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Application of Process Capability Study as a Diagnostic Tool for Process, Productivity and Quality- In- Management Improvement

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Abstract
This case presents a process capability study in a light engineering firm involved in manufacturing welding equipment in India. Apparently the company was not facing any quality problem- rejections of components were low and customer complaint was also minimum. But CEO felt there was a scope to improve the Productivity. A quick study of the assembly shop indicated that assembly of components are not random, it is 'pick & choose' type. To diagnose the problem, process capability study was undertaken which is not a common approach in addressing productivity improvement issues. The study was a great eye opener for the top management and opened a Pandora's Box revealing plethora of basic shop management issues including design related issues. Most of the processes are not capable of manufacturing as per the drawing dimensions.

Keywords: Process capability, Cpk, Ppk, sigma level, productivity, IMR, MINITAB

Teaching objectives

1. Help students understand and interpret Minitab Process Capability Output and implication of process capability on productivity.
2. To encourage students to use process capability data to get a big picture view of designing the product and daily management issues
3. It will also sensitize the students how process capability study help identify understanding and communication gap between several stakeholders.

Introduction

In order to examine the capability of producing output within specification limit and to understand the variability of the output from a process and machine, process capability indices have been introduced. Process capability index measures the variability of process relative to the specification limits of its intended output [1]. Use of this parameter is widespread in the industry with the advent of Sixsigma movement [2,3].Anecdotal evidence suggests that it has almost become a standard practice to measure and even report process capability indices to the customer in Auto component industry due to QS 9000 / ISO/TS169469 [4]. Process capability is denoted by Cp, which is calculated by the ratio of specification width and process width (6σ). A process may produce out of specification products due to higher spread or due to location shift of the process mean or due to both higher spread and location shift. While Cp indicates spread of the process relative to the tolerance width it gives no idea about process location shift. In order to capture the location shift of the process, Process capability index, Cpk has been introduced and it is defined by the equation 1.

$$Cpk = \text{Min}\{(USL-\mu)/3\sigma,\ (\mu - LSL)/3\sigma\} \qquad (1)$$

USL = Upper specification limit, LSL = Lower specification limit and σ is the process standard deviation.

In case of centered process, Cp = Cpk. Higher the Cp and the Cpk better is the process performance. A shop engineer is more bothered with lower Cp than the Cpk. Lower Cp is due to both assignable and inherent variation of the process which is difficult to remove. Higher Cpk is generally due to assignable causes, which are easy to locate and rectify. While there is no magic number for the value of Cp and Cpk, practitioners consider a Cpk value of ≥ 1.66 very satisfactory [5]. In summary, process capability indices predict the probability of producing out of specification products by the process or equipment as it indicates the repeatability and consistency of a manufacturing process relative to customers' requirement [6]. And it is for this reason it has become quite common to examine the Cp, Cpk during evaluation of supplier. As the nature of the process varies with time due to several reasons, suppliers are interested to calculate the long term sigma level, which is a derived index from the process capability, for critical processes. In order to capture the long term capability of the process generally three to six months' data are used. The long term capability is denoted by Pp and Ppk (known as process performance and process performance index). Though the formula to calculate Pp and Ppk are same as Cp and Cpk, the sample standard deviation is used for calculating Pp and Ppk instead of within group standard deviation which is used in case of Cp and Cpk.

How It Is Measured

In ideal condition capability indices indicate the inherent variation of a machine when everything is in ideal condition. In practice, no one is interested in assessing the inherent variation of the existing machines. What they are interested is to know the capability of the machine under most economic operating condition of the machine, which Gregory Roth calls as "acceptable operational level machine spread" [4]. Roth has outlined a seven step process to determine the machine/ process capability. These are 'Planning' which involves selection of variables and the purpose of the study, 'Measuring'- selecting the measurement instrument-the gauge should be calibrated and should follow 10 to 1 rule for measuring dimensions of the product to reduce measurement error, 'Personnel'-the person selected to carry out the measurement should be aware of the product and knowledgeable in the operation to be studied, 'Sample size'- there is no single number for the right size. It depends on the purpose of the study and precision required. Generally 50 consecutive pieces are good enough to determine short term capability. Pieces taken over a time period indicates long term capability, 'Approval'- approval of the concerned supervisor is a must and the operator should also be aware of the study before commencing the study, 'Recording'- the raw data shall be recorded as per the order. This is very important. The machine parameters shall also be noted, 'Analysis'- normality test, histogram, X bar and R Chart and the descriptive statistics along with the values of capability indices should be worked out. For short term capability the standard deviation is calculated by R Bar/d_2 , where d_2 is a constant for a given sample size. In the case of long term capability the standard deviation is determined by $\sqrt{\Sigma}$ (X-X Bar)^2 / n or (n-1). At present, most of the industry is using Minitab software for calculation of process capability. A brief on Minitab output of process capability will help us later to follow the discussions.

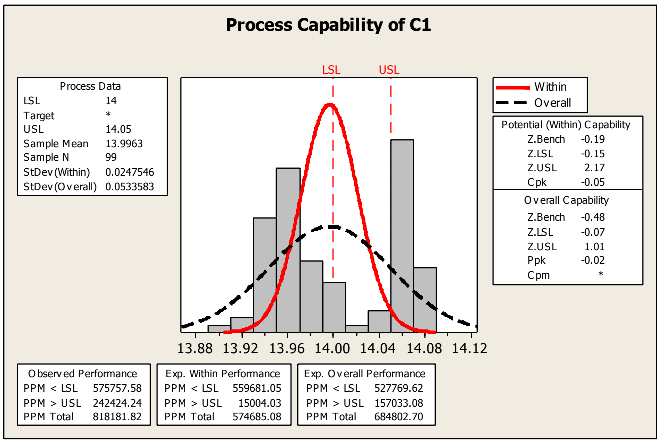


Fig. 1. A Typical Minitab 16 Output

Cpk is arrived at from the lower Z value. In this case it is Z.LSL, -0.15. Cpk = Z.LSL/3 = -0.05. It is calculated based on StDev (Within) which is known as short term standard deviation. Minitab uses pooled standard deviation for calculation of within sample standard deviation. Ppk is calculated by using StDev (Overall). Observed performance is the actual number of defectives from the data. 'Exp. Within performance' and 'Exp. Overall Performance' are the probabilistic estimation of rejection in short term and long term respectively. It is calculated based normal distribution formula by the software. Z Benchmark is the sigma level of the process, considering total number of defectives. Minitab does not provide Z Benchmark (Sigma level) if any of the Z value is negative.

Use of Process Capability Index

The usual practice of using Process capability indices may broadly be divided in two groups, determining capability assessment or for diagnostic reasons for a particular machine/process. They are also used for robust design though they are not effectively used by design [7]. The present study reveals that the process capability data may be used to get the big picture view of the shop floor environment and help asking relevant questions for not only improvement of manufacturing quality but also help diagnose overall productivity and quality problems including interdepartmental interaction issues.

Case Study

Zinser Manufacturing co. (real identity is changed for maintaining confidentiality) is a welding equipment manufacturing company in India. The company has plants in different locations. The CEO had a feeling that the productivity of the manufacturing shop of this plant was low and there must be some problems. A study was assigned to a consulting firm to study and suggest improvement. Rejection percentage in the shop, as per record, was not high compared to similar industry and customer complaint was also less. The consultants first made a study of the assembly shop as assembly shop is the mirror of the part supplying shops. The products, assembled parts, were undergoing a pressure test before releasing for dispatch. It was found that in about 15% cases the component parts were undergoing rework either with minor filing at the time of assembling or the products were being re-assembled with other pieces of respective parts. In other words, it was 'pick and choose' type of assembly. It was quite clear that variability was very high in each component/part. It was decided to conduct a process capability study at the machine shop where different components/parts were manufactured. The machines were CNC machines.

Process capability study

In consultation with the design department out of 42 dimensions, 22 were identified as critical and for all these processes, process capability study were carried out with the help of Minitab 16 Software. Mitsubishi digital Vernier Caliper was used for taking the measurement. An experienced retired operator was deployed to take the measurement after going through the Gauge R & R test. It was told by the CEO not to rely on existing data. Thus top management's lack of trust of data was very prominent. Consecutive samples were collected on different days and shifts to capture both short and long term variation, in a limited way, for each identified critical dimension selected for study. As the objective of the study was to get a big picture of the shop management practices and to get indicative machine capability, strict protocol of process capability study was not always followed. In most of the cases more than 50 pieces were collected. The data were first tested for normality and when the data were not normal, Box-Cox transformation was used before calculating Process capability. IMR Charts have also been prepared. Out of 22 dimensions, study output of 6 dimensions is presented here for discussion. The output pattern of all other dimensions was of similar type. The study was spread over a month.

Study output

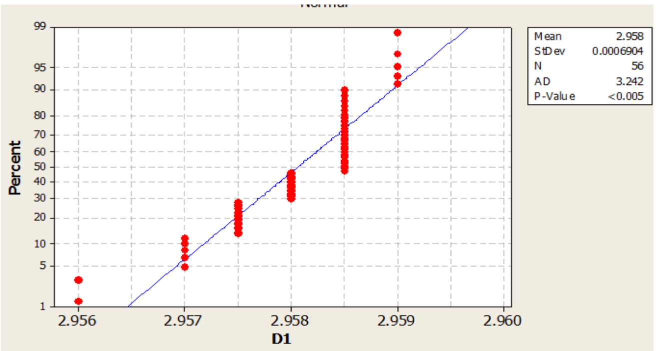
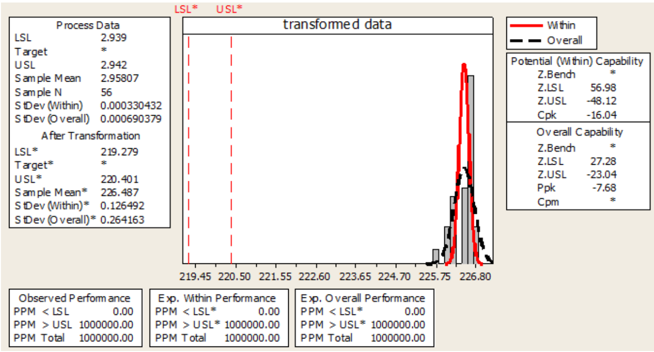


Figure.2. Normality test of Dimension 1



Cp = 1.515

Figure 3. Process Capability of Dimension 1 After Box-Cox Transformation with Lamda =5

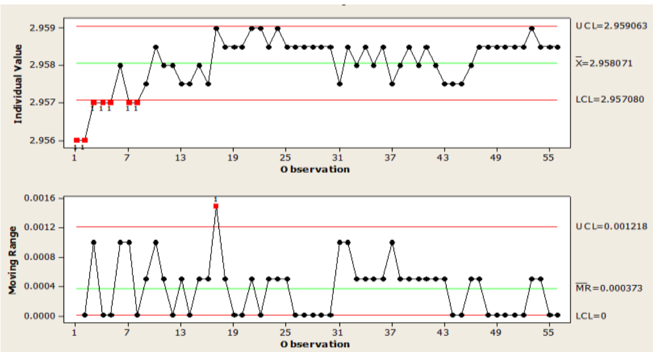


Figure 4. IMR Chart of Dimension 1

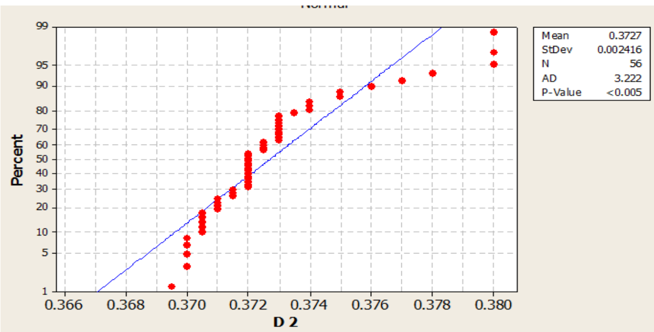
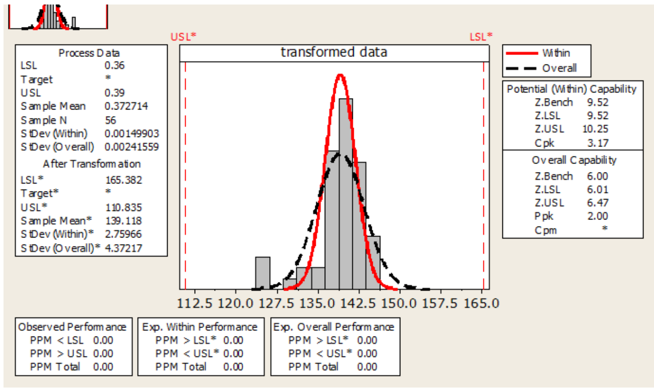


Figure 5. Normality test of Dimension 2



Cp = 3.33

Figure 6. Process Capability of Dimension 2 After Box-Cox Transformation with Lambda = -5

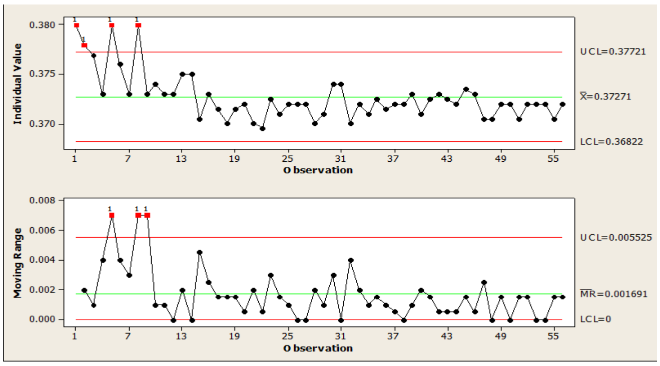


Figure 7. IMR Chart of Dimension 2

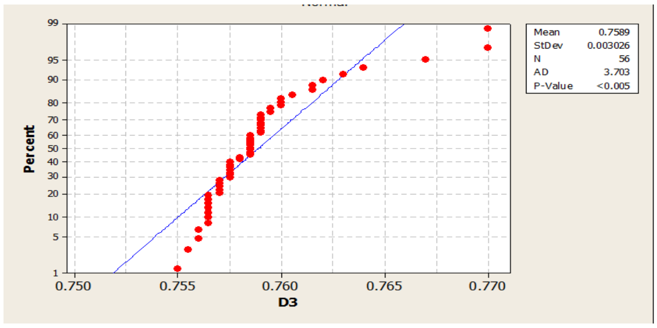
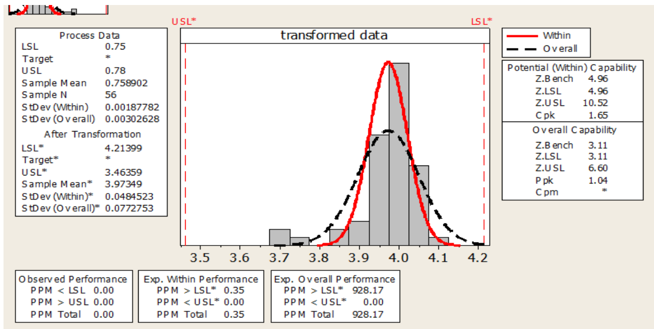


Figure 8. Normality Test of Dimension 3



Cp=2.580

Figure 9. Process Capability of Dimension 3 Using Box-Cox Transformation With Lambda= -5

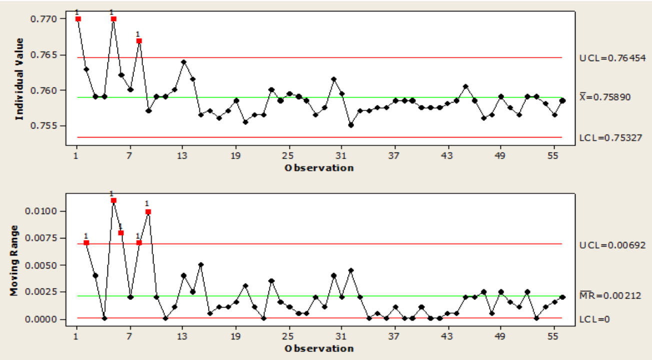


Figure 10. IMR Chart of dimension 3

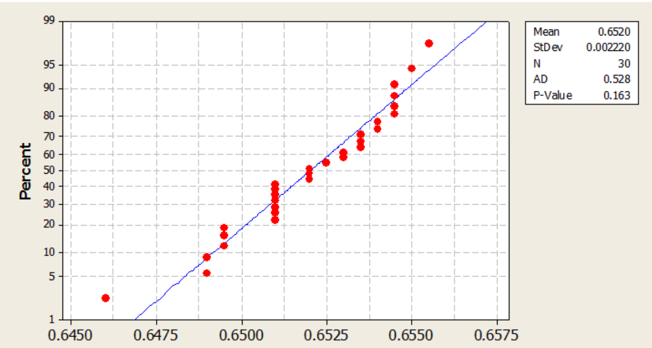
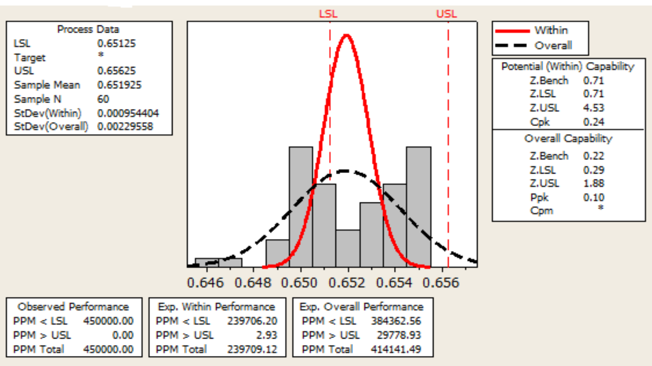


Figure 11. Normality Test of Dimension 4



Cp = 0.88

Figure 12. Process capability of Dimension 4

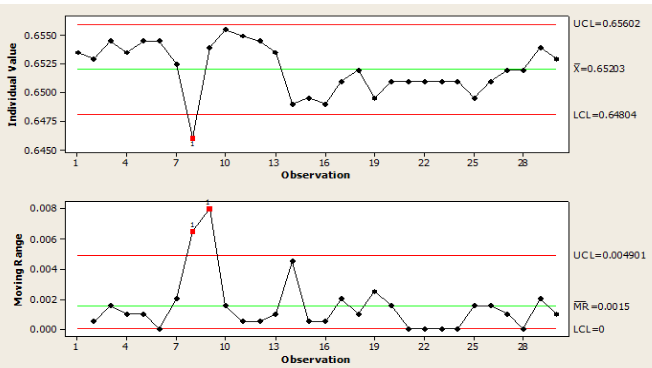


Figure 13. IMR Chart of Dimension 4

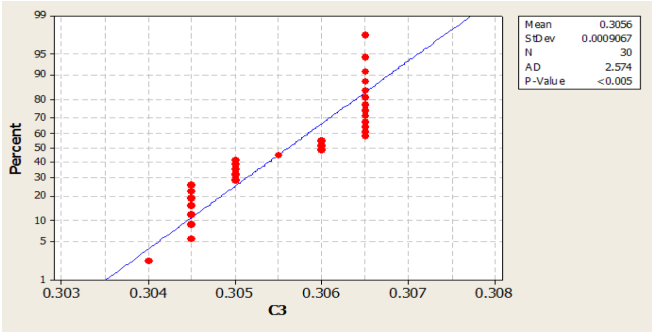
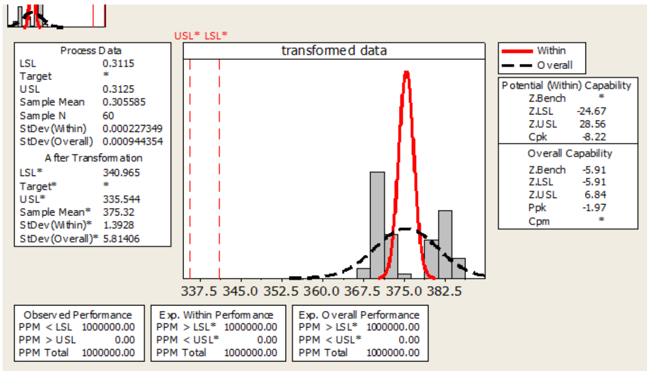


Figure 14. Normality Test of Dimension 5



Cp=0.65

Figure 15. Process Capability of Dimension 5 Using Box-Cox Transformation With Lambda =-5

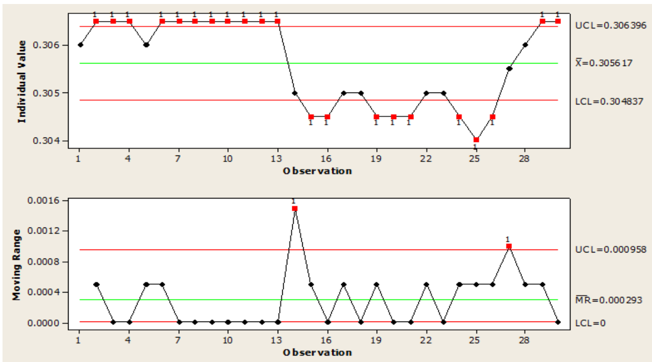


Figure 16. IMR Chart of Dimension 5

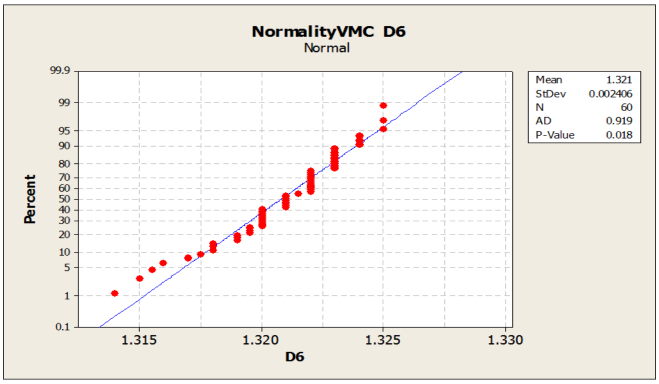
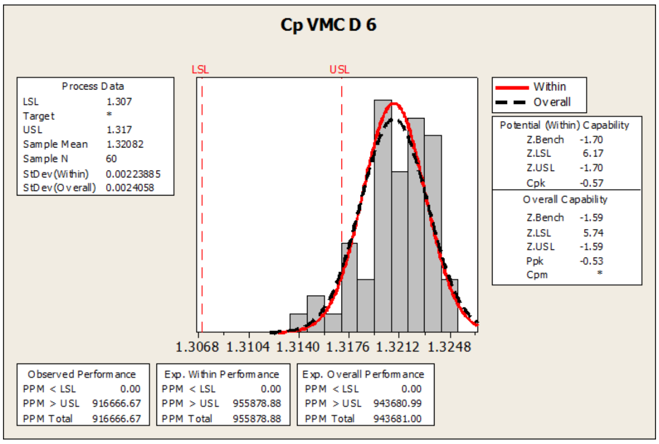


Figure 17. Normality Test of Dimension 6



Cp=0.76

Figure 18. Process Capability of Dimension 6

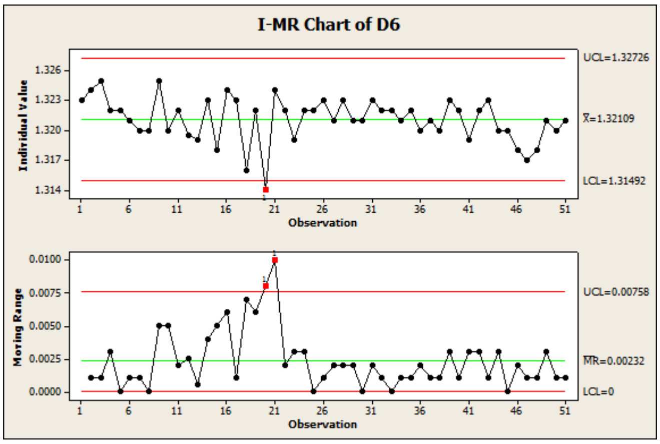


Figure 19. IMR Chart of Dimension 6

Analysis

Examination of the output reveals the following:

1. Out of 22 processes only 4 were normally distributed
2. Only 8 processes were having Cp value more than 1
3. Only 6 were having Cpk more than 1.33, which was the minimum expectation from a good manufacturing shop (anecdotal evidence from industry practice).

Under this scenario it is obvious that the shop will be producing huge number of defective components. But in reality the operators were rejecting very few components at each stage.

Examination of the go-no go gauges which the operators used for inspecting parts revealed that the gauges were having dimensions different from the design tolerance. It may be mentioned that Quality Control department was also inspecting by go-no go gauge to a great extent and very few dimensions were measured and these were not used in decision making process. The operators are not trained to adjust the cutting tools as required through CNC programming. It is done by the shop supervisor who adjusts tool settings occasionally. The QC inspector is also not following the drawing dimensions. He has a good rapport with the shop supervisor. Shop in charge also ignores such issues probably the daily targeted production is not affected and the number of customer complaints are few. The issue was discussed with the Head of design department and he told, "I am not surprised, as the products always fail in the endurance test, which is about 500 Hours of continuous working and the shop management is not listening me." When asked why there is so little customer complaint, he was of the view that the equipment was used by the fabricators/welders whose concern was whether the product was working. And they are not much bothered about the longevity of the product as it is not costly compared to other project item cost. When interacted with the Shop in charge, he pointed out that the maintaining such close tolerance could not be achieved with the present machine tool. The design has been provided by the collaborators and they have not examined the manufacturability of the components under local condition. The local design department is not empowered to make changes. The shop in charge agreed that the operators will be trained for tool setting through CNC programming so that they can do the tool adjustment as and when required. It was quite clear that the variability of the components were causing rework and pick and choose assembly resulting low productivity at the assembly shop. With so many deviations from the original drawing dimensions the drawing has lost its engineering sanctity. Operators are having least respect for the drawing.

Case Study Questions

1. Interpret the capability study outputs in each dimension considering all three outputs: Capability output, Normality test and the IMR Chart. Explain how these help identify the root cause of low productivity at the assembly.
2. If you are the consultant what questions you will ask to the management to identify the major issues the shop is facing and what could be done to improve the situation.

Teaching Note

Teaching objective 1

Help students understand and interpret Minitab Process Capability Output and implication of process capability on productivity.

Here the course instructor shall distribute each Dimension output as a case exercise to different small groups. And ask to interpret based on the information provided in the introductory part of the case study with special emphasis on correlation among three outputs – Normality test, IMR Chart and the Process capability for each dimension. Ask students whether non normality of the distribution of different dimension is an issue or not.

Students should be told that the common myth of normal distribution of variables of mass production components may not be an issue. This is in line with the observation of Thomas Pyzdek-"Numerically controlled (NC) machines often have backlash in their positioning mechanisms that create one distribution when moving away from the home position, and a completely different distribution when moving toward home,

resulting in a bimodal distribution with a "dead zone" in the middle." [8]. This is also stressed by Mohammed Z. Anis [1]. We have quite a few bimodal distributions as depicted in Fig 8, 11, 14.
Students may be asked to indicate implication on the distribution pattern where Cp is high but Cpk is low. What could be the possible reasons? They may be told that such things mainly happen in machine shop if the cutting tool is not adjusted at appropriate frequency. It is also evident that machines are not only affected by mean shift but the spread in several cases are also high compared to the specifications. Less Cp value indicates this.
Interpretation of IMR Charts- both individual value and moving range is very important as these indicate the state of control of the processes. Instructor may draw the students' attention to the moving range chart. Where the range control is very good the Cp value is also good. As for example in IMR Chart of Dimension 1, 2 and 3 the moving range are having lesser variation compared to the rest. Control chart of individual values indicate the state of control of the process. It may be observed that the process of dimension 5 is out of control. Cp and Cpk values of such processes should not be considered, effort should be first made to bring the process under control.
In case of multi component products the dimensional variation is very important as the design of the product assumes tolerances within limits so that components can be assembled easily and assembly process is a random process. This is very important not only for product quality but also for productivity at the assembly stage. Therefore process capability study is an important tool to understand the state of daily management at the shop floor.
At the end of this portion students will be very thorough with process capability, its implication and use of MINITAB and getting sigma level of a process. And will also appreciate how to deal with 'Mean shifting' and general distribution variation.

Teaching objective 2 & 3
To encourage students to use process capability data to get a big picture view of designing the product and daily management issues. It will also sensitize the students how process capability study help identify understanding and communication gap between several stakeholders.
The course instructor should encourage a debate on –"Is it a design problem or manufacturing problem".
Following questions may be asked:
1. How the products are designed and tolerances are allocated?
2. How the design document is translated into part diagram for machining?
3. Who adjusts cutting tool adjustment in different machines and at what frequency?
4. The role of quality control in this case. Do you think the reporting structure should be reviewed?
5. If the product is failing endurance test is it a customer requirement. Is the product over designed?

Though it appears a straight forward problem but in practice the issue is quite complex. No conclusion may be drawn. The answer to each of the above question is not easy to get. But if we are able to give serious considerations then lot of improvement may be done not only on product quality and productivity but also the existing management practices may be changed through open data based discussions at the top management level.
This study indicates that even a comparatively quick process capability study may reveal larger issues faced by manufacturing environment of a shop. It may also reveal organisational politics and conflict of interest of different stakeholders. It will help improve productivity particularly in assembly line. The study also strongly suggests that there exists a high scope of rationalising tolerances as it seems that the tolerances have not been set considering the process capability. These findings support the survey result carried out by Tata & Thornton [7] ,which indicates that while 85% of the responders agree that process capability data should be fed back to design to make products more producible and make design robust but only 14% of projects use it. There should be better communication between design and manufacturing before taking up any process improvement study.

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