Balancing between cost and tester acceptance in case of new product introduction for PCB assembly

Árpád Jankó[1], László Lugosi[2]

[1] Elcoteq SE. Head of Engineering Services Center
1-3 Szilva Str., Pécs, Hungary 7632
[2] Elcoteq SE. Engineering Services Center, Test Software Developer
1-3 Szilva Str., Pécs, Hungary 7632

***Abstract**: Companies which are offering Electronic Manufacturing Services are continuously balancing among fast product introduction of customer products, high quality production and profitable operation. Our paper describes link among producability of PCB boards, process control, test system & equipments reliability and profitabile manufacturing Process control is key in PCB assembly for high quality and profitable operation, however the time pressure limits the development of product test system which is the core of control of board assembly. In order to achieve good control appropriate methods and equipments are essential assets. To be ahead of competition method and process were developed which can be used in production environment for tester system acceptance and regular check of condition of tester system. Beside of a product test coverage the production test system reliability and long term reliability is calculated with the help of statistical methods. The acceptance method can be used both for own product test system development and also for consigned equipments.*

1. INTRODUCTION

This work was motivated by the need to determine quantitative quality charateristics, such as variance parameters, process capability and performance indices, originated from Measurement System Analysis (MSA) techniques called as Gage Repeatability and Reproducibility Study (GR&R) as well as Statistical Process Control (SPC) [1] for the practicing test engineers in industrial mass production environment. The applied calculation procedures are obtained from the well known and standard *Six Sigma* (6σ) [2] methodology in our developed program [3]. This statistical service software conforming to the Third Edition of AIAG MSA Reference Manual [4] and it can be used for the critical test measurement data estimation tasks furhermore the quantitative access of test mesurement systems.

2. MEASUREMENT SYSTEM ANALYSIS (MSA) AND TESTING OF PCBS

The assembled PCBs (Printed Circuit Boards) are tested extensively according to its complexity. Typically a board goes through optical inspection, in circuit testing, flashing (which can be interpreted as a kind of test because it requires partly functioning circuit), functional testing and final testing. Easily 3-5 test steps applied upon need and complexity of boards. Each test step verifies the previous assembly activity i.e.: Surface Mount Assembly, Through Hole Assembly, Final Assembly, and Calibration. At the and the total test coverage is the summary of the individual test steps. In order to obtain reliable and durable test system through the entire production each steps need to perform according to the highest standard which ensured by the qualification system.

In the course of an MSA specially designed experiments are made with purpose of to qualify a measuremt system for use by quantifying its accuracy, precision and stability. The MSA is an important cheking and back-coupling process during the new product indrotuction and tester setup procdures. In the following subsections a brief description of the GR&R and SPC methods which are implemented in our statistical service application [3] will be outlined.

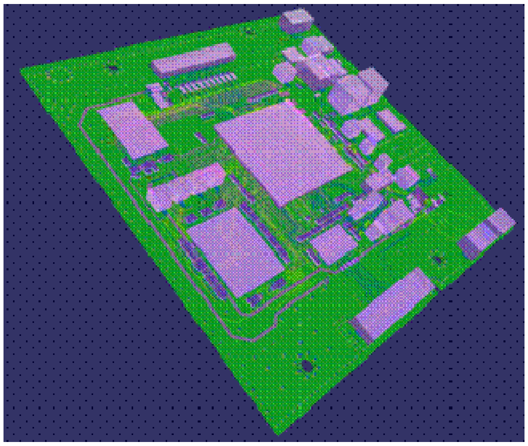

Fig. 1 Example of a producted and tested Printed Circuit Board (PCB).

2.1. Gage Repeatability and Reproducibility (GR&R) Study

The GR&R [1, 2, 4] investigation is an industrial standard method which using the statistical test procedures of repatability and reproducibility (R&R) called as gage study and determines the amount of variation in the measurement system arising from the test station and the product. So, this analysis addresses the issue of precision of measurement. The observed total variability is originated from the following sources: Total GR&R (broken into repeatability and reproducibility) as well as product variabilities (see fig. 2.).

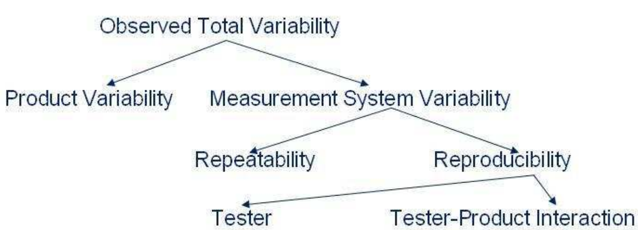

Fig. 2 Components of the total variability

The reproducibility can further be divided as tester and tester-product interaction components. The above variance decomposition can be given as

$$\sigma^2_{\text{Total}} = \sigma^2_{\text{Product}} + \sigma^2_{\text{Measurement System}} = \sigma^2_{\text{Product}} + \sigma^2_{\text{GageR\&R}} \quad (1)$$

$$\sigma^2_{\text{Total}} = \sigma^2_{\text{Product}} + \sigma^2_{\text{Repeatability}} + \sigma^2_{\text{Tester}} + \sigma^2_{\text{Tester-Product Interaction}} \quad (2)$$

and these terms are computed by using the two way ANOVA method [1, 2]. Beside this variance parameters (called as AV, EV, PV, I, R&R and TV) the program calculates the percentage contributions and tolerances, together with the F-ratios and p-values and makes Excel table and graphical reports from this data. On the graphical report sheet (see fig. 3.)

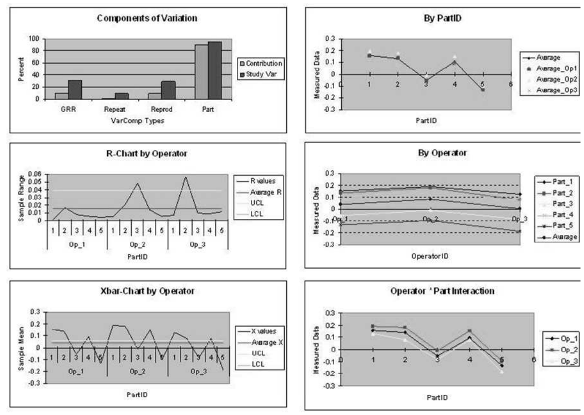

Fig. 3 Excel graphical GR&R report for a given test step

the regular control charts are displayed, such as Contribution chart, R-chart, Xbar-chart, Interaction-plot and the run charts of Measurement by Tester and Measurement by Product. The ANOVA and GR&R tables and the control charts help to identify, localize and eliminate the possible failures which can be arised from the tester device, applied measurement method, the product design or technology processes. The measurement system can be accepted if the percentage tolerance ration of the Total GR&R is under 10%.

2.2. Statistical Process Control (SPC)

The SPC [1, 2, 4] is inspired to unsure the steadiness of quality of produced products. The purpose of the SPC is the investigation of process capability and process perfromance, and then again the statistical conditioning and monitoring of the mass production. If the variance of a given process is relatively small and its measured data are localized around the centre of the specification limits in the range $\pm 3\sigma$ with normal distribution, and its avarage, deviance and shape do not significantly change then the process is controlled. This type of process has six sigma-like ability. The most important quantitative characteristics of the process are the process capabilty (Cpk) and performace (Ppk) indices that can be written as

$$Cpk = \min\left[\frac{USL-\mu}{\frac{v_{\mathrm{StudyVar}}}{2}\sigma_{\mathrm{Within}}}, \frac{\mu - LSL}{\frac{v_{\mathrm{StudyVar}}}{2}\sigma_{\mathrm{Within}}}\right] \quad (3)$$

$$Ppk = \min\left[\frac{USL-\mu}{\frac{v_{\mathrm{StudyVar}}}{2}\sigma_{\mathrm{Overall}}}, \frac{\mu - LSL}{\frac{v_{\mathrm{StudyVar}}}{2}\sigma_{\mathrm{Overall}}}\right] \quad (4)$$

These indices are derived from short term (moment recording) and long term observations and calculated from the σ_{Within} within and $\sigma_{\mathrm{Overall}}$ overall sample deviations, respectively. In eqns. (2) and (4) *USL* and *LSL* are the upper and lower specification limits, and the default value of ν_{StudyVar} study variation is 6 according to the expected coverage level, because this width of the interval is needed to capture the 99.73% spread of a given process measurement.

The Cpk index asks two questions: (a) Does the process driven on along of the centre of tolerance ? (b) Does the process deviation systematically change during the time ? The Ppk index shows that what is the probable rate of produced products inside of the specified limits in a controlled process.

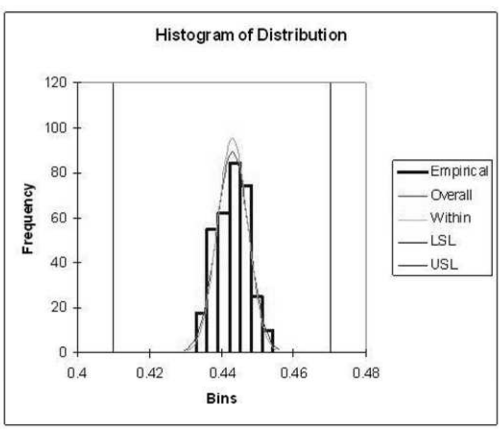

Fig. 4 Excel graphical SPC report for a given test step

In the case of SPC investigation, our program also calculates the process means, standard deviations and defects per million opportunities (DPMO). These data are displayed on Excel tables, in addition on the graphical report sheet (see fig. 4.) the histogram of the empirical relative frequency density just as the overall and within Gaussian distribution curves are shown. In the industrial practice the indices can be accepted if those have values higher than 1.67 (it means that the failure rate less than 0.57 ppm).

3. FINDING OF OPTIMAL COST

The reaching of demanded values for total GR&R and Cpk, Ppk are required to establish a good measurement system and production process. These two thinks are the key to gain high yield and quality with respective low and optimal cost (see fig 5.). Fig. 6 shows the budgeted investment as a function of consumed time. In fig. 7. the coherence between projetcs' time and yield is shown. The presented tendency curves were calculated by fitting three parameter exponential functions to the empirical data of Elcoteq Engineering Services Centre.

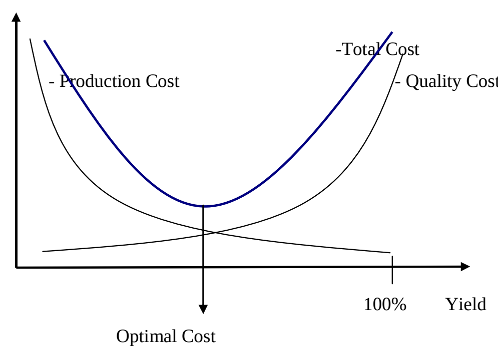

Fig. 5 Production and quality parts of total cost

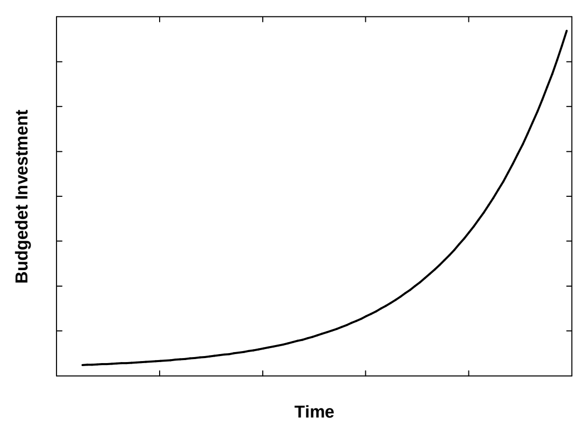

Fig. 6 Cost of quality as a function of time

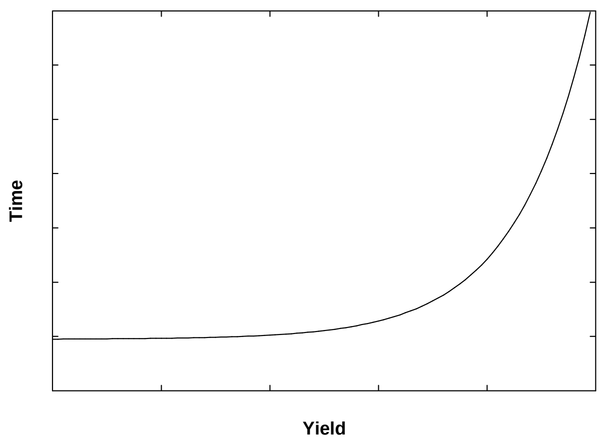

Fig. 7 Projects' Time depend on reached yield

4. Results and Summary

The program supports up to 128 test stations (operators), 64 products (parts) and 32 replicates (trials) for GR&R study as well as 4096 samples for SPC calculations, respectively. It processes measured data up to 1500 numeric limit test steps per sequence and stores these in well defned and structured XML files.

The reults of the GR&R and SPC investigations gives help to adjust the specification limits of different test steps. This is the main goal in case of a new product introduction activity, since it can lead to a stable-, controlled process and equable quality that ensures the possibility of decreasing the cost of the quality systems itself together with cost of production. On the other hand, our statistical tool -which was developed from the engineering point of view instead of a theoretical software package- are applied to validation and qualification of many test stations, are belonging to such product lines of the Elcoteq multinational company, that products are made to highly respected customers (e.g. Nokia, Ericsson, Philips, Thomson, Research In Motion - RIM). Due to the applied state-of-art numerical algorithms [5], the modern application development technologies and the tracking of the sophisticated *Six Sigma* methodology [2], this work should be an example of a successful innovation via applied informatics resulting cost saving and increasing quality.

The industrialization and new product introduction is part of the ready product marketing program. The campaign defines the exact timing of product launch on the market. Relative to the product launch, the industrialization and production test system development time can be calculated and milestones can be established. The required development cost of test system exponentially increasing assuming that the aim is to approach the 100% quality level. Having number of product introduction experimental data the required budget can be well calculated in case of milestones and quality (yield) expectations are the boundary conditions of the project. In the above described case the project cost goes exponentially which is becoming even heavier for complex test systems. The collected empirical data provides good grounding for further fine tuning of our method. In the following work our aim is to generate explicit equations which describes for a type product the relation between yield and time relative to budget.

5. Acknowledgements

This work was supported by the Economic Competitiveness Operative Programme (Grant No. GVOP-3.3.2-2004-0008/3.0) and the National Researching, Developing and Innovation Programme (K+F+I).

References

[1] National Institute of Standard and Technology (NIST), Gaithersburg, MD 20899-1070, USA: Engineering Statistic Handbook (2007)

[2] Thomas Pyzdek: The Six Sigma Handbook, *"A Complete Guide for Green Belts, Black Belts, and Managers at All Levels", 2nd Edition*, McGraw-Hill, Professional (2003)

[3] L. Lugosi, B. Merkl, R. Salk, Á. Jankó, "*A review about the Quality Tool Industrial Statistical Service Software" ,Proceedings of microCAD International Scientific Conference, Section O: Applied Information Engineering (2008), pp. 89-94.*

[4] Automotive Industry Action Group (AIAG), "Measurement System Analysis**,** Reference Manual"; Chrysler, Ford, General Motors Supplier Quality, Requirements Task Force (2002)

[5] W. H. Press, Saul A. Teukolsky, W. T. Wetterling, B. P. Flannery, "Numerical Recipies in C++, The Art of Scientific Computing ", Cambridge University Press (2002)