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Full Length Research Paper

Applying process capability analysis chart (PCAC) in measuring sewing machine quality

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The purpose of this paper is to promote a case study on a professional manufacturer of sewing machine was studied in central Taiwan. The research will construct a process capability analysis chart (PCAC) to evaluate process capability for a multi-process produce based on C_{pk}. The PCAC method improvement a technique of Six Sigma was introduced in this research which has three phases. The first phase calculates the values which are C_{pk} in 6, 5, 4 and 3 when the process means shifts by 1.5 ; and then to construct PCAC in 6, 5, 4 and 3 when the process means shifts by 1.5 in the second phase. Finally, the influential quality characteristics that need to be improved must be located by the PCAC method. This method will be used to measure the aforementioned arbour bearings of sewing machine. The measuring outcome follows that the quality level of orthogonal degree arrived 6 . Not only can the PCAC model evaluate process capability for a product which holds many quality characteristics, but it can judge the process of precision and accuracy soon according to the points of fall for managers.

Key words: Six sigma, process capability analysis chart, sewing machine.

INTRODUCTION

There is core area of mechanical production and manufacturing industry in central Taiwan. The machine industry is a professionalism and division of labor, thus not only creating industrial cluster effect but also bringing with technological innovation and rapid economic growth. The case Z. company founded in 1968, the total number of 194 employees, the turnover is 3.14 million NTD in 2009 and products are business area include Europe, America/Canada, East-South America, Japan and Africa, etc.

The Z. company are mainly specialized on manufacture of household sewing machine, household vacuum cleaner and spare parts which has been reputable and popular in the market. The team has expanded its service from Original Equipment Manufacturer (OEM) to Original Design Manufacturer (ODM) by the application of the advanced technologies. They do not only apply innovation concepts and advanced technologies to the development of new models with government, schools and institutions but also got international ISO 9001 and ISO 14001 quality assurance standard together with environmental management license. Quality assurance concepts are incorporated into new product in each stage from research and development to product in Z. company. They spend a considerable amount of budget each year in research and development for products quality control and management, investing a lot of time and effort in market researches and customers service on the markets all over the world. However, according to customers continued demand for high quality, so Six Sigma will be introduced in the Z. company for keeping competitive and pursue sustainable operation in the market place.

Six Sigma is a concept that was originated by Motorola Inc. in the USA in about 1985. At the time, they were facing the threat of Japanese competition in the electronics industry and needed to make drastic improvements in their quality levels (Harry and Schroeder, 2000). Six Sigma is named after the process that has six standard deviations on each side of the specification window. Such

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a process produces 3.4 defects per one million opportunities in the long term (Wyper et al., 2000). Based on (Tong et al., 2004; Pfeifer et al., 2004) to present Six Sigma has been initiated using statistical tools and techniques in business, transactional and manufacturing process. It has been proven to be successful in reducing costs, improving cycle times, eliminating defects, raising customer satisfaction and significantly increasing profitability (George, 2002; Mahanti and Antony, 2009). There are many leading organizations with a track record in quality have adopted Six Sigma and claimed that it has transformed their organization. For examples, in 1999 General Electric (GE) company spent over half a billion in Six Sigma initiatives and received over two billion in benefits for the fiscal year (Pande et al., 2000). Bank of America (BOA) reported a 10.4% increase in customer satisfaction and 24% decrease in customer problems after implementing Six Sigma (Roberts, 2004). Knowles et al. (2004) looking at the successful application of the Six Sigma (Define, Measure, Analyze, Improve, and Control) DMAIC methodology and associated tools to the medicated sweet manufacturing process in a southern UK plant of an international food manufacturer that total savings of £290,000 per annum is demonstrated for an investment of approximately £13,000. Ricardo et al. (2005) apply Six Sigma to reduce waste, this allowed material waste to be reduced by nearly 50,000 per year. The Six Sigma approach can effectively improve the upper process capability index CPU from 0.57 to 1.75, that is, 0.07 defects per million, without an upgrade of production equipment or an increase of production costs (Lo et al., 2009).

Six Sigma implementation uses a systematic procedure; a five-step DMAIC methodology. A detailed description of DMAIC methodology can be found in Pyzdek (2003) or Keller (2005). GE and others have added a “Define” phase at the beginning, to assure that the right projects are selected. So we will follow the improvement model in (Measure, Analyze, Improve, and Control) MAIC in the research. Because many companies achievements of Six Sigma implementation are positive, we want to apply Six Sigma in process capability improvement. According to Chen et al. (2001), the Process Capability Indices (PCIs) can be viewed as an effective and excellent means of measuring product quality and performance. Thus, we want to use PCIs to measure process capability in measure step of Six Sigma. But the product usually holds many quality characteristics (Bothe, 1992; Chen et al., 2001; Huang et al., 2002).

Similarly, customers will accept products whenever all process capabilities of each characteristic satisfy preset specifications, so to measure process capability for a product must consider many quality characteristics. Obviously, univariate process capability indices cannot meet the requirements stated as above. The research will construct a process capability analysis chart (PCAC) to evaluate process capability for a multi-process produce based on C_{pk} which was proposed by Kane (1986). Besides the above, we will also compute the values which are C_{pk} in 6, 5, 4 and 3 when the process means shifts by as much as 1.5σ. And then to constructing PCAC in 6, 5, 4 and 3 when the process means shifts by 1.5σ. Not only can the PCAC model evaluate process capability for a product which holds many quality characteristics but it can judge the process of precision and accuracy soon according to the points of fall. If the process of accuracy is not enough, you can comprehend the average specification which slanting large or small on the PCAC model. Following on the above analysis, the worker on the line and the manager can comprehend whether the process of precision and accuracy is enough on the PCAC model. If the process of accuracy is not enough, they can analyze the reasons on the PCAC model. Thus, PCAC model is not only a measure tool but also a preliminary analysis tool.

PROCESS CAPABILITY ANALYSIS CHART

Basic elements to evaluate process capability are the process mean ( ), the process variance (^{2}) and the product specification. Because the specifications are different in different product, manager of process cannot evaluate process performance from and right away. For this reason, Juran (1974) combined process para-meters with product specifications to bring up the idea of PCIs. Later, Kane (1986) proposed the formulas as following:

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

$$C_{pu} = \frac{USL - }{3}$$

$$C_{pl} = \frac{ - LSL}{3}$$

$$C_{pk} = \min\{C_{pu}, C_{pl}\} = \frac{d - | - m|}{3}$$

where *USL* is the upper specification limit, *LSL* is the lower specification limit, is the process mean, is the process standard deviation, *m* is the target, and *d* is the tolerance (that is, *d* = *USL*-*m* = *m*-*LSL*). PCIs are convenient tools which can evaluate process capability and performance.

Numerous statisticians and quality engineers have emphasized on the research of process capability indices to propose more precise methods on the evaluation of process potentials and performance (Kane, 1986; Singhal., 1991; Boyles, 1994; Chen and Pearn, 1997; Huang et al., 2002; Chen et al., 2006). As noted by Chen et al. (2001), most products have multiple characteristics. In fact, customers will accept products whenever all process capabilities of each characteristic satisfy preset specifi-cations. Obviously, univariate process capability indices cannot meet the requirements stated in the work. The

The research constructs a PCAC to evaluate process capability for a multi-process produce based on C_{pk} which was proposed by Kane (1986).

The product usually holds many quality characteristics (Bothe, 1992; Chen et al., 2001). For example, the key quality characteristics of a backlight module include: (1) length, (2) width, (3) thickness, (4) brightness, (5) equalization (Huang et al., 2002). The yield of a multi-process product is lower than individual process capability of each characteristic. Likewise, when process yield is set to meet required level, then process capability of each characteristic should be greater than the preset standard for entire product. The minimum process capability indices C_0 of each individual process characteristic was asserted by Huang et al. (2002) as

$$C_0 = \Phi^{-1}[(\sqrt[t]{2\Phi(3c)-1}+1)/2]/3)$$

where c is the integrated process capability index; t is the total number of quality characteristics.

The critical values C_0 for individual process capability can be attained by solving the previous inequality when the integrated process capability index exceeds c that is, ($C_T \geq c$). Now we let $P = /d$ denote the precise index and $A = (-m)/d$ denote the accurate index, and then the relation between P and A can be found by using the formula of C_{pk} when C_0 was attained. That is from $C_{pk} = \frac{d-|u-m|}{3\sigma} = \frac{1-|A|}{3P} = C_0$ which implies $|A| + 3C_0P = 1$

A MEASURING MODEL OF SIX SIGMA

According to (Linderman et al., 2003) mentioned motorola set this goal so that process variability is ± 6σ from the mean. They further assumed that the process was subject to disturbances that could cause the process mean to shift by 1.5σ off the target. Hence, this section will research the corresponding value between numbers of Sigmas and C_{pk} when the process mean shifts 1.5σ that is (- m =1.5). When that the process quality level arrived k that is (d = k) and the process mean shifts 1.5σ, C_{pk} can be showed as follows:

$$C_{pk} = \frac{d-|-m|}{3} = \frac{k\sigma-1.5\sigma}{3\sigma} = \frac{k-1.5}{3}$$

And then yield percent (%) is the probability which is between USL and LSL. USL is $m+k\sigma$ and LSL is $m-k\sigma$. Because the process means shifts 1.5σ, is 1.5σ when the process mean shift is 1.5σ right (Figure 1). The yield % when the process mean shifts 1.5σ right can be described as:

$$\text{Yield \%} = P(LSL \leq X \leq USL)$$
$$= P(m-k\sigma \leq X \leq m+k\sigma)$$

$$= P[\frac{(-k-1.5)\sigma}{\sigma} \leq Z \leq \frac{(k-1.5)\sigma}{\sigma}]$$

$$= \Phi(k-1.5) - \Phi[-(k+1.5)]$$
$$= \Phi(k-1.5) + \Phi(k+1.5) - 1$$

Based on the formula, the corresponding values which are yield % and C_{pk} can be computed for different value $d \in$ { 6, 5, 4 and 3 } and the process mean shifts1.5σ. The results are shown in Table 1.

Based on this study, most products have multiple characteristics. When the integrated process capability index c is taken as that is (c=C_{pk}), and from formula $C_0 = \Phi^{-1}[(\sqrt[t]{2\Phi(3c)-1}+1)/2]/3)$, we can obtain the minimum process capability indices C_0 of each individual process characteristic in 6, 5, 4 and 3 for different the total number of quality characteristics (t). Table 2 indicates the corresponding value. For example, one single product consists of 4 processes (A1, A2, A3 and A4). If the quality level of the product is preset to be 6 , the critical value C_0 =1.595 for individual process capability index can be attained by Table 2. Similarly when the quality level of the product is preset to be 5, 4 and 3 , the critical values C_0 for individual process capability index dividedly are 1.288, 0.982 and 0.702. And then we can attain the PCAC chart (Figure 2) which the quality level is from 3, 4, 5 and 6 based on the . The quality level of process A1 arrived 6 already, and the process A1 yield is preset to be greater than 99.99966%. The quality level of process A2 is between 3 and 4 . The process variation of A2 is so large. To reduce the process variation of A2 it can increase the process capability. The quality level of process A3 is less than 3 which implies process mean of A3 is so large. So the process mean of A3 should be backed to the closer process target to upgrade the process capability. The quality level of process A4 is less than 3 . Process mean of A4 is so small. So the process mean of A4 should be increased to the closer process target to upgrade the process capability. According to the above arguments, we can establish an algorithm to find the points which are not qualified. The steps of this calculation are:

Step 1: Total number of quality characteristics t must be known and $C_0 = \Phi^{-1}[(\sqrt[t]{2\Phi(3c)-1}+1)/2]/3)$ in 6, 5, 4 and 3 must be decided. And then we can attain the PCAC which the quality level is from 3 to 6 based on the relationship: $A + 3C_0P = 1$.
Step 2: To collect data of each quality characteristics and then to compute precise index (P) and accurate index (A).
Step 3: Pointing the points which are computed in Step 2 in PCAC.
Step 4: To find the points which are not qualified after to improve them.

A REAL EXAMPLE

The arbour bearings (Figure 3) in the work are produced by Z. company in Taiwan. They are used in a sewing machine. The Z. company is not only specialized manu-facture of arbour bearings which has been reputable and popular in the market but also successive research, development and support in the industrial domain for many years. For the quality of the aforementioned arbour bearings to arrive as the best, Z. company implements Six Sigma. Based on the description in this study, there are four steps in the flow path to evaluate process capability. We will follow the flow path to evaluate process capability of the aforementioned arbour bearings module.

The flow path is as follows:

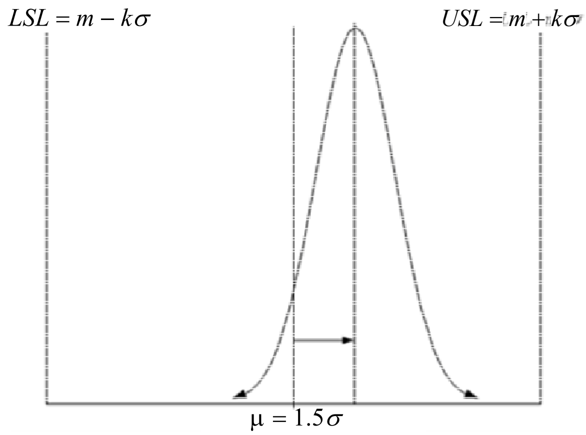

Figure 1. The process mean shifts 1.5σ right chart.

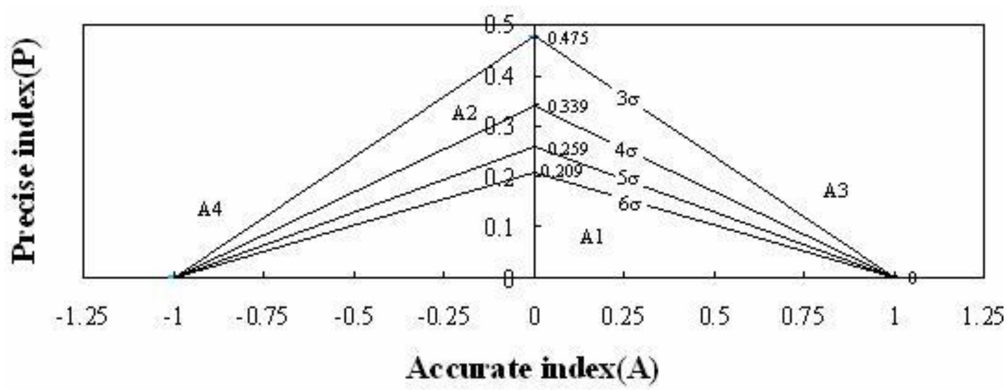

Figure 2. The PCAC chart which the quality level is from 3 to 6 .

Figure 3. The aforementioned arbour bearings.

Table 1. The corresponding values of yield % and C_{pk} for different value of *d*.

d = *k*	Yield %	C_{pk}
3	0.9331928	0.50
4	0.9937903	0.83
5	0.9997673	1.17
6	0.9999966	1.50

Table 2. The minimum process capability indices C_0 of each individual process characteristic for *t*.

t	3 (*c*=0.5)	4 (*c*=0.83)	5 (*c*=1.17)	6 (*c*=1.5)
1	0.500	0.830	1.170	1.500
2	0.606	0.909	1.23	1.548
3	0.663	0.952	1.264	1.576
4	0.702	0.982	1.288	1.595
5	0.731	1.005	1.305	1.610
6	0.754	1.023	1.320	1.622
7	0.774	1.039	1.332	1.632
8	0.79	1.052	1.343	1.641
9	0.804	1.063	1.352	1.649
10	0.817	1.073	1.360	1.656

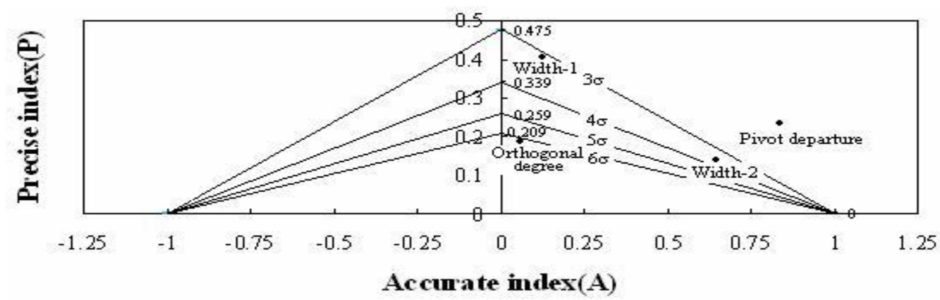

Figure 4. The PCAC chart of the aforementioned arbour bearings.

Table 3. Process capability of the characteristic of the aforementioned arbour bearings.

Quality characteristic	Type	*USL*	*T*	*LSL*		σ	(C_{pk})C_{pu}	A	P
Width-1	N	6.9	6.8	6.7	6.824	0.0406	0.6232	0.24	0.4065
Width-2	N	30.15	30	28.85	30.103	0.0235	0.6664	0.6867	0.1567
Orthogonal degree	S	0.036	-	-	0.037	0.0072	1.5003	0.1019	0.1996
Pivot departure	S	0.05	-	-	0.0447	0.0122	0.1452	0.8933	0.2449

Note: N denote Nominal-the-best, S denote Smaller-the-better.

Step 1: Because there are 4 quality characteristics in the aforementioned arbour bearings, the critical values C_0 for individual process capability indices dividedly are 1.595, 1.288, 0.982 and 0.702 when the quality level of the product is preset to be 3, 4, 5 and 6 based on Table 2. And then we can attain the PCAC which the quality level is from 3 to 6 based on the relationship: $A + 3\ C_0 P = 1$ (Figure 4).

Step 2: Thirty samples are collected in respective quality characteristic. Process capability indices of respective quality characteristics are computed in Table 3.

Step 3: Pointing the points which are computed in Step 2 in PCAC (Figure 4).

Step 4: The quality level of process width-1 is between 3 and 4 . The process variation of width-1 is so large. To reduce the process variation of width-1 can elevate the process capability. The quality level of process width-2 is between 3 and 4 . Process mean of width-2 is so large. So the process mean of width-2 should be backed to the closer process target to upgrade the process capability. The quality level of process orthogonal degree arrived 6 already, and the process orthogonal degree yield is preset to be greater than 99.99966%. The quality level of process pivot departure is less than 3 . Process mean of pivot departure is so large. So the process mean of pivot departure should be backed to the closer process target to upgrade the process capability.

CONCLUDING REMARKS

Implementing the Six Sigma can be a very successful approach to process improvement. Six Sigma has seen their product quality improve, costs decrease and effi-ciency level increase in many companies today. However, product usually has many characteristics (Huang et al., 2002), and it is difficult to implement of Six Sigma.. The research constructed a PCAC to evaluate process capability for a multi-process produce based on C_{pk} which was proposed by Kane (1986). Besides, we computed the values which are C_{pk} in 3, 4, 5 and 6 when the process means shifts by as much as 1.5σ. Following C_0 = $\Phi^{-1}[(\sqrt[t]{2\Phi(3c)-1}$ + 1)/2]/3), the minimum process capability index C_0 of each individual process characteristic can be computed. And then the PCAC can be built if the quality level is from 3 to 6 based on the relationship: $A + 3\, C_0 P = 1$.

Not only can the PCAC model evaluate process capability for a product which holds many quality cha-racteristics but it can judge the process of precision and accuracy soon according to the points of fall. The worker on the line and the manager can comprehend whether the process of precision and accuracy is enough on the PCAC model. If the process of accuracy is not enough, they can analyze the reasons on the PCAC model. Thus, the PCAC model is not only a measure tool but also a preliminary analysis tool. Finally, the PCAC model was used to measure the aforementioned arbour bearings. The measuring outcome follows that the quality level of orthogonal degree arrived 6 , but the others are less than 6 .

Obviously, the case under study has made significant progress. To fulfill the real goal of Six Sigma and meet satisfaction of customer, other factors affecting quality characteristics need to be focused.

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