Field data reliability analysis of highly reliable item

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Abstract

In recent years the effect of electronic elements has become more and more significant in many areas of human activity. Automotive engineering is one of the areas which have been also importantly affected. Electronic elements, processors and other information technology items are implemented there to a great extent. It is hard to imagine nowadays that a brand new system would not have the electronic elements.

The paper deals with dependability namely reliability analysis procedure of a highly reliable item. We always believe that such items are reliable enough to fulfil our requirements regarding the system operation. Sometimes it may happen that such device does not control comfort electronics only. From this point of view possible failure might have significant effect onto humans' lives, property damages and the environment. The data on manufacturing and operating of a few hundred thousands pieces of this device are available and it is statistically a very important collection/set. However, concerning some items the manufacturing procedure was not checked and controlled accurately. It is a case of software during manufacturing which is more the area of software dependability. This manufacturing inaccuracy might be manifested notably in availability and safety of a certain system subsystem. The failure/error manifestation might be observed both during operating and downtime. The procedure described in the paper is based on the thorough data analysis aiming at the operating and manufacturing of these electronic elements. The results indicate some behaviour differences between correctly and incorrectly made elements. It was proved by the analysis that dependability and safety of these elements was affected to a certain degree. Although there is a quite big set of data the issue regarding the statistical comparability is very important.

1 Introduction

In the paper we are going to address reliability assessment of a highly reliable electronic item. In this paper the evaluated application is perceived as an item produced for systems' specific use/utilization. Item is implemented in a system in order to control one of the step functions of the transport means. The manufacturer has had long term experience of item manufacturing. This item is also widely introduced into the market where it successfully meets the parameters within technical applications. The introduced item has been applied in the systems' environment many times and no major problems have been detected regarding its function. All terms are in accordance with the IEC 60050 (191).

As we know the electronic item is initialised by start power. Unfortunately non-intentional causes resulted in non-compliance with the manufacturing process during development and manufacturing a new item. While manufacturing the item a relatively minor shortening of program protocol took place, thereby shortening the initialisation time. This situation resulted in the production of many of incorrectly manufactured items where the initialisation time was shortened by the program. The non-compliance with the manufacturing process was detected only by accident and that was after some time. However, most of the items manufactured this way have been mounted in systems and they have been in operation.

The non-compliance with the manufacturing process itself, thereby shortening the programming time might not be a serious problem. More related circumstances might be the real problem. The first one is the fact that the items have been mounted in systems and they have been in operation. Another quite serious problem is the fact that a item function failure can result in failure occurrence on the device which is supposed to perform a system's step function. If a system step function is just being used, its interruption-failure might lead to a critical accident with serious consequences. In case this type failure occurs, it affects significantly system's dependability. Moreover, it breaks the confidence in the step function which leads to the lack of confidence in a system as a whole.

Resulting from the arguments mentioned above the producer decided to solve the problem immediately. The producer wanted to find out if the errors occurring when manufacturing items have a possible effect upon operational dependability—reliability. Basically a few solutions could have been taken into account at that moment. Finally two of the solutions were chosen to be accomplished.

One of the options is to carry out a one-side interval calculation of a item reliability measure at a required confidence level. This intention is easy to be fulfilled since the data on the item operation was carefully and systematically collected. The aim of the paper is to describe a measure calculation procedure and assess statistically if testing of an available data set is suitable.

2 Field data assessment procedure

The procedure follows widely known and basic approaches and terminology. The producer provided data on the item operation over a complete period. Regarding the nature of the analysis the following facts were agreed on:

1) The aim of the analysis was to calculate the one-side item reliability interval. The item "programmed incorrectly" was assessed first, and the item "programmed correctly" was assessed as the second. The calculation of a reliability one-side interval determined for each set separately was the outcome of the analysis.

2) The next step was to compare both items sets and decide whether the ,,incorrect programming" can/cannot affect the item reliability. A one-side interval was determined at a required confidence level and it specifies a minimal reliability level of a item set obtained by a calculation.

3) The operation time of the item started the moment a production range was delivered plus two weeks (the assumption that it will be delivered to the customer, mounting into the system, and physical start of the operation).

4) The real operation time equivalent was determined by recommending the standards GS 95003-1 and is based on a calendar time. The real operation time started the moment a manufactured range was expedited plus two calendar weeks. The transforming coefficient value following the sources mentioned above is: dormant time versus operation time $\approx 24,836 : 1$.

5) The standard IEC 60605-4 "Equipment reliability testing" - Part 4: Statistical procedures for exponential distribution - Point estimates, confidence intervals, prediction intervals and tolerance intervals" has been used for calculating the reliability measure one-side interval at a required confidence level.

6) The reliability confidence interval was set as 95%.

7) The hour [h] is a reliability measure unit.

Since the standard IEC 60605-4 deals with a few possible types of the assessed sets, it is necessary to determine what type it is referred to. The operation profile and the agreement that the analysis assessment will be finished on a certain day indicate that this is a case of a specific field test finished by time without replacing the item. This assumption resulted in the following solution taking into account the standard mentioned above and well known authors in this field Holub (1992), Lipson and Sheth (1973), Neson (1982) or Kapur and Lambertson (1977).

Following the standard IEC 60605-4 recommendation a lower limit of mean time to failure at the required confidence level was calculated. In order to estimate one-side interval of a lower level of mean time to failure we used the following equation:

$$m_{l\,F/C} = \frac{2T^{*F/C}}{\chi^2_{\alpha,\nu}} \tag{1}$$

where:

$m_{lF/C}$ – is a lower limit of mean time to failure of either "F"—"incorrectly" programmed sets or "C"—"correctly" programmed sets.

$T^{*F/C}$ – is accumulated operation time of all items sets (either "F"—"incorrectly" programmed or "C"—"correctly" programmed) observed in the operation during an evaluation period. It is calculated using the equation $T^{*F/C} = \sum_{t=i}^{n} t_i^{F/C}$ ("t_i" = real operation time of all items of i-th production range of either "F"—"incorrectly" programmed sets or "C"—"correctly" programmed sets. The interval is the period in which they are put into operation which lasts up to the day when the temporary observation is finished.

$\chi^2_{\alpha,\nu}$ – chi square for a given number of degrees of freedom ν; "α"—confidence level agreed on 95 %.

Since it is a one side censored set (it is censored by the agreed date when the observation is to be finished; this date is the last possible day when the operation record is to be made), the number of degrees of freedom ν to determine chi square is going to be calculated using the standard IEC 60605-4 recommendation following the formula:

$$\nu = 2r^{F/C} + 1, \tag{2}$$

where: r is a number of events (failures) in a given group of sets.

Based on the assumptions and the calculation which have been made before, the reliability measure values for correctly and incorrectly programmed items were found. These values were calculated at the required confidence level. By comparing these values we were able to determine whether the error affects the item reliability during a manufacturing process.

However, concerning the field data we face a theoretical problem. The data set is apparently different concerning a digit place in terms of the operation time of the item sets. It means that correctly manufactured items obviously operate for a shorter time than the ones manufactured incorrectly. This situation can affect a calculation procedure as well as a comparison of the results. Taking into account this situation it is necessary to test the field data using the statistical test which is supposed to prove their comparability. The results of the test are mentioned in the second paper named "Statistical comparing of reliability of two sets of highly reliable items".

3 Risk analysis resulting from the failure occurrence

In this phase of observing the object we are talking about partially predictive risk assessment. We could choose fully theoretical way, but the field data are available so there is no need to do it. Following the theoretical approach we would focus on individual risk contributors which would be thoroughly examined. The classic probability methods would be used for determining the event occurrence probability. The expert assessment based on the defined scales would be used for analysing the consequences. Usually we do not count on other factors when dealing with theoretical risk analysis. However, some special characteristics still exist and that is the reason why one of the possible approaches where another factor occurs is described below. However, further verification and validation of the obtained result will pose a problem while assessing the risk theoretically. In our case, when undesired event occurrence probability might be recorded when observing the field data, the result will be more realistic and consequent verification of the result will be also possible. Such event occurrence information is not a prediction then, but it is estimation based on the real information. Consequence decisions resulting from the occurred event might be regarded as a prediction in this case. Consequences description options are stated in many well known standards. Using either fully standardised approach, namely automotive standards or software support can be another option when analysing the risk. An event occurrence rate or its criticality may be obtained using well known dependability analysis methods, e.g. FMECA, PHA or OSHA. The total risk is usually based on these two contributors we often work with in industry practice. Concerning software support when analysing the risk it is possible to use widely available tools, e.g. Risk Spectrum based on the FTA method supported by the ETA method, or the tools by Relia Soft or Item Software – Item QRAS which uses both methods individually but basically leads to the same result.

Using so called soft methods when analysing the risk and dependability is another possibility. It is namely about non-stochastic methods which are based mostly on the deterministic approach and iteration principles. Also the probability plays an important role but most approaches of these methods are based just on empiricism and practice. We would highly recommend fuzzy logic which allows us to work very well with qualitative characteristics of some events, and which is able to quantify them. If we were to define individual process states in system operation and they would represent the periods in which the system is run, we would be able to determine to what extent the event belongs to a defined state while an event occurs. That is how we would cover the failure criticality level regarding the defined states set and the time vector in which a system might occur during its operation/technical life. Unfortunately, in this paper there is no space for presentation and development of this approach.

4 Conclusion

The procedure as described above was used to calculate reliability of the single sets which served as correctly and incorrectly programmed items. Following the obtained results a possible effect of a manufacturing error upon the items reliability was estimated. Following the results it is obvious that manufacturing error could affect items reliability in some way. Both sets are from the statistical point of view slightly different, which is an essential piece of information. This fact should be referred to when carrying out statistical data evaluation using the introduced tools.

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Statistical comparison of reliability of two sets of highly reliable items

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Abstract

The application of electronic elements introduces a number of advantages as well as disadvantages. Let us start with operating process itself—the operating is more ecological, smoother and cheaper. Also the area of safety, both passive and active, is optimised. On the other hand the complexity of a system is getting higher as well as its sensitivity to previously not perceived factors. The electronic elements are also applied into so called service and comfort systems. However new the technology would be, all the elements are subject to certain factors set by a design, manufacturing, operating and environment in which they are used. Besides performance and utility properties we are supposed to follow dependability as well. Regarding electronic elements they are highly reliable and in terms of dependability measures they are at the highest level. If the elements are well manufactured and their construction and software equipment meets the required dependability level, we are usually satisfied and there is no reason to act otherwise. If occasional fluctuations in the dependability level do not limit the function or safety of a system or its operating, the problem of unreliability of electronic elements in systems is not so serious. The real problem is not meeting the requirements and errors.

The paper deals with advanced method of dependability-reliability analysis procedure of a highly reliable item. The data on manufacturing and operating of a few hundred thousands pieces of this device are available and it is statistically a very important collection/set. However, concerning some items the manufacturing procedure was not checked and controlled accurately. The procedure described in the paper is based on the thorough data analysis aiming at the operating and manufacturing of these electronic elements. As the data sets collected are statistically non-coherent the objective of the paper is to make a statistical assessment and evaluation of the results. Failure rates calculation and their relation comparability regarding the both sets is presented in the paper.

1 Introduction

As we know from previous publications the item is initialised by start power. We have also discovered from the previous publications that the reliability assessment of the items may highlight some mathematical non-coherence. The data sets which are available have different digits number therefore their comparability might be problematic. That is why the measures—failure rates calculated must be tested before claiming their comparability in terms of the functional description—characteristic of the item. All the terms used are in accordance with the IEC 600500(191).

The whole calculation has been made from the reason that unfortunately non-intentional causes resulted in non-compliance with the manufacturing process during development and manufacturing a new item. While manufacturing the item a relatively minor shortening of program protocol took place, thereby shortening the initialisation time. This situation resulted in the production of many of incorrectly manufactured items where the initialisation time was shortened by the program. The non-compliance with the manufacturing process was detected only by accident and that was after some time. However, most of the items manufactured this way have been mounted in systems and they have been in operation. In the paper we are going to address reliability assessment of a highly reliable electronic item.

In this paper the evaluated application of reliability data analysis techniques—procedure for comparison of two constant failure rates is perceived of an item produced for systems' specific use/utilization. Item is implemented in a system in order to control one of the step functions of the system.

Based on the assumptions and the calculation which have been made before, the reliability measure values for correctly and incorrectly programmed items were found. These values were calculated at the required confidence level. By comparing these values we were able to determine whether the error affects the item reliability during a manufacturing process.

However, concerning the field data we face a theoretical problem. The data set is apparently different concerning a digit place in terms of the operation time of the item sets. It means that correctly manufactured items obviously operate for a shorter time than the ones manufactured incorrectly. This situation can affect a calculation procedure as well as a comparison of the results. Taking into account this situation it is necessary to test the field data using the statistical test which is supposed to prove their comparability. The results of the test are mentioned in the second paper named "Statistical comparing of reliability of two sets of highly reliable items". For more details see e.g. Holub (1992).

2 Application of the reliability analysis – comparison technique

In this case when taking into account two sets of objects we have to consider reliability measures where there is a presumption that the sets can be different. Time to failure is for both sets independent and fulfils the presumption of exponential distribution. For more details see IEC 60605-4, IEC 61650 or Lipson, CH.& Sheth, N. J. (1973).

It is necessary to introduce other important relations which are essential for next steps. Because it is a case of non-repaired items, we can assume that:

- accumulated operation/test time is calculated as a sum of times to failure;
- all the objects belong to the same original set.

In order to use the comparison procedures the following data are required:

- an observed number of valid failures r_1 a r_2 in two observing periods – it is fulfilled;
- accumulated valid test times T_i^* in these two periods – it is fulfilled;
- the confidence level should be stated/chosen if required.

All the information is available and it is possible to continue working with it.

Following the IEC 61650 we choose the accurate calculation of two constant failure rates comparison using F - distribution. We calculate f using the equation (1).

$$f = \frac{r_2}{r_1 + 1} \times \frac{T_1^*}{T_2^*} \tag{1}$$

For the chosen confidence level we get the f_c (either for $1 - \alpha_0 = 0,90$ or for $1 - \alpha_0 = 0,95$) from the tables of F - distribution stated in the appendix A of the document 8.

$$f_c = F_{1-\alpha_0}(\nu_1, \nu_2) \tag{2}$$

where $\nu_1 = 2(r_1 + 1)$;
$\nu_2 = 2r_2$.

Next we use the decision criteria given in the table 2 of the IEC 61650 stating that if $f > f_c$, then $w_1 < w_2$, or if $f < f_c$, then $w_1 = w_2$). Generally the recommended confidence level for calculation is $\alpha_0 = 5\%$ or 10% which corresponds with $(1 - \alpha_0)$ - fractiles, that is 0.95 - fractiles or 0.90 - fractiles of F-distribution.

The calculation:

The calculation has been intentionally modified due to the industrial secret and due to not providing the sensitive data about the product. The confidence level was stated at 95%.

The mean time to failure is calculated according to the (1).

a) for incorrectly manufactured items:

$$m_{l\,F/C} = \frac{2T^{*F/C}}{\chi^2_{\alpha,\nu}} = \frac{2 \cdot 230\,995\,532h}{68,648} = \frac{461\,991\,064h}{68,648} \cong 6,73 \cdot 10^6\,h$$

where:

- accumulated operation time of all wrongly manufactured items according to the assumption given in IEC 60650, chapter 4, article 4, and according to the formula is $T^{*F} = \sum_{t=i}^{n} t_i^F = 230\,995\,532\,h$
- a number of the degrees of freedom according to the formula (2) is $\nu = 2r^F + 1 = 2 \cdot 25 + 1 = 51$
- the chi-square for 51 degrees of freedom and the confidence level $\alpha = 95\%$ is $68,648$.

b) for correctly manufactured items

$$m_{l\,F/C} = \frac{2T^{*F/C}}{\chi^2_{\alpha,\nu}} = \frac{2 \cdot 56\,864\,717h}{7,8} = \frac{113\,729\,434h}{7,8} \cong 1,46 \cdot 10^7 h$$

where:

- accumulated operation time of all wrongly manufactured items according to the assumption given in chapter 4, article 4, and according to the formula is $T^{*C} = \sum_{t=i}^{n} t_i^C = 56\,864\,717h$
- a number of the degrees of freedom according to the formulae (2) is $\nu = 2r^C + 1 = 2 \cdot 1 + 1 = 3$
- the chi-square for 3 degrees of freedom and the confidence level $\alpha = 95\%$ is $7,8$.

The calculation of the f according to the formula (1)

$$f = \frac{r_2}{r_1 + 1} \times \frac{T_1^*}{T_2^*} = \frac{1}{25 + 1} \times \frac{230\,995\,532}{56\,864\,717} = 0,156$$

Next, the calculation of the f_c according to the formula (2)

$$f_c = F_{1-\alpha_0}(\nu_1, \nu_2) = 19,476$$

where $\nu_1 = 2(r_1 + 1) = 2(25 + 1) = 52$,
$\nu_2 = 2r_2 = 2$.

As the calculation introduced above shows that $f < f_c$, we can state that the failure rates of the basic sets $w_1 = w_2$, so they are constant.

3 Evaluated factors in risk assessment

Speaking about risk we can use the existing model described in standards (e.g. IEC 60812:2006 or MIL-STD-1629a) considers two evaluated factors, Probability – P of an event-failure occurrence and Severity – S of the event-failure or three evaluated factors, Probability, Detection and Failure Consequences. These factors result from a fully quantitative assessment where the risk is expressed by a conjunction of probability and consequences

$$R = P * S$$

The Detection Factor – D in a full quantitative assessment would decrease the probability that a failure will not be detected during design/manufacturing process (see e.g. SAE J 1739), thus

$$R = P * D * S,$$

whereas its value would belong to the interval $\langle 0; 1\rangle$ (or $\langle 0; 100\%\rangle$).

4 Scales for assessment

In the standards IEC 60812:2006 or SAE J 1739 for example there are scales for assessment for all three criteria which are used namely in automotive industry. The scales are put in the form of tables with verbal explanation of every level at the scale. These are severity, occurrence probability and detection scales. Sometimes a consequence scale in relation either to the customer or manufacturing process or operation is completed. These scales are going to be used in the next procedure. Other existing and used scales are for example those which are applied in a part of software, Item Toolkit or Reliasoft XFMEA.

5 Conclusion

The procedure as described above was used to calculate and compare the reliability measures – failure rates in this case of the single sets which served as correctly and incorrectly programmed items. Following the obtained results a possible effect of a manufacturing error upon the items reliability was estimated. As we can see from the results although the data sets are different – they have different size of the information which they contain – we need to compare them. Consequently we need to state if the results in the form of the failure rate are comparable and statistically same. These claims can prove the dependability of the product and finally safe the good name of the company producing a valuable goods. This fact should be referred to when carrying out statistical data evaluation using the introduced tools.

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