Improving Capability in Small Thai Manufacturing Companies

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Abstract— **Statistical Process Control (SPC) is definitely one of the most powerful scientific methods for process control in manufacturing industry. Application of suitable SPC tools and techniques, e.g., graphical representation, scatter diagrams, variable and attribute control chartsand the assessment ofcapability via suitable indices could help improve and assure product quality and minimize losses due to non-conformity. Application of machine and process capability studies would be really beneficial for small and medium sized manufacturers. Capability assessment involves relatively little cost and effort but can contribute to significant improvement in performance. This paper reviews and explains the background to the application of machine and process capability studies in manufacturing processes. Capability study is also shown to be very useful in the development of a new process or product as well as for ongoing production.**

Index Terms—**Statistical Process Control, Machine Capability Study, Process Capability Study**

I. Introduction

Capability is the power or ability to do something. In reviewing the competitiveness of Thai industries, especially in the automotive sector, a number of recent studies [1-3] have considered approaches in policy and strategy that may be used towards improving capabilities in Research & Development and Innovation in parts producers. This paper considers the situation in small Thai manufacturing companies but, rather than discuss policy for capability improvements, it outlines some practical steps that can be taken by such small companies to improve their technical performance. By using basic statistical techniques improvements in ability to satisfy customer requirements which can be made with minimum investment apart from time and effort.

Much of the manufacturing industry in Thailand is associated with the automotive sector. Hence, in discussing capability and its improvement, reference is made to the special requirements of this sector. Many small companies provide material or components to OEM automotive parts suppliers or themselves produce replacement parts. It is therefore important that such small manufacturers have some understanding of the requirements of the automotive sector regarding quality systems and in particular the application of capability studies as part of Statistical Process Control (SPC) in general.

One Thai company that applies statistical process parameters such as Cp and Cpk found that by monitoring these two parameters the quality of outgoing products could be quantified before dispatch to customers. Hence quality assurance targets could be satisfied thus minimizing product recall and its associated penalties while maintaining customer confidence.

II. Variation in Processes

A given process or machine cannot produce consecutive items which are identical in every respect. SPC techniques via the application of variable and attribute control charts recognize variation in processes and divide the sources of such variation into two types called *Common* and *Special* causes [4]. Common causes occur randomly and are always present during the operation of a process, for example, slight variations within compositional specifications, temperature differences between first and last castings poured out of a ladle, limitations of temperature control in heat treatment furnaces, acceptable tool wear in machining, vibration in machines, etc. Common causes result in variation which is the characteristic of the process and which is *predictable within set limits*. In contrast Special causes are not inherent in a process and give rise to *variation which is not predictable*. Examples of special causes include use of incorrect raw materials, temperature controller not working correctly, heating or cooling rates in heat treatment incorrect, work by incorrectly or insufficiently trained operators, etc.

During the introduction of SPC into a company, special cause variations in processes are identified and eliminated such that only common cause variations remain, resulting in processes which are predictable. Predictable processes, free from special cause variation, are said to be in a *"state of statistical control"*.

Common cause variation may then be examined and be gradually reduced leading to more consistent processes and products. The level of common cause variation can be compared with component tolerances and property requirements to assess both *Machine* and *Process Capability*. Such capability studies determine whether the customer design requirements and tolerances can be satisfied in a predictable manner over an extended run of production.

Variation from a machine or process usually follows a certain pattern. The simplest way of showing this pattern, i.e. the distribution of the results, is to arrange the measured values or data in the form of a bar chart or histogram. If a large number of measurements are taken and the accuracy of measurement is high, the bars on the bar chart would be narrow and a smooth curve could be drawn to model the distribution as shown in Fig. I. In most cases variation usually follows a bell shape called a *Normal Distribution*. Other types of distribution can also occur e.g. *Skew distributions*.

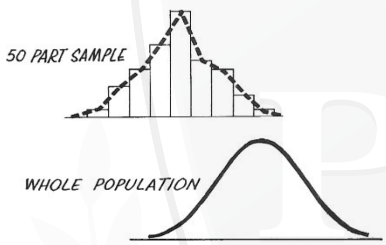

Fig. I. Distribution in a 50 part sample and the whole population [5].

Distributions may differ in setting, in variation and in shape as shown in Fig. II.

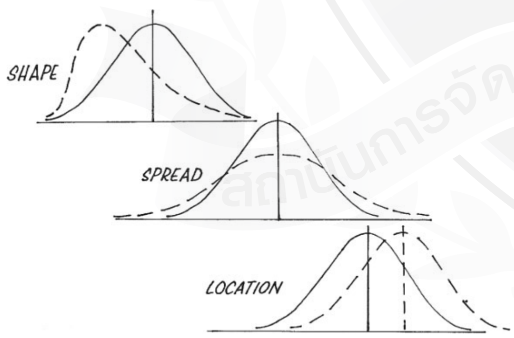

Fig. II. The shape, spread (variation) and location (setting) of distributions [5].

Mathematical models of distributions enable confident predictions to be made about process variables and/or product characteristics. A normal distribution is described by the *Mean (or average) value, X bar* and by *its Standard Deviation, s or σ (sigma)*. The mean (X bar) is a measure of the central value of a normal distribution and describes the setting or location of a process or product characteristic. Standard deviation (s) is a measure of variation or spread in a process or product characteristic. It can be calculated from a standard formula or found by simple graphical methods as in a machine capability study. The use of standard deviation to describe spread about the mean value is shown in Figure III, which illustrates the % spread of results between +1, +2, +3 and +4 standard deviations about X bar. For example if the mean and standard deviation of a set of measurements are 100 and 1 respectively, then we expect 68.26% of the values to lie between 99 and 101, 95.46% between 98 and 102, 99.73% between 97 and 103, and 99.994% between 96 and 104. If process characteristics do not alter, then these predictions should remain true for all subsequent runs of production. These values can be used to assess the capability of a process against customer requirements. This is the basis of :

- Short term *Machine Capability* studies, which are carried out to establish the capability of a machine or process to satisfy the required specification or tolerances *prior to an extended run of production.*
- Longer term *Process Capability* studies which are on-going and *performed during runs of production* using data obtained via plotting of variable SPC control charts.

III. Machine Capability Studies

A machine capability study provides a snap-shot of the process to determine if the process is capable in the short term of meeting customer requirements and tolerances before the start of production. Such studies first became more widely used in parts manufacture when they were made mandatory in the SPC Instruction Guide issued by the Ford Motor Company in 1984 as part of the company's Quality System Standard Q-101 [5]. Each machine capability study is short term and is based on a prenominated sample size of statistically acceptable proportions, this is normally 50 parts. The sample batch is taken as part of a normal production run after any "start-up" or "warm up" fluctuations have been removed. The process parameters must not be altered during the sample run. The required measurements of dimensions, weight, strength, etc. are then performed on each of the 50 parts which have been consecutively produced. The measured values are entered onto a machine capability study sheet as in the example shown in Fig. III.

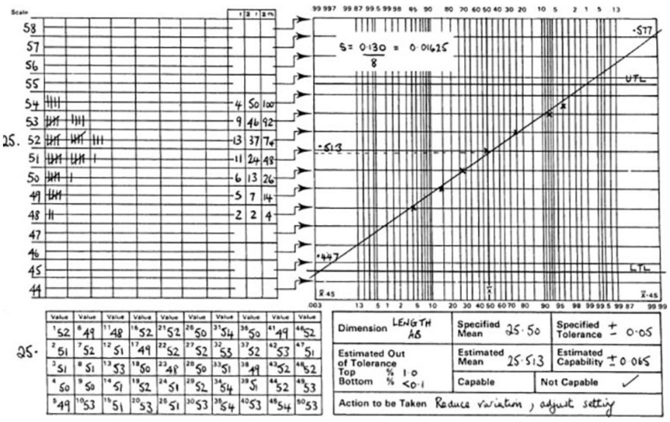

Fig. III. Example of a machine capability study.

The requirement for the part dimension AB is 25.50 +/- 0.05mm. The 50 measured values are entered onto the study sheet and then used to draw up a tally chart which indicates the shape of the distribution. For ease of reading only the figures after the decimal point are given. The tally values are converted to % values and each value plotted on the probability paper at each upper class limit using the "step-up" arrows. The study shows that variation must be reduced and the setting adjusted.

In this sheet, probability paper is used to present a normal distribution as a straight line to enable the results to be extrapolated to +4s and –4s values. This example shows that for the key dimension AB the process is providing a mean value of 25.513 with a 4s variation of 0.065. The customer requires a mean of 25.5 with a 4s variation less than 0.05. Hence the current production set up is not capable of meeting the needs of the customer; so the producer must adjust the process to reduce variation and to reset the process mean to the target of 25.5.

The standard deviation s (σ) is estimated from the slope of the capability study plot on the probability paper. Using this value of s the result of a machine capability study may be summarized by two index values called Cm and Cmk.

Spread is assessed by the machine capability index Cm which is given by(1):

$$Cm = \frac{(USL-LSL)}{6s} \quad (1)$$

Where USL is the Upper specification limit, USL is the Lower specification limit (LSL) and s is the estimated standard deviation.

Using s and the mean value X bar the setting and spread are assessed by the index Cmk which is given by the minimum of the two values calculated from (2) and (3) :

$$Cmk1 = \frac{USL-X\,bar}{3s} \quad (2)$$

$$Cmk2 = \frac{Xbar-LSL}{3s} \quad (3)$$

When the process is set at the specified mean, the two calculated values for Cmk will be the same and will equal Cm. When the process is not on target, the two values for Cmk will be different and the lowest value is reported. In satisfying the original motor industry requirements the minimum requirement for both Cm and Cmk is a value of 1.33 i.e. when the mean value (setting) is on target the variation of +/-4s must not be greater than the specified tolerance (USL - LSL). For a situation where capability is just satisfied, then 8 (+/-4) standard deviations equals the total specified tolerance. When Cm and Cmk both equal 1.33 then 99.994% of production is expected to be within specification. A Cm value smaller than 1.33 shows that the variation is too large and specified tolerances cannot be satisfied i.e. the process is not capable. This is illustrated by the example in Fig. III for which the calculated Cm value is 1.03, with Cmk values of 1.29 and 0.76. The lower value of 0.76 is quoted.

The automotive industry continues to tighten quality assurance standards for parts suppliers. Towards reduced variation, depending on the complexity of the part and the manufacturing method, a minimum short term capability index of 1.67 is required.

Machine capability is an approximate measure of potential capability when a process or a machine is being commissioned at the start of a new product or after a break in production. For example, in high pressure die casting (HPDC) where a new die set is brought into production for the first time or a previously used die set is re-fitted to the HPDC machine for further production runs. Machine capability studies are therefore useful in providing an audit of a process. But it is very important to note that, quite often machine capability data is obtained without sufficient data being available to determine whether or not the process in question is in a state of statistical control. Hence although machine capability measurements contribute to correctly starting up production, they cannot be used for long term predictions of process performance. For the longer term capability must be assessed over an extended period of time via Process Capability studies *after all special cause variations have been removed.* The process is then in a state of statistical control and therefore predictable. The changing situation with time towards achieving a stable process is illustrated by Fig. IV.

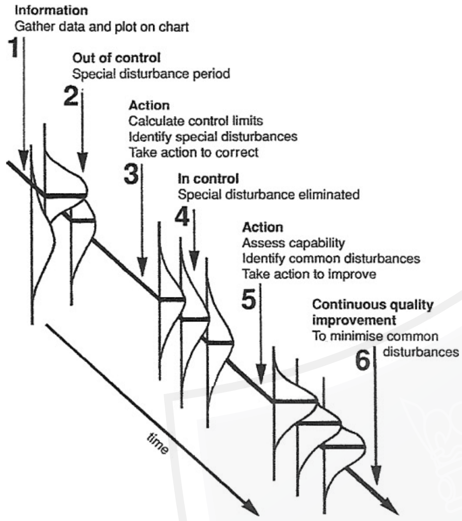

Fig. IV. Stages in process improvement [14] Process Capability is assessed at Step 5 after all special cause variation is removed and the process in a state of statistical control

When the Q-101 Standard was revised to become part of Quality System Requirements QS-9000 in 1994 [6], the approach to capability was modified and Capability was re-defined as *"the total range of inherent variation in a stable process".* As a consequence, as outlined in the section below on process capability, new descriptions were given to the type of capability index to be reported.

For small manufacturing companies, who are not seeking to achieve compliance with QS-9000 or other automotive standards, the application of machine capability studies via probability paper plotting remains a useful practical tool when setting up their processes. When judging initial performance, it is not always necessary to take measurements on 50 parts. Using a cumulative percentage plot for individual values, an estimate of likely variation can be obtained from as few as 15 measurements. This is often called a "pass-off" capability plot; an example of this method is given in Fig. V.

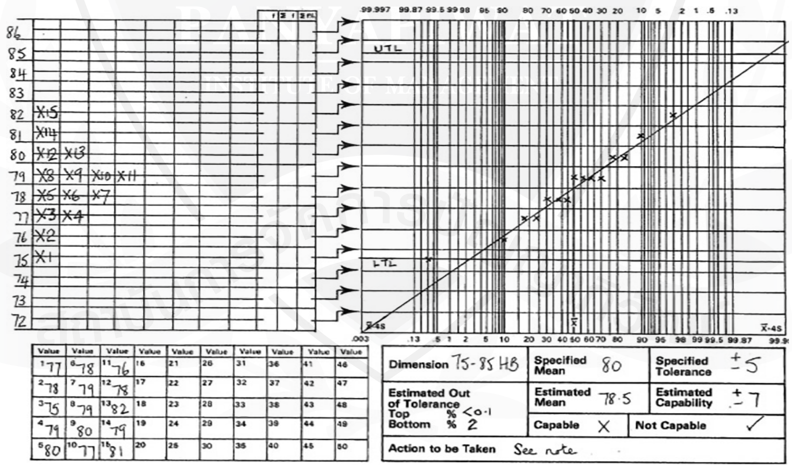

Fig. V. Example of a "Pass-Off" study using only 15 measurements.

A company is starting production of a new casting design in a Al-Mg-5Si alloy using gravity diecasting (permanent mould) and needs to satisfy a specification for Brinell hardness after precipitation heat treatment of 80 +/- 5 HB. To asses initial performance the hardness at a fixed position is measured for each of the first trial batch of 15 castings. Instead of using a tally chart each individual result is plotted in order of magnitude from 1 to 15 as indicated.

Plotting positions are calculated for each result in order of magnitude at a cumulative % value (p) given by (4):

$$p = \frac{\left(i-\frac{1}{2}\right) x100}{n} \quad (4)$$

For value no. 1 p = 3%, for no.2 p = 10%, and so on to for no 15, p= 97%. Each cumulative % value is plotted at the measured value; the "step- up" arrows are not used for individualvalues. Where there is more than one measurement of a particular value the calculated % values are plotted side by side at the same measurement as shown. Plotting of the values in this way indicates the shape of the variation as for a tally chart. In this example the estimated capability is +/- 7 with the mean value below target predicting that unless process control is improved about 2% of production will have too low a hardness. Hence the company must look at tighter control of variables such as composition, pouring temperature, die pre-heat, cooling time, and heat treatment conditions such as ageing time andtemperature towards satisfying the customer requirements.

IV. Process Capability Studies

When using variable control charts, spread is assessed simply by determining the Range R of a small number of measurements taken on consecutively produced parts or parts taken from the same batch of production; in the latter case, for example, this may be parts taken from suitable positions within a tray of heat treated material. In conventional Mean (X bar) and Range (R) charts, the range is the difference between the largest and smallest value in a group of measurements (e.g. dimensions or hardness values of 4 or 5 items). Alternatively where only single measurements can be used (e.g. carbon equivalent liquidus determination, or measurement of liquid metal temperature in a pouring ladle), difference between consecutive values are expressed as a moving- range when using Reading (X) – Moving Range charts [7].

When control charting has shown that all special causes have been eliminated and that only common cause variation exists (at position 5 in Fig. IV), then standard deviation s is estimated from the mean range values using statistical constants and process capability described by calculating the indexes Cp and Cpk as for machine capability. As for Cmk, when the process is not centered on the target value Cpk will have two different values and the lower value is reported.

Cp and Cpk can be calculated by (5) and (6);

$$p = \frac{\left(i - \frac{1}{2}\right) x100}{n} \quad (5)$$

In (5), (6) and (7) USL and LSL are respectively the upper and lower specification limits and s is the estimated standard deviation.

Cpk is given by the minimum of the two values CPU from (6) or CPL from (7):

$$Cp = \frac{USL - LSL}{6s} \quad (6)$$

$$CPU = \frac{USL - X \ double \ bar}{3s} \quad (7)$$

CPU is a measure of setting X double bar (the overall process mean) in relation to the upper specification limit USL, while CPL compares this mean value with the lower specification limit.

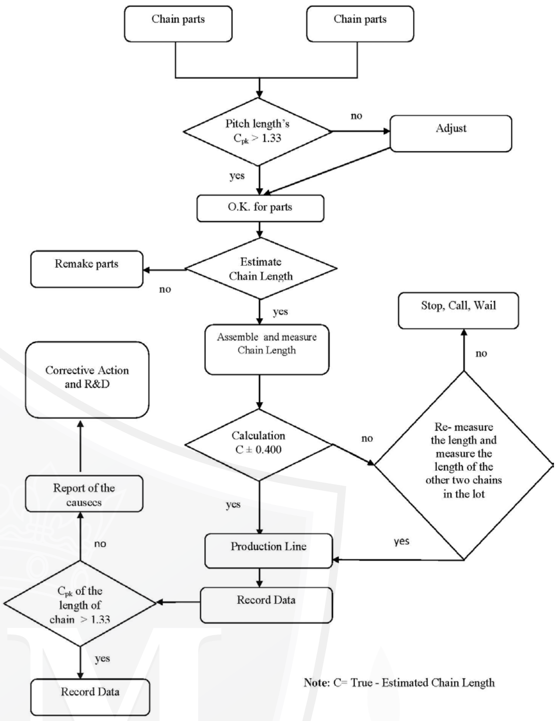

Fig. VI. Flow process of Cpk application in a Thai roller chain manufacturing company

Fig. VI. shows the quality control process of the length of the roller chain in a Thai company before and after assembly. The dimension of each part has been measured and Cpk of the pitch length would be calculated. When the parts are ready, the chain length would be estimated and the partsproceed to assembly. Parameter C which is the difference between the measured chain length and the estimated value would be determined. Actual production would be started then or after any required corrective actions were taken. It was found that the proportion of length defectives in final products was reduced from 0.14% to zero after the Cpkapproach was applied to the process.

In the original auto-industry requirements the minimum required value for both Cp and Cpk is 1.0 i.e. over the long term, when the setting is on target, at least 99.73% of production should be within specification [4, 5]. As for short term capability suppliers are required to continually reduce variation with minimum process capability requirements being increased to 1,33.

When QS-9000 was issued, as part of the Production Part Approval Process (PPAP), requirements for potential suppliers, emphasis was placed on Preliminary Process Capability studies rather than on Machine Capability. Attention was also given to the question of accuracy and reliability of any measurements used in assessing variation and the automotive industry guidelines for Measurement Systems Analysis were revised [8]. If measuring gauges or any other pieces of testing equipment are not correctly calibrated and kept well-maintained, then we cannot have confidence in the resultant measured data and such data will be misleading in studying the capability of machines or processes. In small companies seeking to improve their performance the purchase, calibration and maintenance of measuring and test devices and training in correct usage is the main area where investment is needed.

Preliminary Process Capability studies are normally carried out at key stages in the development of a new process or product. In a Preliminary Process study, the data is required to be collected and analyzed using X bar and R charting. In reporting capability at least 25 sub-groups of data with at least 100 individual readings must be used. As for Cp and Cpk studies the overall processes mean (X double bar) is taken as a measure of setting with respect to the target value. Estimated standard deviation s (variation) are determined via the initial control charts and are used to calculate the capability indices Pp and Ppk. As for machine and process capability indices mentioned earlier, the Pp index describes variation with respect to the tolerance band and Ppk describes both variation and setting. As for Cmk and Cpk the lower value of Ppk is reported.

In some companies confusion can arise over how capability studies should by summarized using capability indices. To avoid any misunderstanding between the producer and the customer both should be in full agreement about how machine or process capability indices should be defined, determined and represented.

In carrying out capability studies or in the application of SPC companies whether large or small must be aware of the routes via which the products have been manufactured, including information on raw materials. With this knowledge an effective plan can be drawn up to show how the data is to be collected. Problems caused by combining data from measurements on a batch of nominally the same product but which has been produced by different sources can then be avoided. Examples of different sources producing an "identical" product include:

- Use of different batches or supplies of alloy ingot
- Sheet blanks or cut bar stock from different suppliers
- Multi-cavity or multi-impression moulds and dies
- Multi-spindle machines
- Separate machines of identical type
- Different combination of dies or moulds on different identical machines, etc.

In some cases we can recognize mixed work in a product batch by examining the shape of the resultant histogram, e.g. two peaks in a bimodal distribution, or by examining the straight line fit on a probability paper plot as in a machine capability study. In other cases we may believe that we have a non-normal distribution e.g. skew e.g. when measurements on some products from rogue cavities or positions in a mould have distorted the distribution. For example, in sand castings production these positions may arise due to:

- Original variation in mould or core-box dimensions from patternmaking or caused from damage, distortion or wear during use.
- Differences in the flow of sand around the pattern during filling and compression of a green sand mould or during filling/blowing and subsequent curing of a chemically bonded sand during core-making.

It is important to perform capability studies of the different combinations of dies or tooling sets and their host machines that are used to manufacture a given product so that combinations which give increased and possibly unacceptable variation can be identified and thus avoided. To avoid confusion and misconceptions in capability studies or in applying SPC it is paramount that systems for accurate recording of production information must be established. In seeking to improve capability small companies in general need to improve production record keeping so that raw materials, tooling and production variables used to produce a given product or part can be readily identified.

V. Concluding Remarks

The ongoing use of suitable control charts and assessment of process capability has proved to be one of the key steps in improving quality in manufacturing industries such as castings or forgings production where final product quality depends on a number of interrelated factors [7, 9-10].

Any manufacturing company must make products which are technically correct, are produced within budget, and are produced on time with a minimum wastage from defectives. In deciding which jobs to take on and how to cost them correctly without making a loss; small companies, in particular, must be able to recognize any limitations or deficiencies in their abilities and must be able to identify where improvements are needed. Small companies tend to have limited resources and difficulties in recruiting and training of workers. Nevertheless, with support from the topmanagement, suitable data collection procedures can be established and performance assessed using basic capability studies and introduction of suitable control charts. Progress can be made using simple manual plotting etc. on paper but where companies are confident in their understanding of the principles and application of capability studies and use of control charts, then it is likely to be more convenient to use a simple computer based system.

Other steps that can be taken include Process Mapping of procedures [11], use of Continuous Improvement techniques such as Plan – Do – Study – Act [12], Cause & Effects Analysis [13] and Pareto Analysis, etc. [14]. Table I summarizes the usefulness of some of these basic techniques.

TABLE I
SOME BASIC TECHNIQUES THAT CAN CONTRIBUTE TO IMPROVEMENTS

Technique	How this technique can help
Process flow charts	Show sequential stages of what is being done
Check and tally sheets	Record how frequently a particular event occurs
Bar charts (Histo-grams)	Give visual descriptions of pattern of variation
Scatter diagrams	Examine if there is a relationship between factors
Cause & effects analysis	Considers potential problems & possible causes
Pareto Analysis	Identifies the 2 or 3 main problems – “vital few”
Control charts	Differentiate between common andspecial causes – use statistics to control processes

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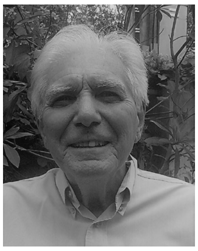

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