull shape parameter for mechanical components in Brazil and Argentina

Subsystem	Mechanical Components	Shape Parameter (β)	
		Brazil	Argentina
Series	Brakes	1.326	1.225
	Shafts	0.765	1.724
	Drive-train	1.115	1.027
	Gearbox	1.082	0.734
Parallel	Chassis/Body	0.969	0.867
	Engine	1.177	1.145
	Injection	1.186	0.976
	Electric System	1.000	0.836

With the Weibull curves for all mechanical components of Fig. 1 the vehicle reliability can be calculated using equations (5) to (7). The results are shown in Fig. 7 for both countries. Even though, some individual mechanical components show different reliability values, the reliability values of the vehicle are quite similar in both countries. The sharp decrease of reliability with life indicates that these vehicles need premature maintenances, which means high costs for the car owner.

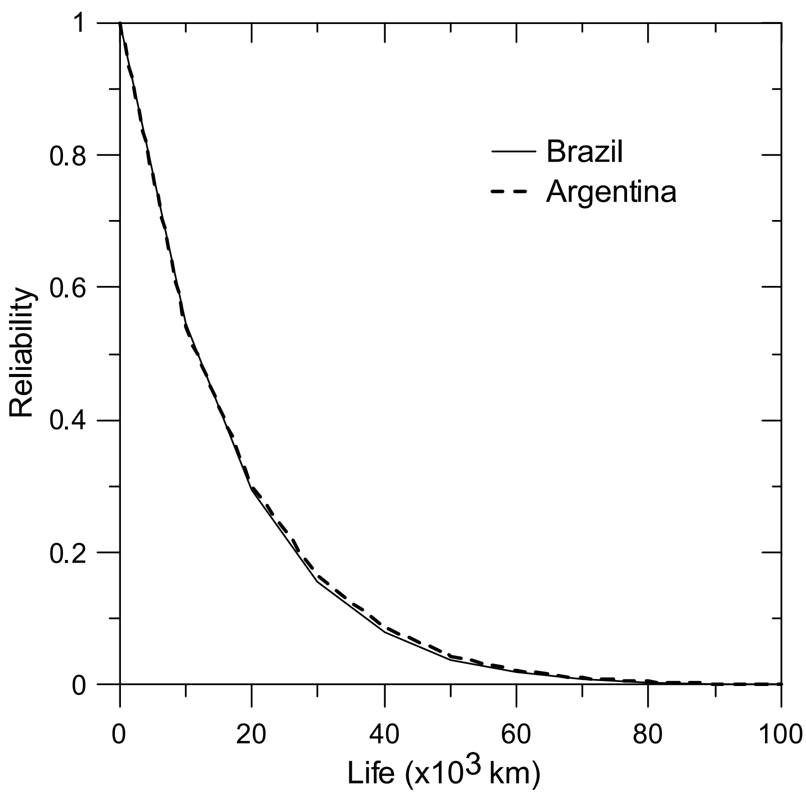

Figure 7. Reliability of vehicles in Brazil and in Argentina

An analysis of failure probabilities together with reliabilities of the individual components and vehicle is an important tool for determination of maintenance policies. Preventive maintenance actions in components with low reliability values may increase equipment lifetime and decrease breakdowns frequency. The reliabilities of each individual mechanical component for vehicles in Brazil are shown in Fig. 8. It can be seen from this figure that the reliability behaviors of the components are similar. Until 60,000 km, the shafts are the mechanical components with the smallest reliability values. After 80,000 km, the brakes have shown smaller reliability than all others components. Thus, the reliability of the vehicle can be improved if an appropriate preventive maintenance of shafts is implemented. These results are similar to those obtained in vehicles from Argentina.

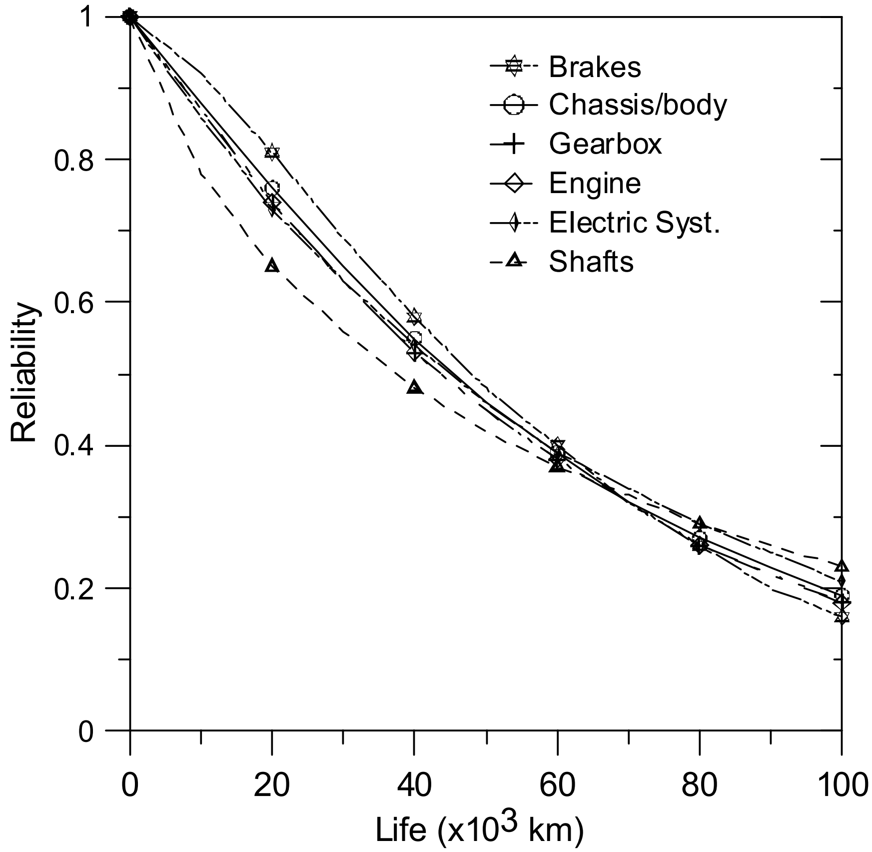

Figure 8. Reliability of Mechanical components in Brazil

4. CONCLUSIONS

In this paper the reliability and failure rate of heavy duty vehicles in Brazil and Argentina were determined. Besides, it was determined how much the reliability of the vehicle is affected by the reliability of individual mechanical components. The failure rate was smaller in Argentina than in Brazil. The reliability behavior of the vehicles in both countries was similar with differences in individual components: Drive trains and electric systems failures were the most responsible for breakdown in service in both countries. The shat failures in Argentina were higher than in Brazil. All these issues are responsible for the low reliabilities and high failure rates. The clearest evidence of this paper is that the assessment of in-service failures requires a careful examination of reliability and failure rates of individual mechanical component. The sharp decrease of reliability with increasing life indicates that these vehicles need premature maintenances. Thus, maintenance policies have to be implemented with the aim of reducing premature failures.

5. ACKNOWLEDGMENTS

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