UDK 621.941:311.2
Professional article/Strokovni članek

ISSN 1580-2949
MTAEC9, 43(1)55(2009)

IMPROVING THE PROCESS CAPABILITY OF A TURNING OPERATION BY THE APPLICATION OF STATISTICAL TECHNIQUES

IZBOLJŠANJE PROCESA SPOSOBNOSTI STRUŽENJA Z UPORABO STATISTIČNE TEHNIKE

Aysun Sagbas

Mersin University, Tarsus Technical Education Faculty, Department of Mechanical Education, 33400 Tarsus-Mersin/TURKEY
asagbas@mersin.edu.tr

Prejem rokopisa – received: 2008-08-05; sprejem za objavo – accepted for publication: 2008-10-22

Process-capability indices are effective tools for the continuous improvement of quality, productivity and managerial decisions. Statistical process-control techniques improve the quality in mass production. In this study, a process-capability analysis was carried out in the machining line of a medium-sized company that produces machine and spare parts. For this purpose, normal probability plots and histograms were prepared and the process-capability indices C_p and C_{pk} were calculated. It is shown that the process capability for the whole process was inadequate and that the mass production was unstable. In order to satisfy the process-capability measures it is necessary to improve the quality level by shifting the process mean to the target value and reducing the variations in the process.

Keywords: process capability analysis, quality improvement, turning operation

Indeksi sposobnosti so za procese učinkovita orodja za stalno izboljševanje kakovosti, produktivnosti in vodstvenih odločitev. Statistična tehnika kontrole procesa omogoči izboljšanje kakovosti pri masovni proizvodnji. V tej študiji je bila izvršena ocena procesa za obdelovalno linijo srednje velike družbe, ki izdeluje stroje in rezervne dele. Za ta namen so bili pripravljeni histogrami normalne verjetnosti in izračunani indeksi sposobnosti procesa (C_p in C_{pk}). Pokazalo se je, da je bila procesna sposobnost za celoten proces neprimerna in je zato bila nestalna masovna proizvodnja. Za izboljšanje stanja je bilo treba sprejeti ukrepe za dvig nivoja kakovosti s premikom povprečja procesa na ciljno vrednost in znižati njegovo variabilnost.

Ključne besede: analiza sposobnosti procesa, izboljšanje kakovosti, struženje

1 INTRODUCTION

Process-capability analysis is a technique applied in many stages of the product cycle, including process, product design, manufacturing and manufacturing planning, since it helps to determine the ability to manufacture parts within the tolerance limits and engineering values. There are several capability indices, including C_p, C_{pu}, C_{pl} and C_{pk}, that have been widely used in manufacturing industry to provide common quantitative measures of process potential and performance. Process-capability indices are powerful means of studying the process ability for manufacturing a product that meets specifications [1,2].

There is considerable theoretical and experimental research work on improving product quality and process efficiency using a process-capability analysis. Kane [3] described six areas of application for capability indices: the prevention of the production of nonconforming products, the continuous measure of improvement, communication, prioritization, the identification of directions for improvement, and the auditing of the quality system. Wright [4] discussed the cumulative distribution function of process-capability indexes.

The process-capability indices, including, C_p, C_{pk} and C_{pm}, have been proposed in manufacturing industry to provide a quick indication of how a process has conformed to its specifications, which are preset by manufacturers and customers. Pearn et al. [5] indicated the index of capability for monitoring the accuracy of the manufacturing process. Singhal [6] introduced the multi-process performance-analysis chart (MPPAC) based on process-capability indices for controlling and monitoring multiple processes. The MPPAC provides an easy way to process improvement by comparing the locations on the chart of the processes before and after the improvemet effort. Pearn and Chen [7] proposed a modification to the MPPAC, combining the more advanced process-capability indexes C_{pm} and C_{pmk} to identify the problems causing the process failing to centre around the target. Pearn et al. [5] introduced the MPPAC based on the capability index, which is a simple transformation of C_{pmk}. They developed the multi-process performance-analysis chart based on process-capability indices to analyze the manufacturing performance for multiple processes. Deleryd et al. [8] investigated experiences of implementing statistical methods in two small companies from the ceramics industry. Motorcu and Güllü [9] used some statistical calculations to eliminate quality problems, such as undesirable tolerance limits and the out of circularity of spherodial cast-iron parts during machining. Dolinsek and Kopac [10] presented particular examples of machining crank shafts. From the results obtained from statistical process control (SPC), they identified tool wear and machine inaccuracies. Deleryd [11] performed a survey among 97 Swedish organizations that use process-capability studies. Corbett and Pan [12] described a quantitive procedure for the monitoring and evaluating of environmental performance using statistical process-control techniques. Chang and Wu [13] provided explicit formulas with efficient algorithms to obtain the lower confidence bounds and sample sizes required for the specified precision of the estimation of C_{pk} for processes with asymmetric tolerances. Ramakrishnan et al. [1] discussed process-capability indices and product reliability. Chen et al. [14] constructed a process-capability-monitoring chart (PCMC) for evaluating the process potential and performance for the silicon-filler product, which is designed for practical applications.

The purpose of this study was to focus on the process-capability analysis in a medium-sized company to eliminate quality problems during machining. A normal distribution curve and histograms were prepared, the process-capability indices were calculated, and the number of nonconforming parts was determined.

2 PROCESS-CAPABILITY STUDIES AND PROCESS-CAPABILITY INDICES

Process-capability indices have been widely used to measure product qualities and process performance that meet specifications in the manufacturing industries. The procedure for the analysis of process performance is shown in **Figure 1**.

Many engineers use process-capability indices as communication indicators to evaluate the manufacturing process. The quality characteristics of items are often measured in order to determine the capability of the production process. Usually, the customer determines a specification area or tolerance zone by setting lower and upper specification limits to require a certain quality from the supplier. Process capability is the repeatability and consistency of a manufacturing process relative to the customer's requirements [15]. Since the estimated capability index is a random variable with a distribution, most engineers look at the value of the capability index calculated from the given sample and then draw a conclusion on whether the given process is capable or not and whether or not it is reliable. When a process is in a state of statistical control, and only then, the process can be evaluated with respect to its ability to produce items within specifications. Obviously, the variability of the process is a measure of the consistency of the output products. The stability of a process is an important property, since, if the process is stable in the current frame, then it is likely to stay in a stable condition in the future. Thus, the output of a stable process is in some sense predictable. There are several capability indices, including C_p, C_{pu}, C_{pl} C_{pk}, C_{pm} *and* C_{pmk}. Process variation, process departure, process yield, and process loss have been considered as crucial benchmarks for measuring process performance. The index C_p considers the overall process variability relative to the specification tolerance, and therefore it only reflects the consistency of the product's quality characteristic. The index C_{pk} takes the mean of the process into consideration, but it can fail to distinguish between on-target processes and off-target processes, which is a yield-based index providing lower bounds on the process yield [2]. The index C_{pm} takes the proximity of the process mean from the target value into account, which is more sensitive to process departure than C_{pk}. Since the design of C_{pm}, is based on the average process loss relative to the specification tolerance, the index C_{pm} provides an upper bound of the average process loss, which is also reffered to as the Taguchi index or the loss-based index. The index C_{pmk} is constructed from combining the modifications to C_p that produced C_{pk} and C_{pm}, which inherits the merits of both indices. The index C_{pmk} indeed provides more quality assurance with respect to process yield and process loss to the customers than the other two indices, C_{pk} and C_{pm}. The most widely used capability indices in industry are defined with Eq. 1 and 2. [1,13].

$$C_p = \frac{USL - LSL}{6\sigma}$$

$$C_{pk} = \min\left\{\frac{USL-\mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right\} = \frac{d - |\mu - M|}{3\sigma} \tag{1}$$

$$C_{pk} = C_p(1 - k)$$

$$k = \frac{|T - \mu|}{0.5(USL - LSL)} \tag{2}$$

where USL is the upper specification limit, LSL is the lower specification limit, σ denotes the process' stan-

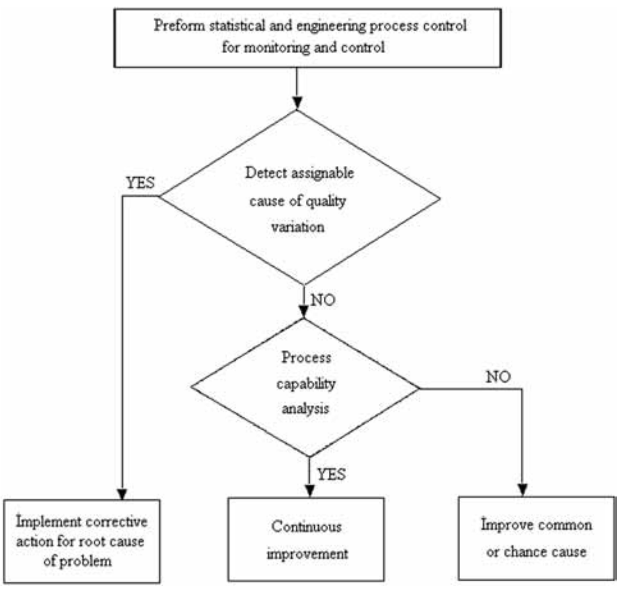

Figure 1: Analysis procedure for process performance
Slika 1: Procedura analize lastnosti procesa

dard deviation, μ denotes the process mean, d is the half-length and M is the midpoint of the specification interval. T is the target value, and k is the variation factor. When the process is perfectly on target, $k = 0$ and $C_{pk} = C_p$ from Eq.(2), the maximum value for C_{pk} is C_p. Examples of the estimation of the capability-process indices C_p and C_{pk} are introduced in **Table 1**.

Table 1: Examples of process estimation based on the indices C_p and C_{pk}
Tabela 1: Dva primera ocene procesa na podlagi indeksov C_p in C_{pk}

Capability index	Estimation of the process
$C_{pk} = C_p$	Process is placed exactly at the centre of the specification limits
$C_p < 1$	Process is not adequate
$1 \leq C_{pk} < 1.33$	Process is adequate
$C_p \geq 1.33$	Process is satisfactory enough
$C_p \geq 1.66$	Process is very satisfactory
$C_{pk} \neq C_{pk}$	Process is inadequate, new process parameters must be chosen

3 PROCESS-CAPABILITY ANALYSIS IN TURNING

The following case is taken from a medium-sized casting and manufacturing factory, making various types machine and spare parts in Istanbul, Turkey. The workpiece was cast, spheroidal iron, cast GGG–40, using investment casting and machined using an industrial type

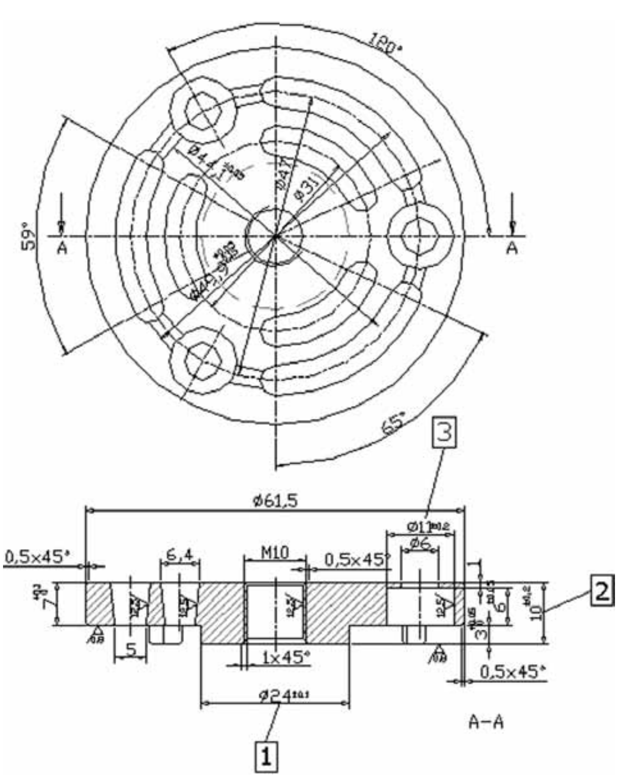

Figure 2: The dimensions and tolerance values of the workpiece and technical drawing
Slika 2: Dimenzije in tolerance za obdelovanec in tehnični načrt

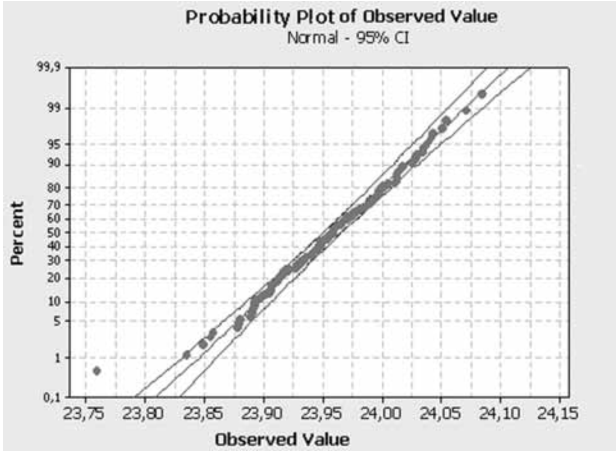

Figure 3: Normal probability plot for quality characteristic (Ø 24 ± 0.1)
Slika 3: Odvisnost normalne verjetnosti za karakteristično kakovost (Ø 24 ± 0,1), $N = 150$

lathe machine. The workpieces were machined under dry conditions, and ceramic-based cutting inserts were used. The quality characteristics considered are shown in 1, 2, and 3 in **Figure 2**. The dimensions and tolerance values of the workpiece and the technical drawing are shown in **Figure 2**.

In this study, in order to demonstrate the applicability of the proposed method and to make a clear decision about the capability of the machining process, the sample size was determined and a sufficient number of sample parts was inspected. A single sampling plan was implemented by using the lot-acceptance sampling plan. Samples were chosen randomly during the turning process. The data for the investigated characteristics were collected for 30 days in the company, determined for 150 samples, i.e., 30 % of a lot size of 500 parts. The same number of workpieces ($N = 150$) was measured every day. Normal probability plots and histograms were prepared and statistical parameters were calculated using the measured values taken from the workpieces that

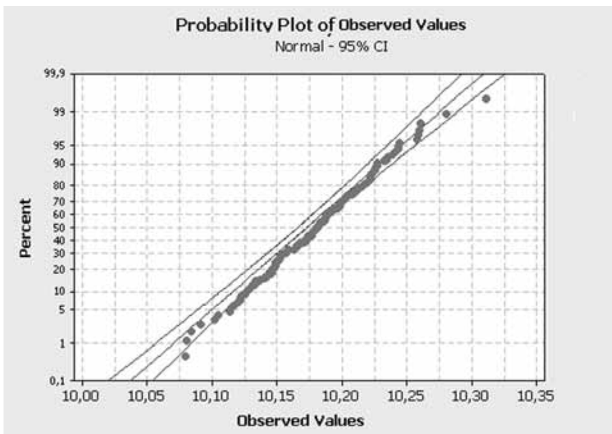

Figure 4: Normal probability plot for (Ø10 ± 0.2)
Slika 4: Normalna verjetnostna odvisnost za (Ø10 ± 0,2), $N = 150$

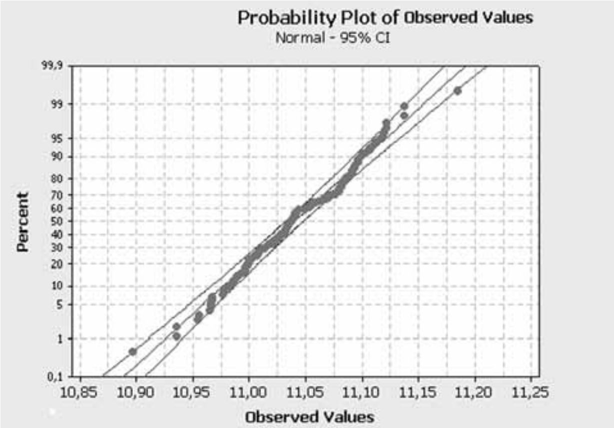

Figure 5: Normal probability plot for (Ø11 ± 0.2)

Slika 5: Normalna verjetnostna odvisnost za (Ø11 ± 0,2), N = 150

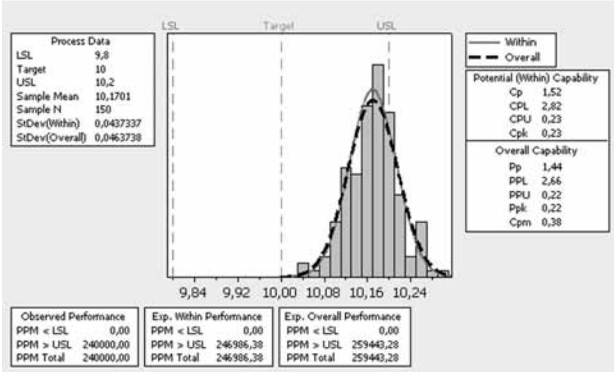

Figure 7: Histograms and process-capability analysis for quality characteristic (Ø10 ± 0.2)

Slika 7: Histogram analize procesne sposobnosti za karakteristično kakovost (Ø10 ± 0,2)

represent the whole process. To receive a numerical measure of the capability, the so-called process-capability indices were calculated. In all the stages of data analysis, Minitab software was used. The validity of the normallity was verified using the Chi-square test, χ^2. **Figures 3, 4 and 5** display the normal probability plots of the sample data and from these figures the sample data appear to be normal.

Figures 6, 7 and 8 display the histograms of the 150 observations with a density line and specification limits (*LSL*, *T*, *USL*) and the results of the process-capability analysis.

Figure 6 shows that the process capability deteriorated during the monitoring period to C_p and $C_{pk} < 1$, which indicates the potential risk of an increase in the number of nonconforming parts. It denotes that the process capability is inadequate. For $C_p \neq C_{pk}$ the process mean is not centred for the process width. The number of non-conforming parts out of the *LSL* is 120,000 and there is a none value out of the *USL* in the observed performance. In a short period of time, the non-conforming parts out of the *LSL* is 119,010 ppm and out of the *USL* is $1837 \cdot 10^{-6}$. In a long period of time, the number of non-conforming parts out of the *LSL* is $126,322 \cdot 10^{-6}$ and out of the *USL* is $2429 \cdot 10^{-6}$. This analysis shows that the specification limits should be rearranged and the process variabilty should be reduced.

Since the calculated C_p value (1.52) is bigger than 1.33 and the C_{pk} value (0.23) is lower than 1.00, the process is inadequate. Some measures must be taken immediately and new process parameters must be chosen. For $C_p \neq C_{pk}$, the process mean is not centred with the process width. If the process mean is not centred relative to the specification limits, the process-capability index will give misleading results. The process mean is near to *USL*. The number of non-conforming parts out of the *USL* is 240,000 and there is no value out of the *LSL* in the observed performance. The number of non-conforming parts out of the *USL* is $246,986 \cdot 10^{-6}$ in a short period of time and $259,443 \cdot 10^{-6}$ in a long period of time. In the short and long periods of time the data fall out of the *LSL*. As the process-capability indices calculated are clearly different, there will be different percentages of non-conforming products. In short and long periods of time the number of parts produced out of the *USL* will be

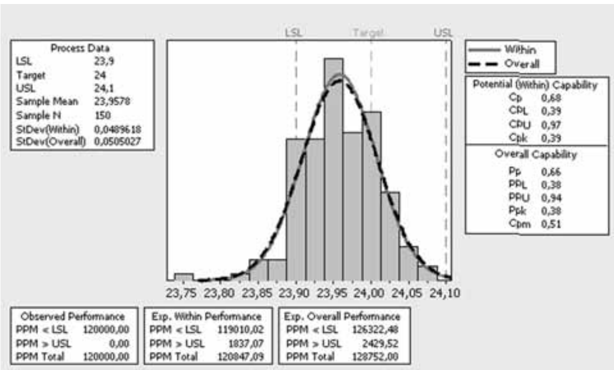

Figure 6: Histograms and process-capability analysis for quality characteristic (Ø24 ± 0.1)

Slika 6: Histogram analize procesne sposobnosti za karakteristično kakovost (Ø24 ± 0,1), N = 150

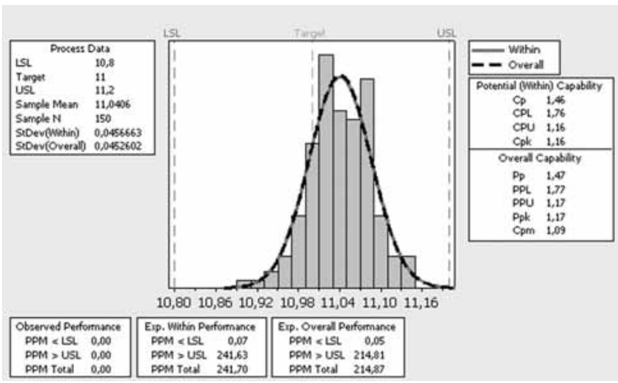

Figure 8: Histograms and process-capability analysis for quality characteristic (Ø11 ± 0.2)

Slika 8: Histogram analize procesne sposobnosti za karakteristično kakovost (Ø11 ± 0,2) increased. In order to satisfy the process capability, some actions must be taken immediately and new process parameters must be chosen.

As the calculated C_p value (C_p is larger than 1.33, the process meets the capability requirement with a 95 % confidence level, or equivalently, at the significance level $\alpha = 0.05$. These product items conform to the manufacturing specifications and are considered as reliable products. For $C_p \neq C_{pk}$, the process mean is not centred on the process width. The process mean is near to the target value. It is clear that in the observed performance no data are outside the speciffication limits. The number of non-conforming parts out of the *LSL* is $0.07 \cdot 10^{-6}$ and the *USL* is 241 ppm in a short period of time. The number of non-conforming parts out of the *LSL* is $0.05 \cdot 10^{-6}$ and the *USL* is $214 \cdot 10^{-6}$ in a long period of time.

4 CONCLUSIONS

In recent years, process-capability analysis has become an important integrated part in the applications of statistical techniques for quality assurance. Quality assurance in mass production is achieved using statistical process-control techniques. The process-capability analysis, which is a SPC technique, helps to determine the ability for manufacturing between tolerance limits and engineering specifications. The capability analysis gives information about the changes and tendencies of the systems during production.

In this study the process-capability analysis was carried out for the elimination of the quality problems during turning operations. The number of non-conforming parts was determined in observed values, in short and long periods of time. For the elimination of the observed quality problems, some suggestions were proposed. Faults regarding manufacturing out-of-tolerance limits were eliminated, the variability in the process and the cost due to low-quality production were reduced in the particular company.

In today's competitive market, SPC is not the most frequently used technique in small and medium-sized companies in Turkey. The most important problems in business are that there are no trained employees to apply it and there is unsufficient investment. Consequently, SPC must be applied widely and continuously to achieve quality improvements.

5 REFERENCES

[1] Ramakrishnan B, Sandborn P, Pecht M. Process capability indices and product reliability. Microelectronics Reliability 41 (**2001**), 2067–2070

[2] Montgomery DC. Introduction to Statistical Quality Control. New York: John Wiley & Sons Inc.; 2005, 364–413

[3] Kane,VE. Process capability indices. Journal of Quality Technology 18 (**1986**), 41–52

[4] Wright PA. The cumulative distribution function of process capability index C_{pm}. Statistics and Probability Letters 47 (**2000**), 49–251

[5] Pearn WL, Shu MH, Hsu BM. Monitoring manufacturing quality for multiple Li-BPIC processes based on capability index C_{pmk}. Int. Journal of Production Research 43 (**2005**) 12, 2493–2512

[6] Singhal, SC. Multi process performance analysis chart (MPPAC) with capability zones. Quality Engineering 4 (**1991**) 1, 75–81

[7] Pearn,WL, Chen, KS. New generalization of the process capability index C_{pk}. Journal of Applied Statistics 25 (**1988**) 6, 801–810

[8] Deleryd M, Garvare R, Klefsjö B. Experience of implementing statistical methods in small enterprises. Total Quality Management, 11 (**1999**) 5, 341–351

[9] Gullu A, Motorcu AR, Statistical process Control in machining, a case study for machine tool capability and process capability. Materials & Design 27 (**2006**), 364–372

[10] Dolinsek S, Kopac J. Linkage between quality assurance tools and machinability criteria. Journal of Materials Processing Technology 118 (**2001**), 133–137

[11] Deleryd M. A pragmatic view on process capability studies. International Journal of Production Economics 58 (**1999**), 319–330

[12] Corbett JCA, Pan JNE. Evaluating environmental performance using statistical process control techniques. Journal of Operational Research 139 (**2002**), 68–83

[13] Chang YC, Wu CW, Assesing process capability based on the lower confidence bound of C_{pk} for asymmetric tolerances. European Journal of Operational Research 190 (**2008**), 205–227

[14] Chen, KS. Pearn, WL. Lin, PC., A new generalization of the capability index C_{pm} for asymetric tolerances. International Journal of Reliability, Quality & Safety Engineering 6 (**1999**) 4, 383–398

[15] Linn R, Tsung F, Ellis LWC. Supplier selection based on process capability and price analysis. Quality Engineering 18 (**2006**), 123–129