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USING RELIABILITY INDICATORS TO EXPLORE HUMAN FACTORS ISSUES IN MAINTENANCE DATABASES

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1. INTRODUCTION

Drayner (1963) stated that modern reliability management is mainly concerned in eliminating the effects of system faults caused by imperfect parts, assembled by imperfect people and used by imperfect individuals. In the most common definition, reliability is the probability that a component will not fail to perform within specified limits in a given time while working in a stated environment (Ebeling, 1997; Moubray, 1997; Neubeck, 2004; O' Connor, 2002; Smith, 2005). The indicators used in equipment reliability are the observed failure rate and the observed Mean Time Between Failures (MTBF); the failure rate is calculated as the total number of failures divided by the total cumulative operational time and the MTBF is the reciprocal of the failure rate.

According to Smith (2005), data collection is an integral part of the reliability evaluation, and the analysis of the failures is the precondition for obtaining reliability improvement and growth. Kirkwood et al (1987) state that a maintenance data base may be a valuable source for getting a first picture regarding any reliability and maintainability problems, but it cannot explain the causes of such problems to assist in making final decisions for improvement programs.

The dominant theory about parts' failure rate pattern during their operational life (e.g. Davidson & Hunsley, 1994; Rao, 1980; Moubray 1997) assumes that the repairs restore the parts to an 'as good as new' (AGAN) condition and the failures occur at random but constant failure rate. However, the research (Davidson & Hunsley, 1994) has shown that the equipment often is not AGAN after the repair due to maintenance errors or poor quality workmanship.

The main causes that affect parts' reliability as described by Allan & Billinton (1982), Davidson & Hunsley (1994), Dhillon & Singh (1981), Lewis (1987), Patankar & Taylor (2004) and Rao (1980) are the improper maintenance or installation, the operating duty referring to the ranges of operating stress imposed, the operating conditions including the working environment, the operators' effects, the training of the staff involved in use and maintenance and the lack of adequate supervision. Apart from the use and maintenance, errors may be attributed to designer's inconsistencies or to the manufacturing and constructing stages (Lewis, 1987; Patankar & Taylor 2004); though such errors become inherent in the system, which may demonstrate lower reliability than expected, but still a constant failure rate.

Regarding the kind of the failures caused due to human interference, the basic forms of the maintenance error are either a discrepancy caused which did not exist before the maintenance task, or damage not detected during the preventive or corrective maintenance leading to equipment degradation (Graeber & Marx, 1994). Hobbs (1996) notices that the maintenance staff face challenges including extremes of weather, noise, height, darkness, too large tasks for a single shift and unrealistic procedures that may lead to divergence between the actual performed tasks and the requirements documented in the technical manuals, causing also the flourish of informal work practices.

Taking into consideration the massive number of tasks taking place especially into the aviation maintenance domain, the idea of this study, comprising an MSc thesis project (Karanikas, 2008), was to search the existence of human factors areas in the maintenance domain by indicating trends in the historical data of repairable parts that may violate the assumption of the AGAN philosophy, and correlations between variables found or calculated from the failures database in order to detect potential areas with significant human factors influence. Such indications may assist on the allocation of resources to procedures and areas that are negatively affected by human influence, and may uncover areas positively influenced by human factors for their use as examples.

2. METHODOLOGY

2.1. Data

The data collection is considered as a labor-intensive feature and this remains a significant problem in recording complete and accurate information (Smith, 2005). Since the failures' recording relies on humans, there is the probability of errors, omissions and misinterpretations.

The researcher used data from a jet-engines workshop database; the parts under study (Table 1) were chosen taking into consideration factors such as their operational diversity (column "Type"), least influence by the operating environment, least effect by environmental conditions, operational independency among the parts under study, existence of failures along their operational life, and diversity in the workshops where the parts are repaired – overhauled (column "Maintenance"). All the parts are replaced by equally qualified engine workshop personnel under same working conditions and with the use of same equipment and documentation.

Part	Description	Type	Maintenance
A	Engine computer	Electronic	Electronics workshop in the Intermediate Maintenance Level (ILM)
B	Hydraulic motor	Mechanical (power transmission driven by hydraulic power)	Approved Maintenance Organization (AMO), Workshop1
C	Master fan flow diffuser actuator assembly	Mechanical (power transmission through mechanical connections)	Approved Maintenance Organization (AMO), Workshop1
D	Exhaust nozzle hydraulic pump	Mechanical (hydraulic power transmission)	Approved Maintenance Organization (AMO), Workshop2

Table 1: Parts under research

Under this concept, the environmental and operational factors influencing reliability were eliminated, with the residual of any remarked variability in the reliability possibly assigned to the human error and human performance factors among different workshops and maintenance levels, either in the operator's or the supervisor's level.

After retrieval from the database, the data were corrected, supplemented, and coded: the inconsistent records were changed, the missing data were included into the database according to the log-cards details, the parts with no failures were not included in the research, in occasions of no sufficient data for the whole part's life the period under study started from its last repair under the assumption of the AGAN condition, and each Serial Number (SN) was referred as A(or B or C or D)x (e.g. A1 as the SN "1" of Part A) The final population / failures proportion of the parts were for Part A: 34 / 73, Part B: 35 / 40, Part C: 46 / 60, and Part D: 44 / 78.

2.2. Reliability Assumptions and Testing Methods

2.2.1. Literature Review

The analysis of reliability data mostly uses the concept of MTBF or failure rates of a part or identical parts operated under similar conditions. The techniques used assume that the Times Between Failures (TBF) are independently and identically distributed (IID) referring to processes called Homogeneous-Poisson-Processes (HPP). However, extensive investigation revealed the existence of features such as trend and serial correlation that invalidate the IID assumption and indicate Non-Homogeneous-Poisson-Processes (NHPP), (Bendell et al, 1985).

The main methods used to test for the assumption of IID and HPP are the following (Ebeling, 1997; Kvaloy & Lindqvist, 1998; Neubeck, 2004; O'Connor 2002):

- Simple monthly MTBF plots, which provide a visual indication of any trend that the MTBF takes.
- The Laplace test that checks for any trend against the null hypothesis of no trend; the values of the u calculated figure define the direction of the trend with u=0 implying no trend, u>0 implying decreasing trend and u<0 implying increasing trend.
- The AMSAA – Duane – Crow model helps to determine if the NHPP is more appropriate model than the constant failure rate model. The model, also known as MIL-HDBK-189 (Department of Defense, 1981), calculates a parameter (β), depicting strictly monotonic increasing failure rate for β>1, monotonic decreasing for β<1 and constant for β=1.
- The serial correlation of the last TBF with the previous TBF underlies the presence of dependencies and discourages the application of standard analysis methods.

2.2.1. Application

According to the methods presented above the researcher applied the following:

- The variability of MTBF's among the fleets was illustrated by using histograms; also, plots were used in order to obtain a first picture of the MTBF and failure rate possible oscillation with time.
- The Laplace test was applied for each SN; histograms were used to illustrate any variability of the u value among the fleet of each part. Although not mentioned in the literature, the Laplace was considered more powerful with the existence of at least two failures in each individual part under study; the existence of a unique failure may also indicate trend if the hours' intervals from the beginning of

operational life to the failure and from the failure to the last observed operational hours are not the same, but this in fact does not compare the trend between successive failures.

- The reliability growth plotting according to the Duane-Crow-AMSAA model was facilitated by Minitab software, which provided three goodness-of-fit tests for data coming from homogeneous systems: AMSAA and Laplace's tests using the chi-square distribution for the statistical significance of the results, and the Anderson-Darling test that compares the AMSAA empirical cumulative distribution function with the distribution expected if the data were normal. The null hypothesis for the tests were that the data come from a HPP with a possibly different MTBF for each part; thus, rejecting the null hypothesis could mean a trend in the data, the latter forming the alternative hypothesis. The statistical P-value was set to 0.05.
- The plotting of TBF for successive failures of each SN helped to picture any dependency in the TBF's that would discourage the implementation of standard reliability methods.

2.3. Simple Correlations

The Pearson correlation coefficient was used along with the P-test for testing the significance of the results regarding correlations between simple number variables. The Pearson coefficient takes values from -1 to 1 and the more the coefficient approaches to -1 or 1 the bigger the effect between the variables. Taking into account the form of the available data in the maintenance data base, the researcher explored the following number variables:

- MTBF and Mean Time Between Installations (MTBI); the latter was calculated as the total operating hours divided by the total installations for each SN, excluding the ones related to tasks after depot maintenance since in that case the replacing task is mandatory. The specific case would demonstrate if there was any effect on failure rate due to frequent replacing tasks, underpinning either the negative or the positive contribution of the human factors (e.g. poor human performance, inadequate equipment, use of defected spare parts, unsuitable procedures etc.) in the engine workshop context in the case of failure rate increase or decrease respectively.
- MTBF and Mean Time Between Depot (MTBD); the MTBD was estimated by dividing the total operating hours by the number of preventive depot maintenances without counting the repair maintenance related to failures. In this case, any MTBF influence by the maintenance frequency would uncover similar to the previous paragraph indications regarding human factors influence for the Approved Maintenance Organization context.

2.4. Statistics with Database Parameters

It was observed that there were different numbers of the depended variable measurements against the different values of the independent variables, meaning that the "experimental" structures were unbalanced. According to Betha et al (1995), Hollander & Wolfe (1973) and Montgomery (2000), the statistical methods used in these cases are the Kruskal -Wallis Test or the General Linear Model (GLM); the variability among the "experiment" populations leads to the choice of the statistical method used in every case.

The Kruskal – Wallis test is applicable when there is no significance variance between the populations under study; it tests the null hypothesis that all populations have identical distribution functions against the alternative hypothesis that at least two of the samples differ only with respect to the median.

The GLM method is used when significance variance between the populations is observed and constitutes application of the linear multiple regressions for a single dependent variable. The general purpose of GLM is to quantify the relationship between several independent variables and a dependent variable using the least squares procedure.

The statistical methods mentioned were applied for the independent and depended variables shown in Table 2.

DEPENDED VARIABLE (measured in light hours)	INDEPENDENT VARIABLE	NULL HYPOTHESIS	ALTERNATIVE HYPOTHESIS
Installations – Failures intervals (FIHOURS)	Part Serial Number (SN)	No effect of installation tasks on failures' frequency of specific SN's.	More frequent failures of specific SN's after replacement due to factors not related to ILM context.
Depot Maintenance – Failures intervals (FDHOURS)	Part Serial Number (SN)	No effect of depot maintenance tasks on failures' frequency of specific SN's.	More frequent failures of specific SN's after depot maintenance attributed to factors not related to AMO context.
MTBF	Number of Installations (NI)	No effect of replacements number on the frequency of failures.	Negative effect of the replacements number on the frequency of failures due to engine workshop context problems.
MTBF	Number of Preventive Depot Maintenances (ND)	Neutral or positive effect of number of depot maintenances on the frequency of failures.	Negative effect of the number of depot maintenances on the frequency of failures due to ILM or AMO context deficiencies.
Installations – Failures intervals	Month of Installation task	No effect of the month of replacement on the frequency of failures after its installation.	Effect of the month of replacement on the frequency of failures after its installation, indicating engine workshop personnel performance fluctuation along the year.
Preventive Maintenance – Failures intervals	Month of Preventive Maintenance	No effect of the month of maintenance on the frequency of failures after its installation.	No effect of the month of maintenance on the frequency of failures after its installation, indicating ILM or OLM personnel performance fluctuation along the year.

Table 2: Depended and independent variables

3. RESULTS

3.1. Trends and Dependencies

The histograms showed variability in the MTBF values for each fleet, meaning that the frequency of failures varied among the individual parts and did not tend to a central value (Figure 1). In addition, the plots of MTBF along the time pictured fluctuations in different time periods for each fleet with either increasing or declining trends; Part B and D fleets showed an overall declining MTBF, whereas part C fleet presented a continuously increasing MTBF. These observations evidenced the violation of IID failures theory, and indicated NHPP.

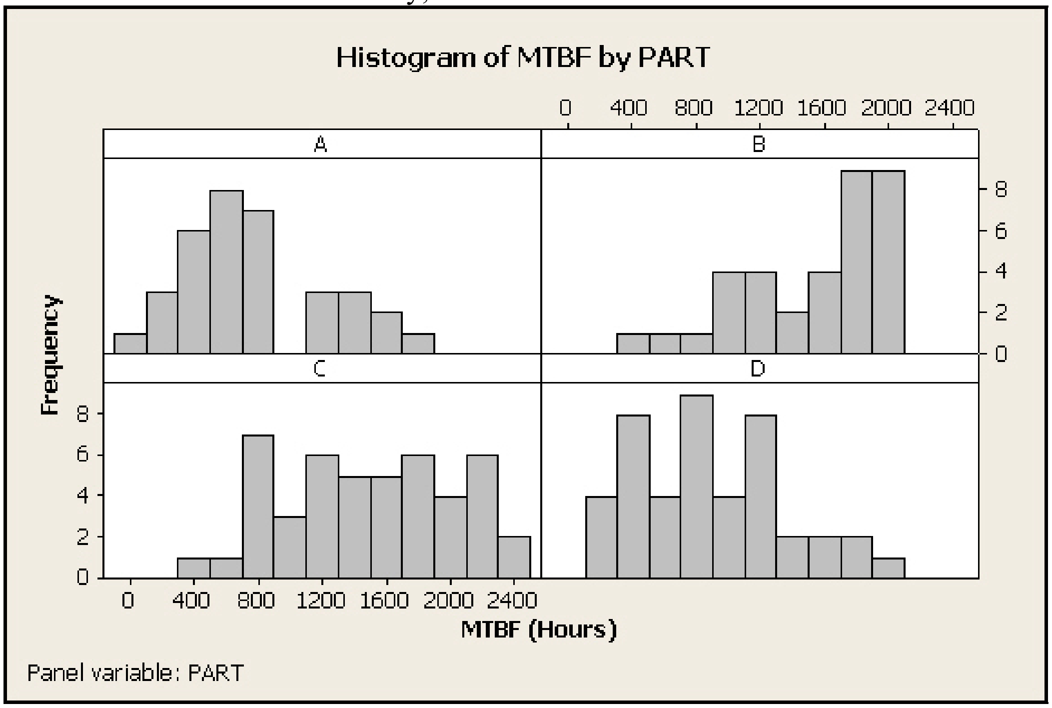

Figure 1: Histogram of MTBF's for Parts A, B, C and D

The Laplace trend test (*u*) values demonstrated a high variability among the parts of each fleet; the values of the most SN's were either lower or higher of the zero value, hence indicating trends in the failure rates (Figure 2).

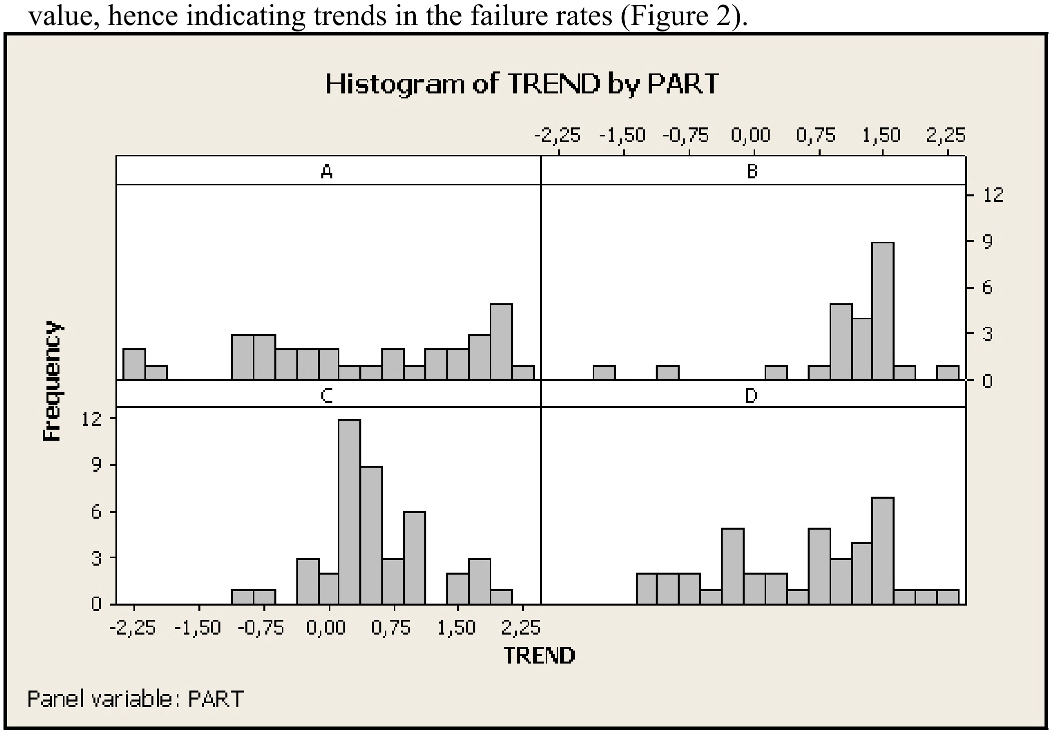

Figure 2: Histogram of Laplace trend test values (u)

Regarding the Duane-Crow-AMSAA model, part A fleet demonstrated decreasing trend in failure rate ($\beta<1$) whereas parts B, C and D had increasing failure rates. The three goodness-of-fit tests agreed for parts A, B ($p<0.05$) and D ($p>0.05$) results whereas for part C fleet only the Anderson-Darling showed possibility of rejecting the null hypothesis of no-trend in failure rate. The statistical significances observed for A and B parts showed that for both fleets there was strong evidence for trends in the failure rates.

Since at least three failures are required for any individual component in order to calculate and plot successive TBF, the TBF values against previous TBF values were calculated only for parts of A, D fleets; Part B and C fleets had mostly one to two failures, and consequently the serial correlation plots could not be generated. The plots did not show any strong pattern meaning that there was no obvious evidence of dependencies between the depot maintenances for each fleet.

The correlations between the MTBF and MTBI – MTBD variables, discussed in paragraph 2.3., showed statistically significant result only between the MTBF and MTBD variables for B parts (Pearson's correlation coefficient 0.6, p=0.004).

3.2. Depended and Independent Variables Statistical Results

Table 3 shows the statistically significant results obtained by the Minitab software concerning the variable pairs described in Table 2; the value R^2 is the squared value of the Pearson's correlation coefficient and stands for the percentage of the independent variable effect on the depended variable. According to the descriptive statistics that estimated for each fleet and pair of variables, the General Linear Model (GLM) was applied in every case because the variances differed significantly. The following observations were made:

- According to the SN versus FIHOURS and FDHOURS statistics:
  - In Part D fleet there were components more vulnerable to failure after replacement.
  - In Part A fleet some individual parts had failed more frequently after their maintenance.
- The effect of NI on MTBF appeared significant only for Part B fleet with a percentage of 32.70%. In conjunction with the trend test results above, the NI influenced negatively the reliability of the specific part.
- The ND factor seemed to affect significantly the parts C fleet with a percentage of 45.41% and P-test value of zero. In this case as well, according to the trend tests results above, the ND presented a negative effect on part's C reliability.
- Regarding the independent variables of installation and maintenance month, and the depended variables of the installation–failure and maintenance-failure intervals, only parts' A maintenance - failure intervals seemed to be affected from the month that the maintenance task took place; some A parts maintained during September demonstrated shorter intervals, followed by parts that underwent maintenance on May and August.

Independent variable	Depended variable	Part	R^2 value	P-test value

Serial Number (SN)	FIHOURS	D	58.9%	0
	FDHOURS	A	32.69%	0.036
Number of Installations (NI)	MTBF	B	32.70%	0.019
Number of Depot Maintenances (ND)		C	45.41%	0
Month of depot maintenance task	Maintenance – failure interval	A	22.79%	0.007

Table 3: Depended and independent variable significant statistical results

4. DISCUSSION

Regardless the total available fleet of 237 parts that were included in the database, eventually only 159 were suitable to be inducted in the current research. This fact decreased the sample for the statistical calculations without decreasing the significance of the results since the methods used do not explicitly require large samples. Furthermore, the choice of different electronic and mechanical parts maintained in different workshops by different personnel contributed to avoid any bias in the consideration of the depended and independent variables statistics.

4.1. MTBF and Laplace Trend Test Histograms

Each fleet was manufactured by the same supplier, had been operated in the same environment, was replaced and maintained by equally qualified personnel; thus, the fleets would be expected to demonstrate MTBF and *u* following the Central Limit Theorem (CLT), cited by Feller (1968). According to the CLT, the sample mean of MTBF and *u* for the parts under study would be normally distributed regardless of the population distribution. The human and equipment reliability oscillation during the replacements and maintenance tasks would affect any part in each fleet and not particular ones; therefore, the MTBF and *u* would be expected to fluctuate about the same value. However, the significant variability in the MTBF and Laplace test values (*u*) revealed potential factors influencing the components' erratic behavior; the literature expectations were not fulfilled, comprising the first stimuli for deeper search regarding the form and the extent of the potential factors influencing the parts' reliability, either positively or negatively.

Regarding the manufacturing process, there could be deficiencies in specific batches that affect the reliability of some parts. However, the data did not reveal any strong trend showing that a sequence of serial numbers presented more or no failures; in addition, scatter plots of MTBF and *u* versus SN did not show any batches of SN's with sequence of low or high MTBF's and *u* values.

The indications that may explain the MTBF and *u* variability according to the log-cards data examined are the following:

- The proposed by the manufacturer modifications were not implemented in all parts of each fleet or their modification pace was very slow; consequently each part may had demonstrated different behavior affected by its configuration as well as the time that any modification was implemented. Hence, human factors related to the supervisors and managers responsible for the modifications' application should be explored (e.g. attention, motivation, knowledge etc.).
- There was no information about the procedures of storage, transportation and long-term preservation of the parts; any deviation of the manufacturer's

recommendations would have influenced the parts reliability. Therefore, human factors regarding the warehouse and workshop personnel should be researched (e.g. adequate documentation, knowledge, workload, supervision etc.).

Concerning exclusively the *u* values, the histograms (Figure 2) clearly showed that there was trend in the failure rates of each part but the variability observed did not allow determining if there was an overall decreasing or increasing trend for each fleet. Especially for part B fleet, most of the parts had failed only once and therefore the specific test, which is more powerful for checking trends between at least two observed failures, was not accurate enough.

4.2. MTBF and Failure Rate Time Series / Duane-Crow-AMSAA Model

The declining or increasing MTBF's for every part fleet, meant either reliability degradation or reliability improvement; concerning the main factors that influence reliability, any manufacturing problem should have affected the MTBF over time in the same way, the flight missions and operations had remained similar, the training of technicians followed the same schemes for every kind of part, the parts were replaced by the same personnel, and especially Parts B and C have been maintained by the same AMO workshop staff. Having therefore eliminated the influence of the aforementioned factors, the different oscillations in the MTBF of each fleet was attributed to either the periodical introduction of new maintenance procedures in the airbase or depot level maintenance regarding specific parts, or the variability in the pace of modifications' implementation as discussed earlier. For the first factor, a separate study should explore the MTBF fluctuation between the adoptions of new maintenance procedures in order to reveal any potential positive or negative effect on parts' reliability.

4.3. Simple Correlations

The positive correlation between the MTBF and MTBD for part B, means that the larger the intervals between the maintenances the more reliable the parts were becoming, confirming the modern philosophy of the least possible maintenance in order to avoid reliability degradation due to human interference; the specific result could be used as an example for reliability improvement though the designing process and the manufacturers recommendations regarding the maintenance policy of other part fleets that have not revealed such patterns.

4.4. Depended and Independent Variables

The bias among specific A and D fleets SN's concerning the frequency they fail may be attributed either to production – manufacturing deficiencies that came inherent with the parts and had appointed them more vulnerable to replacement or maintenance tasks, or defective components inside the parts that had not been detected by the technicians and caused either failures to other components or general operational problems. The first should comprise a stimuli for exploring any factors in the production phases; the latter would indicate inadequate troubleshooting procedures in the maintenance documentation or/and insufficient test devices and equipment to detect the defective components, demonstrating human factor problems in the maintenance policy development stage.

Taking into account that the same personnel replaces all the parts under study, the positive correlation between MTBF and NI only for parts B excludes the direct human factor influence and may be attributed to the potentially simpler documented replacement procedures and more sensitive functional tests that revealed early any deficiencies.

Since both parts B and C are maintained by the same AMO personnel, any direct human performance positive influence should be noticed in MTBF and ND correlations for both fleets; therefore the positive correlation only for Parts C could be attributed to their simple mechanical layout consisting of non-complex components which are easier to be maintained and to be inspected; perhaps the manufacturer recommendations had succeeded to increase the reliability by time and the technical documentation supported effectively every maintenance process.

Taking into consideration that the temperature, noise, humidity and generally the environmental conditions regarding the maintenance workshops remain steady during the year with the use of appropriate equipment, the explanation of the influence of the maintenance month on the MTBF for Part A could be assigned to the decreased human reliability due to increased workload or distractions in combination with observed failure rate increasing during the summer period. During summer, especially in August, there is a gradual absence of maintainers due to holidays; therefore, whereas the A parts failures increase, the available staff decrease and the workload become higher. In addition, any parts that are not repaired or checked due to lack of adequate personnel or experienced technicians are rolled to the next months and consequently after summer the workload is both high and demanding from a maintenance level perspective. Moreover, both the holiday's expectation and the period after the holidays may affect the technicians psychologically and distract them during their tasks. During September, the holiday memories and the time required to get back into the work climate probably affect the human reliability, as well the accumulated workload due to the summer holidays. Usually, in May there is no high workload, but the fact that is the first warm month of the summer season may be enough to explain any distractions coming from the nice weather, the beautiful nature and the plans for the forthcoming holidays affecting negatively maintenance quality and reliability. The fact that only the electronics ILM personnel are related to these remarks, the attention should be locally focused on the specific workshop and the relevant supervision; since the human factors related to increased workload and distractions were almost inevitable, potential problems of poor workload management and insufficient supervision should have been considered especially during these sensitive periods of the year.

4.5. Final Remarks

According to the results discussed in the previous paragraphs, it becomes apparent that the use of failure databases may assist in spotting areas of human factors interest in order to reveal system deficiencies related to workload management, parts configuration management, supervision and manufacturing process. However, any benefits coming from the indication of such areas (e.g. establishment of more effective management, control of parts configuration, provision of better training, safety culture growth etc.), can be obtained by further use of research methods, such as field observations for long periods and interviews of airbase and AMO personnel extending from the just - qualified technician to the senior managers.

The more challenging individual human factors issues, which may allow assisting the technicians in person, require more detailed databases integrating information (e.g. names of person(s) involved, state / mood of persons the day of the task, task duration, time of the day / shift, non-ordinary working conditions such as very high or very low temperatures or very noisy environment, management pressure, special day events such as incidents or accidents), and interconnection with confidential human resources database providing details such as age, gender, experience in the organization and before, marital status, reports for inappropriate attitudes and norms in other positions of the same organization, health status, and initial and recurrent training dates, scores and trainers. The use of databases with such variables may allow indicating potential patterns between reliability figures and human factors in order to deepen in the real causes and apply the appropriate remedies.

5. CONCLUSIONS

Taking into account the methodology followed, the results described and the discussion above, the following conclusions may be claimed:

- The corrections made to the data confirmed the literature references concerning the negotiable accuracy of the data input in the electronic databases and the insufficient reporting of failures and maintenance actions.
- Histograms are adequate to show potential high variability in MTBF among the parts of each fleet indicating potential general human factors; SN sequences or correlation between SN and MTBF values may support the claim of batch production deficiencies.
- Laplace trend tests seem useful to reveal the failure rate trend for each individual part, but in case of variability in the trend values (u) it may not possible to decide for the inclining or declining trend of the fleet. Although the literature does not imply any restrictions, the specific test seems better for application in parts with at least two failures in order to picture more evident trend indications between successive failures.
- Time series plot picturing the oscillation of MTBF and failure rates may reveal periods with steep increase or decrease, which can lead to a further research for important events – decisions – changes made, that affected either human or parts' behavior.
- The AMSAA-Duane-Crow model is more suitable than the Laplace test to determine the failure rate trends for a fleet. However, the simpler Laplace test should antecede for the first trend indications in order to decide the need of AMSAA-Duane-Crow model application; the latter sometimes provides ambiguous statistical results and any decision may require the parallel use of time series plots and engineers' knowledge.
- MTBF and Laplace test histograms, time series plots and AMSAA-Duane-Crow model showed that none of the fleets demonstrated random and independent failures patterns or AGAN restoration, confirming part of the alternative hypothesis of this study. Simple correlations and statistics between the several variables considered in the research showed that part of this could be attributed to human factors influence.
- MTBF, MTBI and MTBD figures are easy to be extracted from a historical database and their simple correlations may assist to spot weaknesses; especially,

when MTBF is negatively correlated with the MTBI and MTBF, any issues regarding the procedures and the human influence must be considered.

- The SN vulnerability to replacements and maintenance tasks is able to indicate either inherent manufacturing problems or inadequate procedures/equipment for detecting defective components.
- The time of the year that the replacements are performed seemed to be irrelevant with the reliability of the parts concerned.

REFERENCES

- Allan, R. and Billinton, R. (1982), *Reliability Evaluation of Engineering Systems (2nd edition),* Plenum press, London
- Bendell, A. and Walls, A. (1985), “Exploring Reliability Data”, *Quality and Reliability Engineering International*, Vol. 1, p. 37-51.
- Betha, R. M., Boullion, T. L. and Duran, B. S. (1995), *Statistical Methods for Engineers and Scientists*, 3rd edit., Marcel Dekker, NY
- Davidson, J. and Hunsley, C. (1994), *The Reliability of Mechanical Systems*, Mechanical Engineering Publications, London
- Department of Defense (1981), *Reliability Growth Management*, Military Handbook MIL-HDBK-189, Washington DC
- Dhillon, B. and Singh, C. (1981), *Engineering Reliability*, John Wiley & Sons, NY
- Drayner, A. (1963),”Reliability Improvement During Use Phase”, in *Reliability and Maintainability Conference*, 6-8 May 1963, Washington, AIAA, New York, p. 160-165
- Ebeling, C. (1997), *An Introduction to Reliability and Maintainability Engineering,* McGraw Hill, Singapore
- Feller, W. (1968), *An Introduction to Probability Theory and Its Applications,* 3rd ed., Wiley & Sons, NY
- Graeber, C. and Marx, D. (1994), “Human Error in Aircraft Maintenance”, in Johnston, N., McDonald, N. and Fuller, R., *Aviation Psychology in Practice*, Avebury Technical, Aldershot, p. 87-104
- Hobbs, A. (1996), “Human Factors in Airline Maintenance”, in Hayward, B. and Lowe, A., *Applied Aviation Psychology*, Avebury Aviation, Aldershot
- Hollander, M. and Wolfe, D. A. (1973), *Nonparametric Statistical Methods*, John Wiley & Sons, NY
- Karanikas, N. (2008), *Human Factors Indications in Historical Data of Repairable Parts*, Cranfield University, UK
- Kirkwood, T.F., Petruschell, G.K. and Smith, G.K. (1987), *Using the Air Force Maintenance Data Collection System Data to Identify Candidates for Improvement in Reliability and Maintainability*, RAND Corporation, Santa Monica, CA
- Kvaloy, J.T. and Lindqvist, B.H. (1998), "TTT-based Tests for Trend in Repairable Systems Data", in *Reliability Engineering and System Safety*, vol. 60, p. 13-28.
- Lewis, E. (1987), *Introduction to Reliability Engineering*, John Wiley & Sons, NY
- Montgomery, D. C. (2000), *Design and Analysis of Experiments*, 5th ed., John Wiley & Sons, NY

- Moubray, J. (1997), *Reliability – centered maintenance*, 2nd ed., Butterworth-Heinemann, Oxford, UK
- Neubeck, K. (2004), *Practical Reliability Analysis*, Pearson, NJ
- O' Connor, P. (2002), *Practical Reliability Engineering (4nd edition),* John Wiley & Sons, Chichester, UK
- Patankar, M. and Taylor, J. (2004), *Risk Management and Error Reduction in Aviation Maintenance,* Ashgate, Aldershot
- Rao, B. (1980), *Maintenance for Reliability*, Media Publishers, Bombay
- Smith, D. (2005), *Reliability Maintainability and Risk (7th edition)*, Elvesier, Oxford.