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CHAPTER SIX:

STATISTICAL QUALITY CONTROL FOR AGGREGATE PROCESSING

The process of producing and shipping mineral aggregate is a relatively simple one. The procedure does not require high technology, and the methods used to control this process are equally as simple. These methods, however, account for all the many difficulties a Producer may encounter in production of aggregate. Each time a decision is made that affects the process, at least three principle characteristics of this industry are required to be kept in mind: continuous processing, product alteration, and multiple products.

PROCESS CHARACTERISTICS

CONTINUOUS PROCESSING

Generally, a continuous run of material is produced which tends to lose identity through stockpiling and shipping. Good controls as far upstream as possible in production are very important.

PRODUCT ALTERATION

All aggregate products degrade and segregate with handling and time. This process occurs from beginning to the end of any production. This process may occur later, such as when the aggregates are used for producing other materials.

MULTIPLE PRODUCTS

Most aggregate operations make more than one product concurrently. A change in one product may affect each and every one of the other products.

QUALITY CONTROL

Generally speaking, the process control techniques that are most desirable are predictive in nature rather than detective techniques that provide information on the product after the material has been stockpiled for shipping. Quality control is the prediction of product performance within pre-established limits for a desired portion of the output. Two principles of quality control that are required to be adhered to are:

- 1) Make sure the correct target is understood and achievable
- 2) Control variability within pre-established limits

Once the techniques for prediction of performance are developed, then quality control is required to address three issues: accuracy, precision, and capability.

ACCURACY

If the average of all measurements falls relatively close to an understood point (on target) then the process is said to be accurate.

PRECISION

When all of the measurements over time are very close together, then the process is said to be precise.

CAPABILITY

If the process is both accurate and precise such that the process remains within Specification or other predetermined limits with a high degree of confidence, then the process is said to be capable.

Figure 6-1 gives a graphical representation of accuracy, precision, and capability.

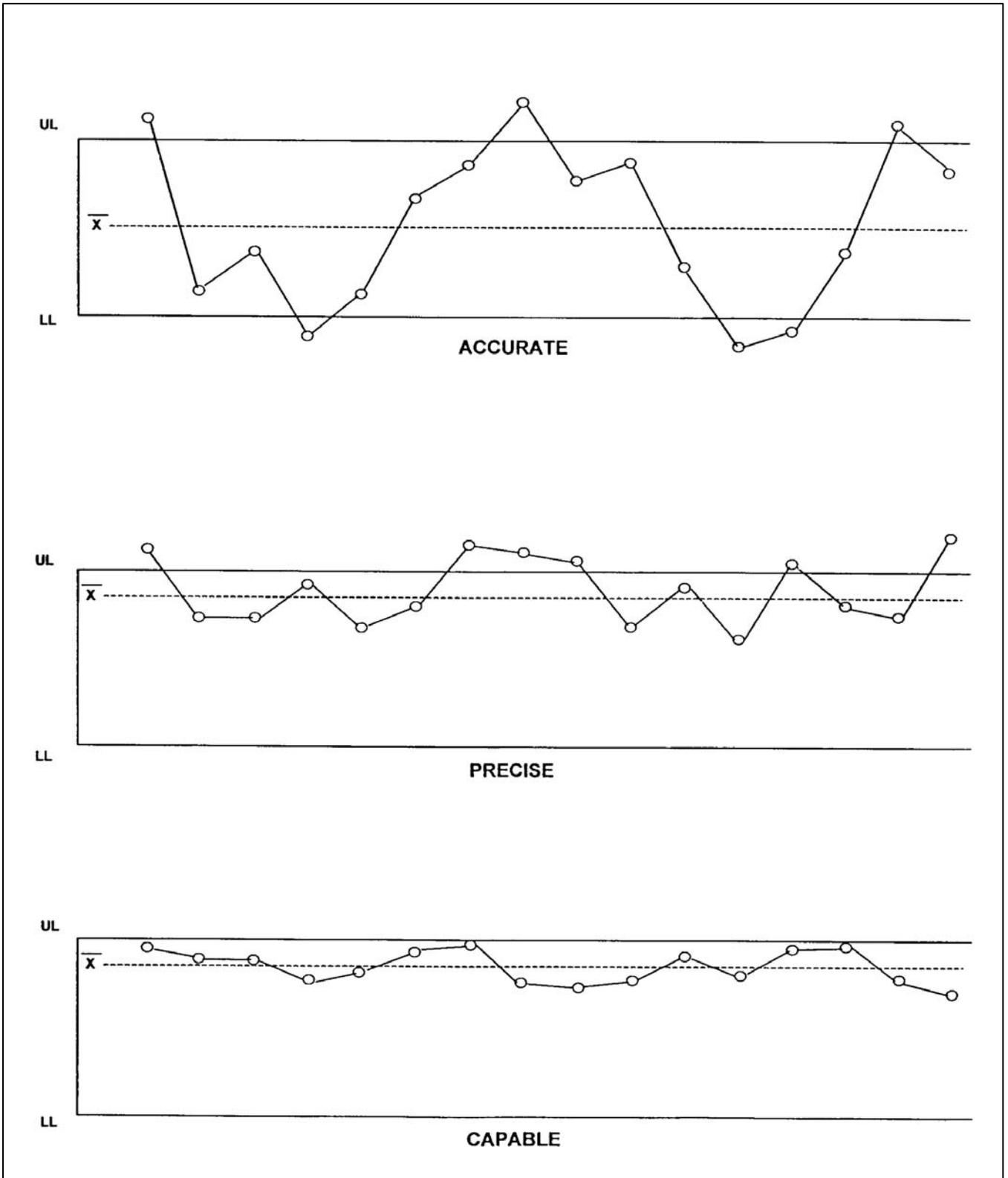


Figure 6-1. Accuracy, Precision, and Capability

STATISTICAL CONCEPTS

Complete control and improvements on any process is made by accurate measurements at critical points within the process. In order to gain confidence, the numbers are required to be generated often at various points so that all the variations of the process are detected. The quantity of measurements accumulates over time and simple tables or listings of these numbers are not enough to evaluate the process. The following statistical tools are used to understand what the numbers mean.

DATA SETS

The numbers from measurements that represent something in common rather than a scattering of unrelated numbers are called a set. When measuring properties of the process that are different, for example, gradation, crush count, or chert count, each property requires a set of numbers. Also, each property has different sets of numbers for different points in the process if the characteristics are known to change. (For example, production gradations versus stockpile gradations). Furthermore, even when properties and points of sampling are the same, a new set of data is required to have to be created if there is a significant sustained change in the process. All of the efforts at understanding, controlling, and predicting the outcome of a process are only as good as the accuracy and make-up of the related data sets. The importance of this step should not be underestimated.

THE MEAN

The average of all the data over time of an unchanged process is sometimes called the "grand mean" or the "population mean". For a shorter snapshot in time, the average may be called the "local mean" or just the "mean". The mean is the center of any distribution of numbers. Figure 1-2 is a graph of a very large group of numbers that are equally distributed on each side of the mean (\bar{x}). The graphic representation of these numbers is called a "standard bell curve".

STANDARD DEVIATION

Whereas the mean is an average of all the data values, the standard deviation is an average value of the dispersion of data from the mean. The standard deviation indicates how much the process varies and determines the shape of the bell curve. Small values reflect a tall, narrow curve (good), while large values reflect a flat, broad curve (poor).

NORMAL DISTRIBUTION

To simplify the interpretation of the data sets, the assumption is made that the data mathematically falls into a normal distribution which when plotted resembles the bell shaped curve. Although few actual processes exactly follow this assumption, they are close enough when stable and in control to be useful statistically. By assuming a normal distribution of the data, a few simple formulas may be applied to give the desired picture of the process. Any area under the bell curve falling between certain limits from left to right when expressed as a percentage of the total indicate the portion of that process that conforms to those limits (Figure 6-2). The further data values move right or left from the center of the curve, the less often these values occur.

Some values that serve as handy reference points for the normal distribution are:

- 1) About two-thirds of the area under the normal curve lies between one standard deviation below the mean and one standard deviation above the mean
- 2) About 95 percent lies between plus and minus two standard deviations
- 3) About 99.75 percent lies within three standard deviations of the mean

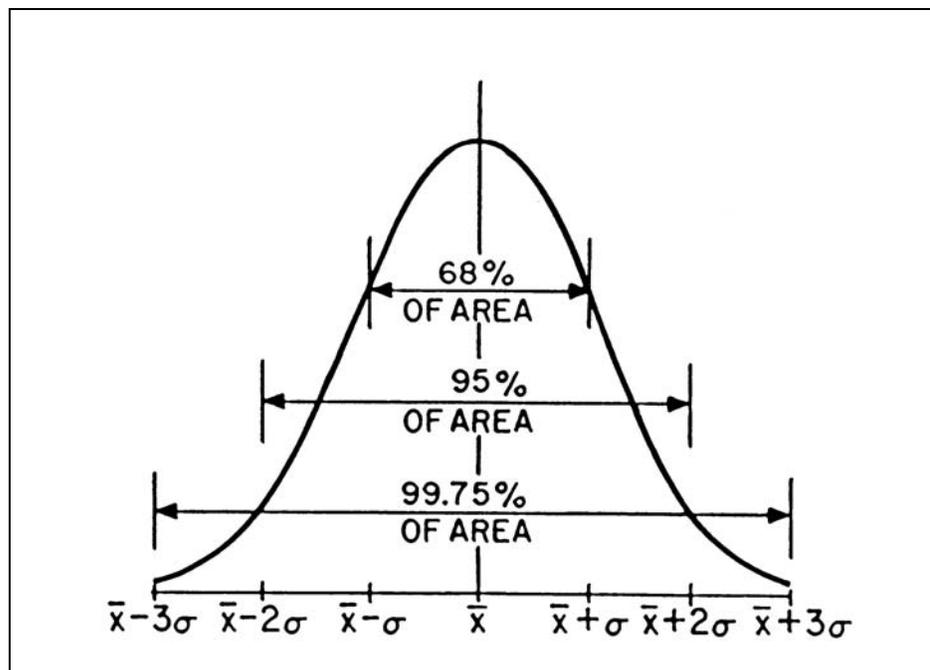


Figure 6-2. Normal Distribution

VARIABILITY

In-control conditions are required to be achieved for each critical characteristic and point in the process. Sources of variability for the same characteristic at different points in the process are cumulative. During the production, handling, and stockpiling of mineral aggregates, the sources of error are potentially many. Therefore, controls are required to be instituted upstream as well as throughout the process. Also, sampling and testing error may affect the variability. Although sampling and testing error will not affect the actual variation of the process, the misleading information may cause incorrect control techniques to be employed and possibly increase variability in the product. The lower the sampling and testing error, the more indicative the data of the process is.

CAPABILITY AND COMPLIANCE

The mean, standard deviation and variance indicate the location of the process and how consistent the process is. This is very important in exercising control. By themselves, however, they do not indicate how well the process meets certain specifications or other limits. The ability of the process to comply with externally imposed limits is called capability. The first useful tool in making this assessment is the Z value. This value indicates the number of standard deviations that the mean is from a particular limit. The greater the Z value, the more compliant or capable the process is (Figure 6-3).

There are two principle applications of the Z value in the Certified Aggregate Producer (CAP) Program:

- 1) Qualifying a Product -- Before a critical sieve product may qualify for use under the CAP Program, the data generation during new product qualification testing is required to demonstrate a Z value of at least 1.65 or higher within the specification limits of that product.
- 2) Control and Compliance -- After qualification of a product, the Z value from the data generated during control and shipping is required to result in a compliance level of 95 % or better for all control sieve products within 10 % above and 10 % below the target mean.

The Z Value

$$Z = \frac{X_{Limit} - \bar{X}}{\sigma_{n-1}}$$
$$Z_{Upper} = \frac{UpperLimit - \bar{X}}{\sigma_{n-1}}$$
$$Z_{Lower} = \frac{\bar{X} - LowerLimit}{\sigma_{n-1}}$$

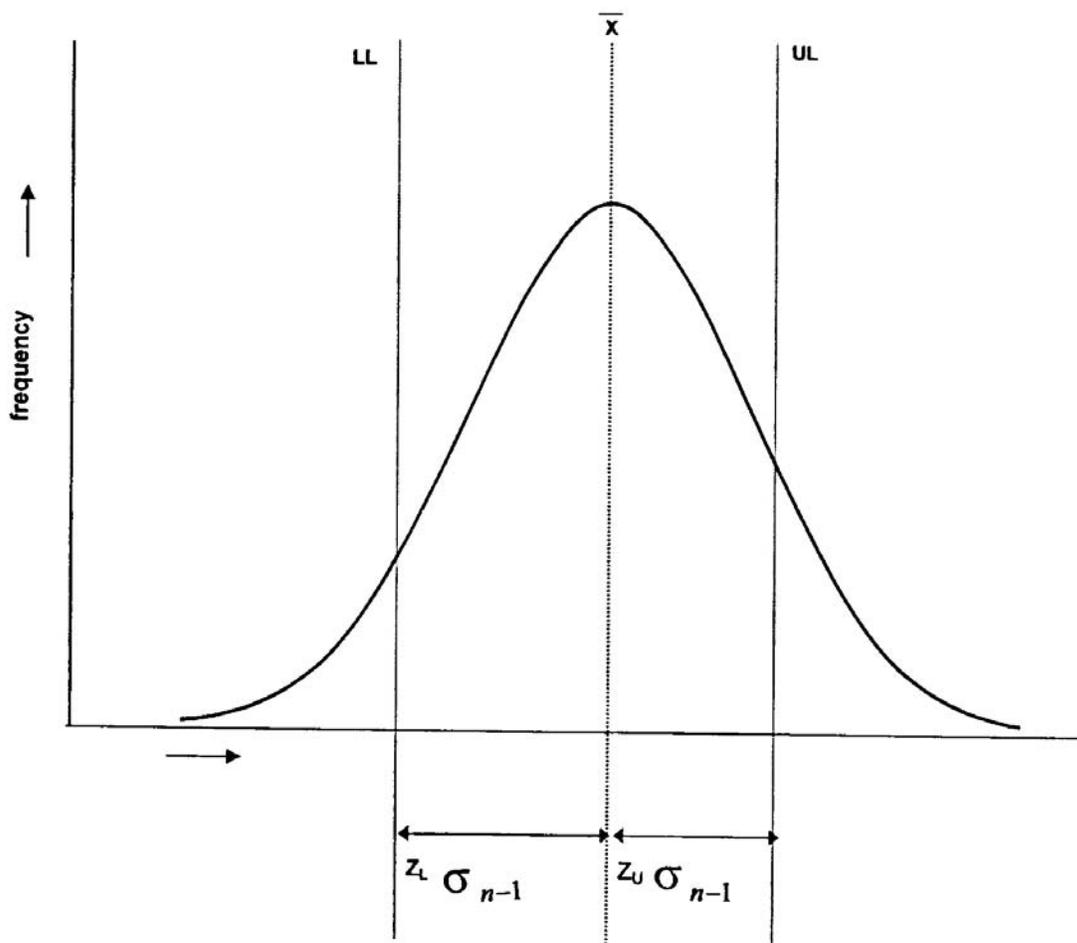
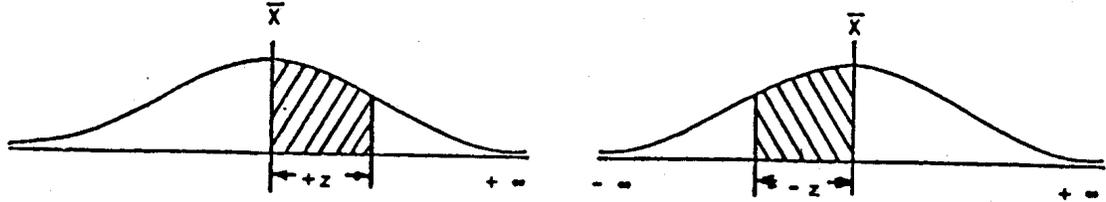


Figure 6-3. The area under the curve between the mean (\bar{x}) and another point (x), depends on Z which is the arithmetic difference between x and \bar{x} , divided by the standard deviation (σ_{n-1}).

When the Z values to each limit are known, this table indicates the area of probability between limits by summing the area left of the \bar{x} with the area right of the \bar{x} . The sum of the two area factors should be multiplied by 100 to give the percent probability of compliance.



	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0159	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2518	0.2549
0.7	0.2580	0.2612	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4083	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4430	0.4441
1.6	0.4452	0.4463	0.4474	0.4485	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4758	0.4762	0.4767
2.0	0.4773	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4865	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4980	0.4980	0.4981
2.9	0.4981	0.4982	0.4983	0.4984	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4986	0.4987	0.4987	0.4988	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990
3.1	0.4990	0.4991	0.4991	0.4991	0.4992	0.4992	0.4992	0.4992	0.4993	0.4993
3.2	0.4993									
3.3	0.4995									
3.4	0.4997									

Table 6-1. Area of Probability Table for Specifications Involving > 0 Percent and < 100 Percent

The CAP Program requires that 95 % of all gradation test results on the critical sieve statistically be between 10 % below and 10 % above the target mean at any one point of sampling. An example of how to calculate percent compliance is as follows:

Product: #8 Stone
 Critical Sieve: 1/2 in.
 QCP Target Mean: 52.2%

The most recent 30 production sample test results:

<u>55.5</u>	<u>49.4</u>	<u>49.5</u>	<u>55.6</u>	<u>61.3</u>
<u>51.2</u>	<u>46.0</u>	<u>50.8</u>	<u>53.8</u>	<u>49.7</u>
<u>53.2</u>	<u>42.4</u>	<u>50.5</u>	<u>52.8</u>	<u>54.6</u>
<u>56.4</u>	<u>53.1</u>	<u>55.2</u>	<u>53.6</u>	<u>58.1</u>
<u>54.2</u>	<u>65.7</u>	<u>56.1</u>	<u>52.6</u>	<u>56.4</u>
<u>48.1</u>	<u>50.3</u>	<u>59.1</u>	<u>52.1</u>	<u>50.9</u>

$$\bar{x} = \underline{53.3}$$

$$\sigma_{n-1} = \underline{4.53}$$

$$Z_{\text{upper}} = \frac{(\text{QCP Target Mean} + 10) - \bar{x}}{\sigma_{n-1}} = \frac{(52.2 + 10) - 53.3}{4.53} = 1.96$$

from Table 6-1, 1.96 is .4750

$$.4750 \times 100 = \underline{47.50}$$

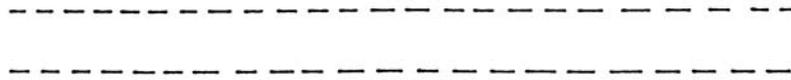
$$Z_{\text{lower}} = \frac{\bar{x} - (\text{QCP Target Mean} - 10)}{\sigma_{n-1}} = \frac{53.3 - (52.2 - 10)}{4.53} = 2.45$$

from Table 6-1, 2.45 is .4929

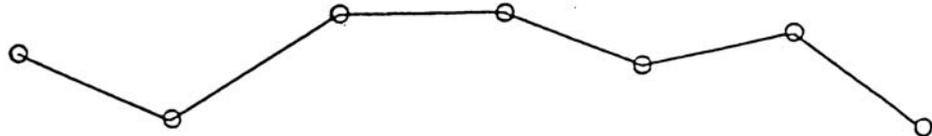
$$.4929 \times 100 = \underline{49.29}$$

$$\% \text{ Compliance} = 47.50 + 49.29 = 96.79 \approx 97 \text{ (Whole Number)}$$

Upper and lower specification limits are indicated by short dashed lines.



Production plot points are surrounded by small circle and each consecutive point is connected by a solid straight line.



The moving average plot point is indicated by a small triangle and connected by straight lines.



The stockpile load-out plot point is indicated by a small square. 

BEGINNING THE CONTROL CHART

The principle purpose of the control chart is to visually depict a repeatable and controlled process. If the new data is expected to be part of the process population, then some definition of the process is required. The entire chart is centered around the target mean value. Ideally, the target mean is the grand mean which would be based on as much data as possible (perhaps a year), providing the process has not changed (Table 6-2 and Figure 6-4). If valid data does not exist on the process, then the control chart is established around a mean calculated from the first ten test results (Figure 6-5). The CAPP requires a QCP Annex to the Quality Control Plan identifying the new target mean to be filed with INDOT. Next, control limits are required to be added at plus and minus two standard deviations from the target mean. In no case may these limits exceed plus and minus 10%. The Z value is required to be 1.65 or greater. If the Z value is not 1.65 or greater, the process is required to be changed.

A quick check of the location of the target mean in relation to the closest specification limit is to multiply 1.65 times the standard deviation. Then, either add or subtract the value, as appropriate, to the target mean. If the resultant number falls outside the specification band, the current process does not meet the requirements of CAPP (Specification Limit Check in Table 6-2).

PLANT:	INDIANA		MATERIAL SIZE: INDOT No. 9		
SPEC.	100	60 - 85	30 - 60	0 - 15	0 - 10
SIEVE	3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8
Mar 19	100.0	68.9	38.4	4.9	2.3
Mar 19	100.0	71.2	40.8	5.2	2.9
Mar 25	100.0	70.8	36.4	3.3	2.8
Mar 25	100.0	69.8	35.2	4.5	3.6
Mar 27	100.0	69.2	37.7	3.9	2.2
Mar 31	100.0	66.3	36.9	3.3	2.1
Mar 31	100.0	70.1	40.1	3.9	2.5
Apr 6	100.0	68.0	37.2	3.6	2.8
Apr 6	100.0	69.7	34.1	3.5	2.8
Apr 8	100.0	71.6	35.1	3.0	1.9
Apr 8	100.0	70.9	37.5	3.7	2.6
Apr 11	100.0	74.8	46.0	4.0	3.1
Apr 15	100.0	77.4	42.9	3.9	1.8
Apr 17	100.0	80.3	49.2	4.9	3.1
Apr 17	100.0	74.0	34.5	3.9	2.4
Apr 20	100.0	73.4	35.4	2.9	1.9
Apr 20	100.0	79.3	40.1	4.4	3.0
Apr 21	100.0	77.5	39.7	4.0	3.2
Apr 21	100.0	78.4	43.1	3.7	2.1
Apr 22	100.0	75.2	39.7	3.6	2.3
Apr 24	100.0	80.9	45.1	4.5	1.9
Apr 24	100.0	80.4	46.5	4.6	2.3
Apr 25	100.0	75.5	38.5	3.5	1.9
Apr 30	100.0	77.2	38.0	5.8	3.6
Apr 30	100.0	76.8	42.2	3.3	2.2
MEAN	100.0	73.9	39.6	4.0	2.5
STD. DEV.	0.000	4.34	4.05	0.71	0.54

For the 3/8 in. Critical Sieve: $n = 25$, $\bar{x} = 39.6$, $\sigma_{n-1} = 4.05$

Specification Limit Check

$1.65 \text{ times } \sigma_{n-1} = 1.65(4.05) = 6.7$

Upper Specification Limit (USL) check = $39.6 + 6.7 = 46.3 \approx 46 \leq 60$

Lower Specification Limit (LSL) check = $39.6 - 6.7 = 32.9 \approx 33 \geq 30$

Z Value Check

$Z_u = \frac{60 - 39.6}{4.05} = 5.04 > 1.65$

$Z_L = \frac{39.6 - 30.0}{4.05} = 2.37 > 1.65$

Establish Control Limits

Upper Control Limit (UCL) = $\bar{x} + 2 \sigma_{n-1} = 39.6 + 2(4.05) = 47.7 \text{ or } 48$

Lower Control Limit (LCL) = $\bar{x} - 2 \sigma_{n-1} = 39.6 - 2(4.05) = 31.5 \text{ or } 32$

Table 6-2. Historical Data Gradation Analysis

FROM HISTORICAL DATA

CONTROL CHART SET-UP

INDOT #9 - 3/8 in. SIEVE

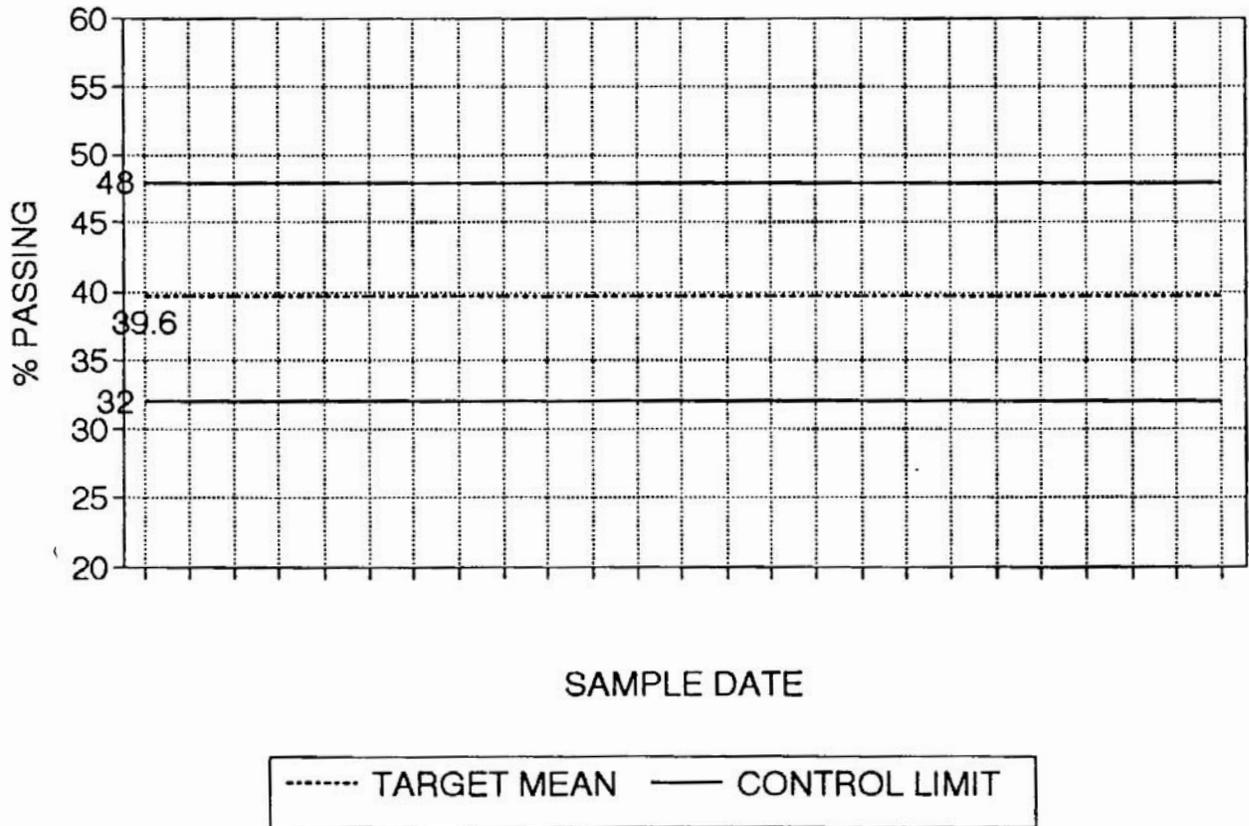


Figure 6-4. Control Chart Set-Up

FROM NEW DATA

CONTROL CHART SET-UP

INDOT #9 - 3/8 in. SIEVE

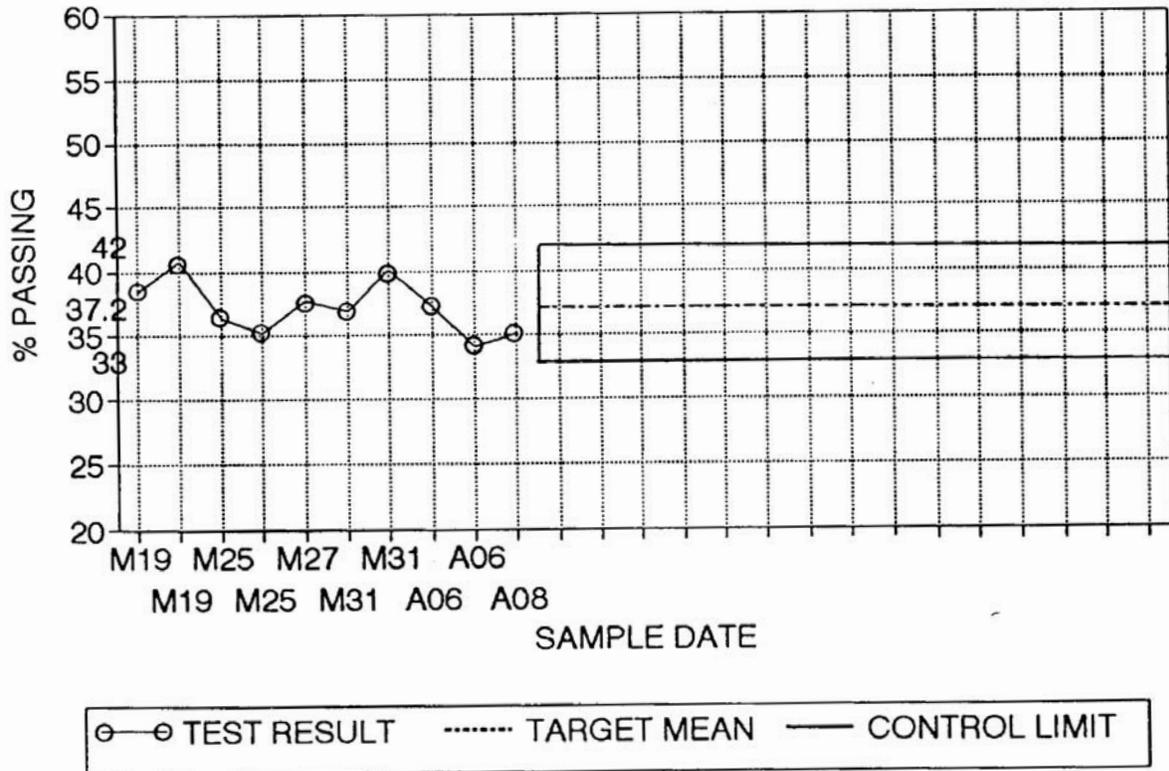


Figure 6-5. Control Chart Set-Up

PLOTTING THE DATA

Control charts indicate constant accuracy and precision if the process is in control and repeatable. The scattering of individual data points give a feel for precision or variability of the process when viewed against the control limits. In addition, a running average of the most current five data points is required to track the accuracy of the process. Averages tend to lessen the effect of erratic data points that could reflect errors not related to the actual material (sampling, testing, etc.) and that distract the viewer away from trends comparing to the target mean. Although this technique is not as accurate as data points that are each comprised of averages of subsets and which require an accompanying chart of ranges, the process works well for the mineral aggregate industry. When aggregates are tested at frequencies of 2000t per sample, the requirement to wait for the accumulation of five tests before generating a single data point is not acceptable. Table 6-3 and Figure 6-6 illustrate how data points and the running average for a product critical sieve are plotted on a control chart with a pre-established target mean and control limits.

ITM 211 requires that non-conforming normal production or load-out tests be followed immediately by a corrective action to include as a minimum an investigation for assignable cause, correction of known assignable cause, and retesting. These retests are not plotted on the control charts.

The check of the specification limits and establishment of the control limits for Table 6-3 are conducted as follows.

For the No. 4 critical sieve for the INDOT Standard Specifications No.11 material:

Data Set Results

$$n = 36 \quad \bar{x} = 14.8 \quad \sigma_{n-1} = 2.60$$

Specification Limit Check

$$1.65 \text{ times } \sigma_{n-1} = 1.65(2.60) = 4.3$$

$$\text{USL check} = 14.8 + 4.3 = \mathbf{19.1} \leq \mathbf{30} \quad \text{OK}$$

$$\text{LSL check} = 14.8 - 4.3 = \mathbf{10.5} \geq \mathbf{10} \quad \text{OK}$$

Z Value Check

$$Z_u = \frac{30 - 14.8}{2.60} = 5.85 > 1.65 \quad \text{OK}$$

$$Z_L = \frac{14.8 - 10}{2.60} = 1.85 > 1.65 \quad \text{OK}$$

Establish Control Limits

$$\text{UCL} = \bar{x} + 2 \sigma_{n-1} = 14.8 + 2(2.6) = \mathbf{20.0} \text{ or } \mathbf{20}$$

$$\text{LCL} = \bar{x} - 2 \sigma_{n-1} = 14.8 - 2(2.6) = \mathbf{9.6} \text{ or } \mathbf{10}$$

PLANT: INDIANA

MATERIAL SIZE: #11

SPEC. SIEVE	100 1/2 in.	75 - 95 3/8 in.	10 - 30 No. 4	5 PT AVG No. 4	0 - 10 No. 8
Jun 3	100.0	87.5	13.1		3.3
Jun 4	100.0	86.7	17.9		4.4
Jun 4	100.0	90.8	17.9		6.1
Jun 5	100.0	85.9	15.1		5.7
Jun 8	100.0	87.1	10.8	15.0	3.9
Jun 8	100.0	89.6	15.4	15.4	5.1
Jun 9	100.0	84.8	10.4	13.9	3.9
Jun 9	100.0	84.8	16.2	13.6	3.8
Jun 10	100.0	85.2	14.4	13.4	4.9
Jun 10	100.0	88.9	17.8	14.8	3.1
Jun 11	100.0	86.2	12.2	14.2	4.4
Jun 12	100.0	87.2	14.1	14.9	5.3
Jun 12	100.0	86.0	13.0	14.3	4.9
Jun 12	100.0	87.7	16.2	14.7	4.5
Jun 15	100.0	82.0	16.1	14.3	4.2
Jun 16	100.0	88.3	14.4	14.8	5.4
Jun 16	100.0	89.7	11.8	14.3	3.5
Jun 16	100.0	89.4	12.5	14.2	4.7
Jun 17	100.0	86.2	11.5	13.3	2.9
Jun 18	100.0	86.1	14.7	13.0	4.3
Jun 19	100.0	88.5	11.2	12.3	5.4
Jun 19	100.0	86.0	18.7	13.7	3.3
Jun 19	100.0	87.4	14.8	14.2	5.8
Jun 19	100.0	87.5	12.1	14.3	3.3
Jun 22	100.0	85.9	16.0	14.6	4.9
Jun 22	100.0	96.3	14.0	15.1	4.5
Jun 23	100.0	86.9	11.3	13.6	3.7
Jun 24	100.0	88.5	16.3	13.9	4.2
Jun 25	100.0	88.6	15.0	14.5	5.0
Jun 25	100.0	89.5	16.9	14.7	5.5
Jun 26	100.0	86.6	13.9	14.7	5.0
Jun 29	100.0	87.9	14.7	15.4	5.1
Jun 29	100.0	89.6	16.7	15.4	6.2
Jun 30	100.0	90.1	18.2	16.1	8.8
Jun 30	100.0	92.3	21.8	17.1	8.3
Jun 30	100.0	90.7	14.0	17.1	4.1
MEAN	100.0	87.8	14.8		4.8
STD. DEV.	0.000	2.50	2.57		1.27

Table 6-3: Gradation Analysis

GOOD PROCESS CONTROL

CONTROL CHART - SOURCE #1 INDOT #11 - No. 4 SIEVE

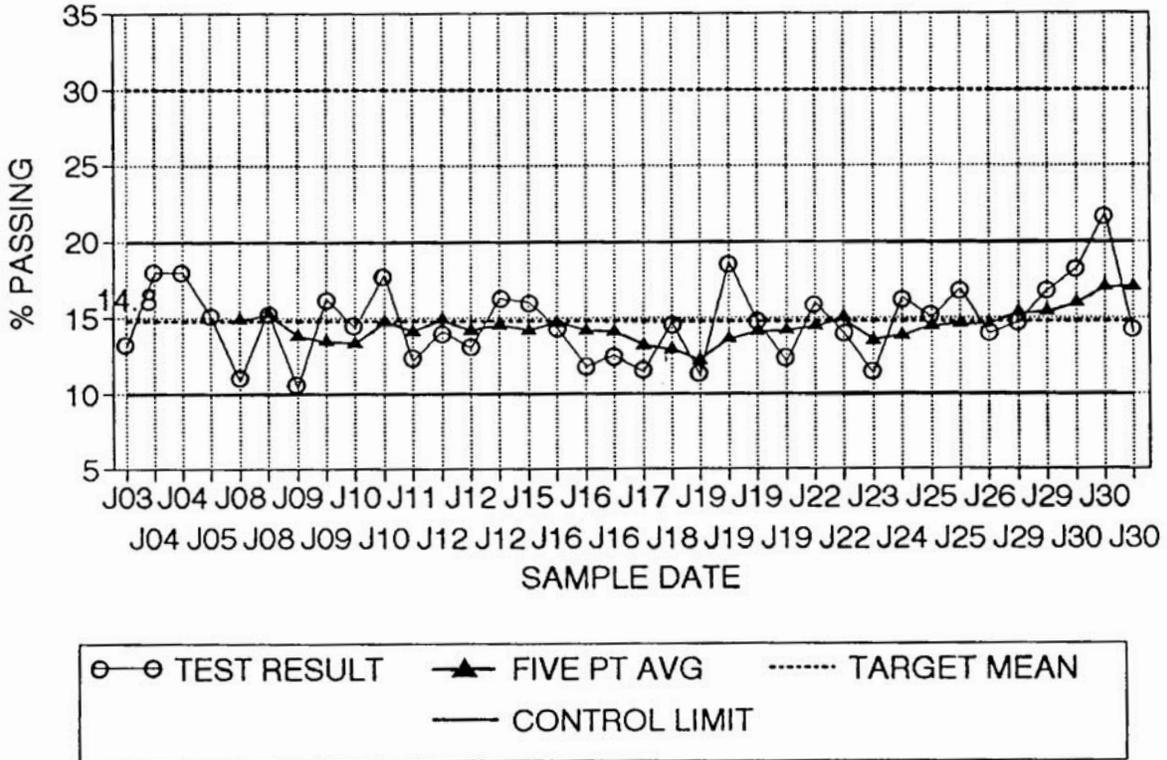


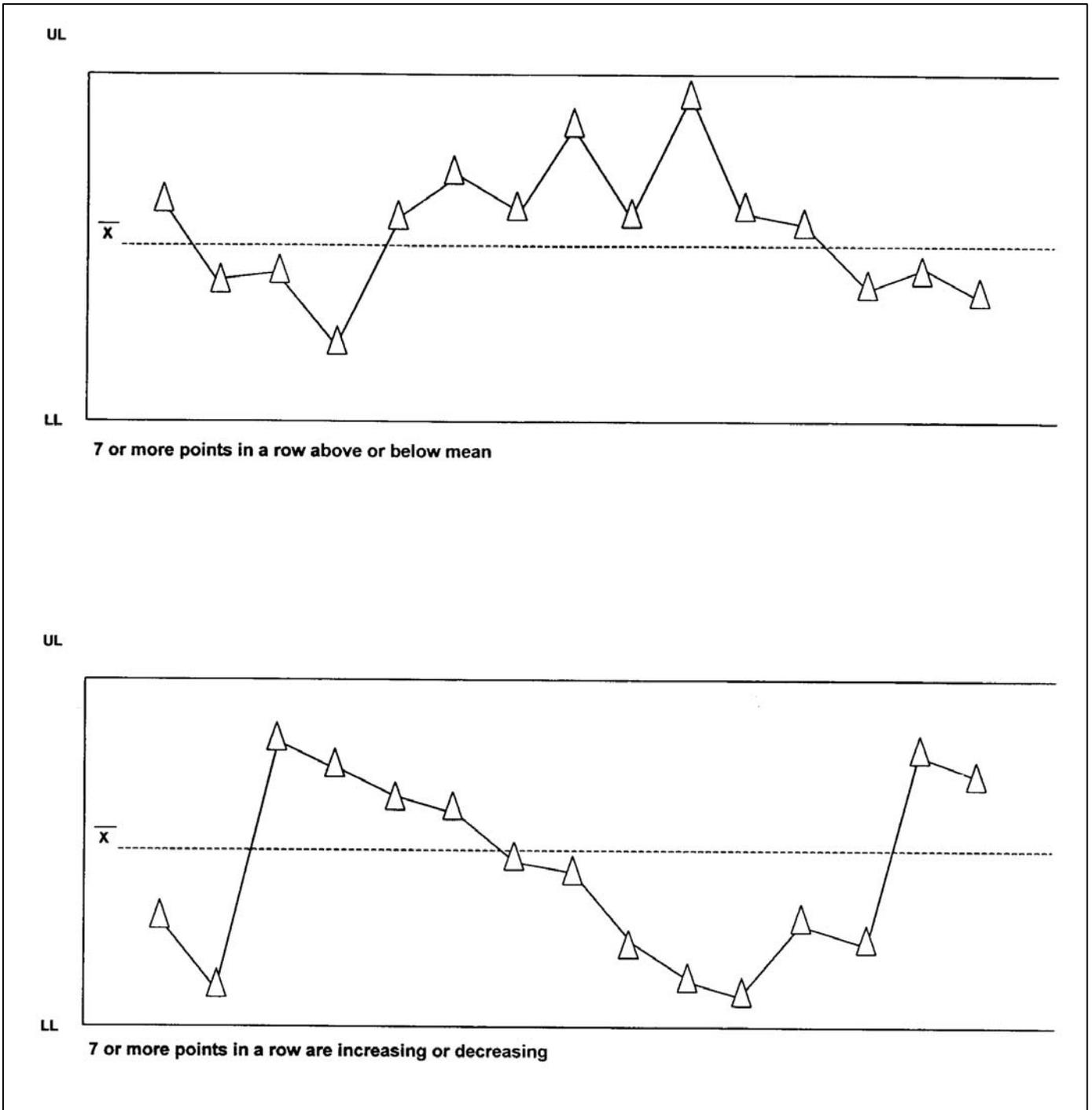
Figure 6-6. Good Process Control

INTERPRETING CONTROL CHARTS

Under the CAP Program, specific treatment of nonconforming tests is required. Action is required to be taken after the first nonconforming test (outside of control limits). These requirements are required to be met in all cases and take precedence over any other control technique. When individual test results, even on an intermittent basis, frequently fall outside the control limits or specification limits, a nonconforming condition exists. A capability calculation in conjunction with whichever limits are being violated may quickly verify the condition. The following trends involving the 5-point moving average points (Figure 6-7) may require investigation by the Producer and as a minimum an entry in the diary to denote the problem.

- 1) Seven or more points in a row are above or below the target mean (\bar{x})
- 2) Seven or more points in a row are consistently increasing or decreasing

Finally, the Technician is required to always be alert for a sudden jump in the data, whether the data remains in control or not. This condition usually represents the addition of a completely different process and may be detected immediately without waiting for trends in the moving average (Figure 6-8). Corrective action is required to be taken immediately. If the shift to a new process is done intentionally, then a clean break is required to be made in the control chart by means of a vertical line on the chart. After ten valid test results on the new process, a new target mean \bar{x} is required to be calculated and new control limits established (Figure 6-9).



7 or more points in a row above or below mean

7 or more points in a row are increasing or decreasing

Figure 6-7. Five-Point Moving Average Trends

NONCONFORMING PROCESS

CONTROL CHART - SOURCE #1 INDOT #8 - 1/2 in. SIEVE

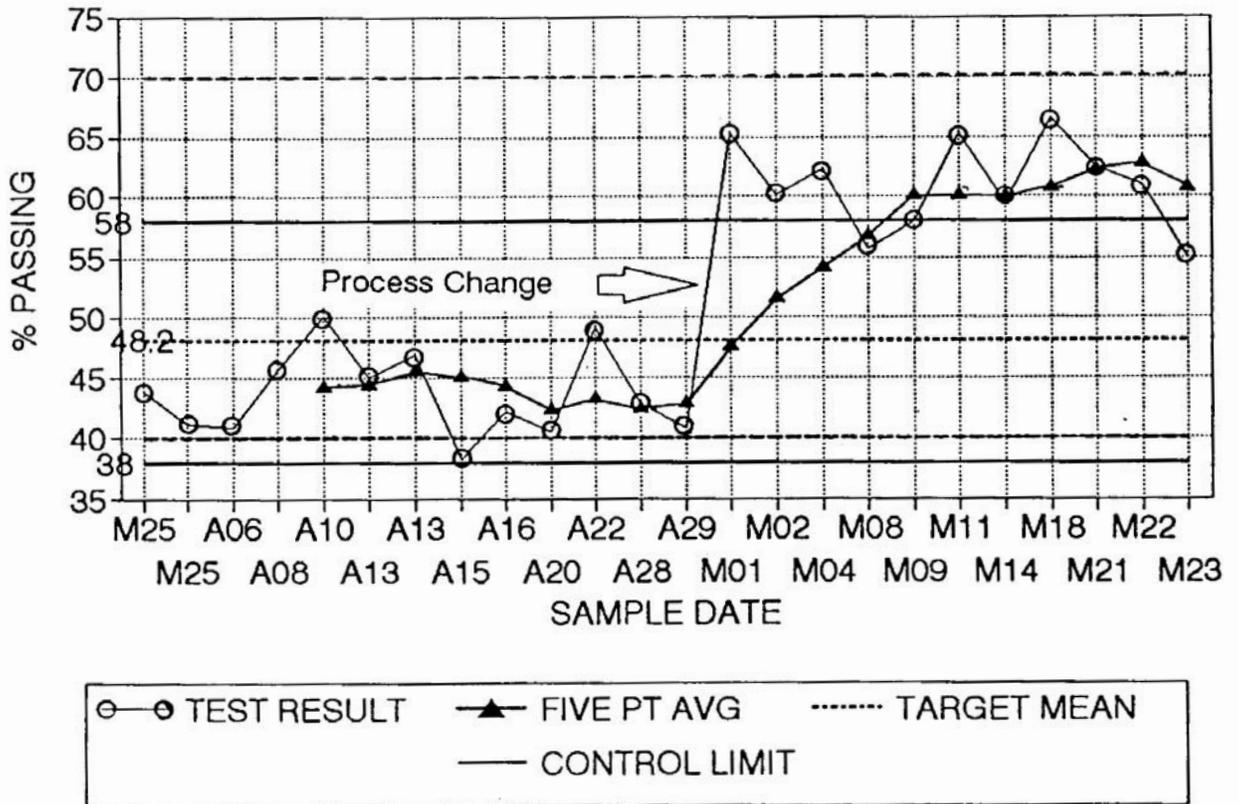


Figure 6-8. Nonconforming Process

PROCESS ADJUSTMENT

CONTROL CHART - SOURCE #1 INDOT #8 - 1/2 in. SIEVE

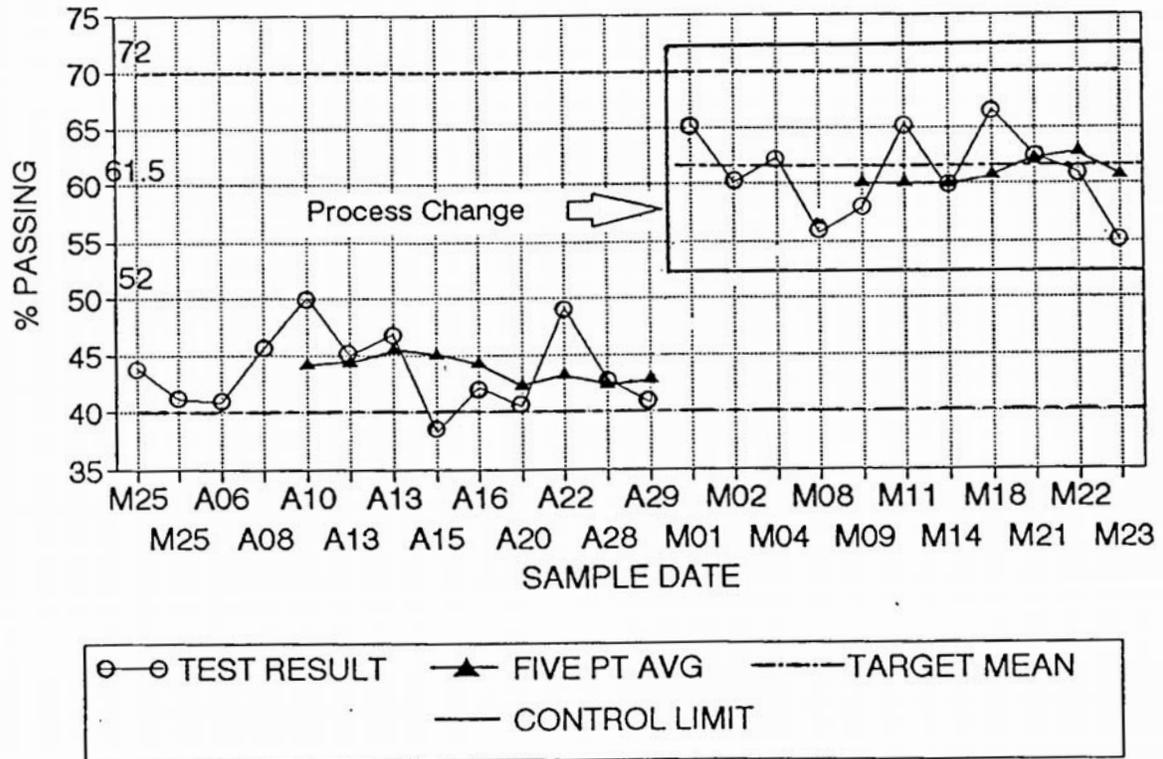


Figure 6-9. Process Adjustment

UNDERSTANDING THE PROCESS

Attempting to control an unstable process is like trying to answer an unsolvable riddle. Nothing is predictable; hence, nothing may be assumed. The Technician is required to follow a logical path to understand how, when, and what controls are necessary. The following path is a series of measurements, observations, communications, and decision-making.

CURRENT PROCESS

The current process is required to be thoroughly understood before making wise decisions on how to make improvements:

- 1) Gather honest employee input so that management knows what they know
- 2) Conduct and document visual observations of which elements seem to cause the greatest variability. Excavating or blasting, crushing, screening, total process stockpiling, and hauling, handling, and loading are all items that may affect quality.
- 3) Learn how and make accurate measurements at uniform intervals over time. Apply statistical principles to determine current stability and capability of the process.

PROCESS STABILITY

The process is required to first be stabilized before any other improvements may be made using the following procedures:

- 1) Identify the variables that most affect the process, called the Key Process Variables. These variables require the greatest attention from the operations managers (Figure 6-10).
- 2) Establish standards. The first reduction in variability may be recognized through "Standard Operating Procedures" (S.O.P.'s). These procedures include job descriptions, measurements (type and frequency), protocol for extreme conditions, etc.
- 3) Determine special causes. An absolute requirement for a stable process is the elimination of special causes of variability, namely, the ones that are external and not a part of the natural process. (e.g. conditions created by personnel)

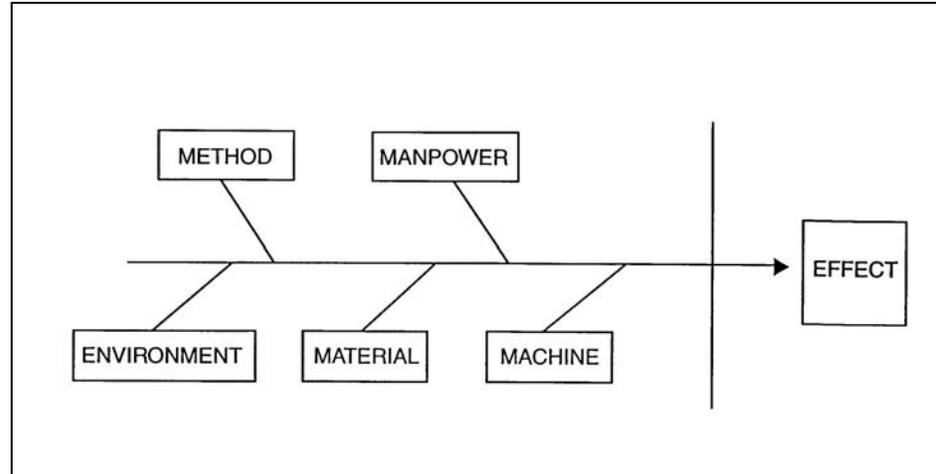


Figure 6-10. Key Process Variables

DECISION MAKING

After operating for some time with a stable process, some important decisions may be made. There are two items that are required to occur first:

- 1) Communicate with customers so they understand the new stable products. Also, obtain input from the customers on the need for further adjustment.
- 2) Make concurrent measurements to assess the need for further improvement

PROCESS CAPABILITY

Decisions previously made are required to include any techniques needed to bring the process into desired compliance with a high degree of confidence such as:

- 1) Establish final desired product targets and limits
- 2) Reduce common causes of variability as required. This generally means a change in the process.

PROCESS CONTROL

Implement ongoing statistical process control along with continuous improvement.

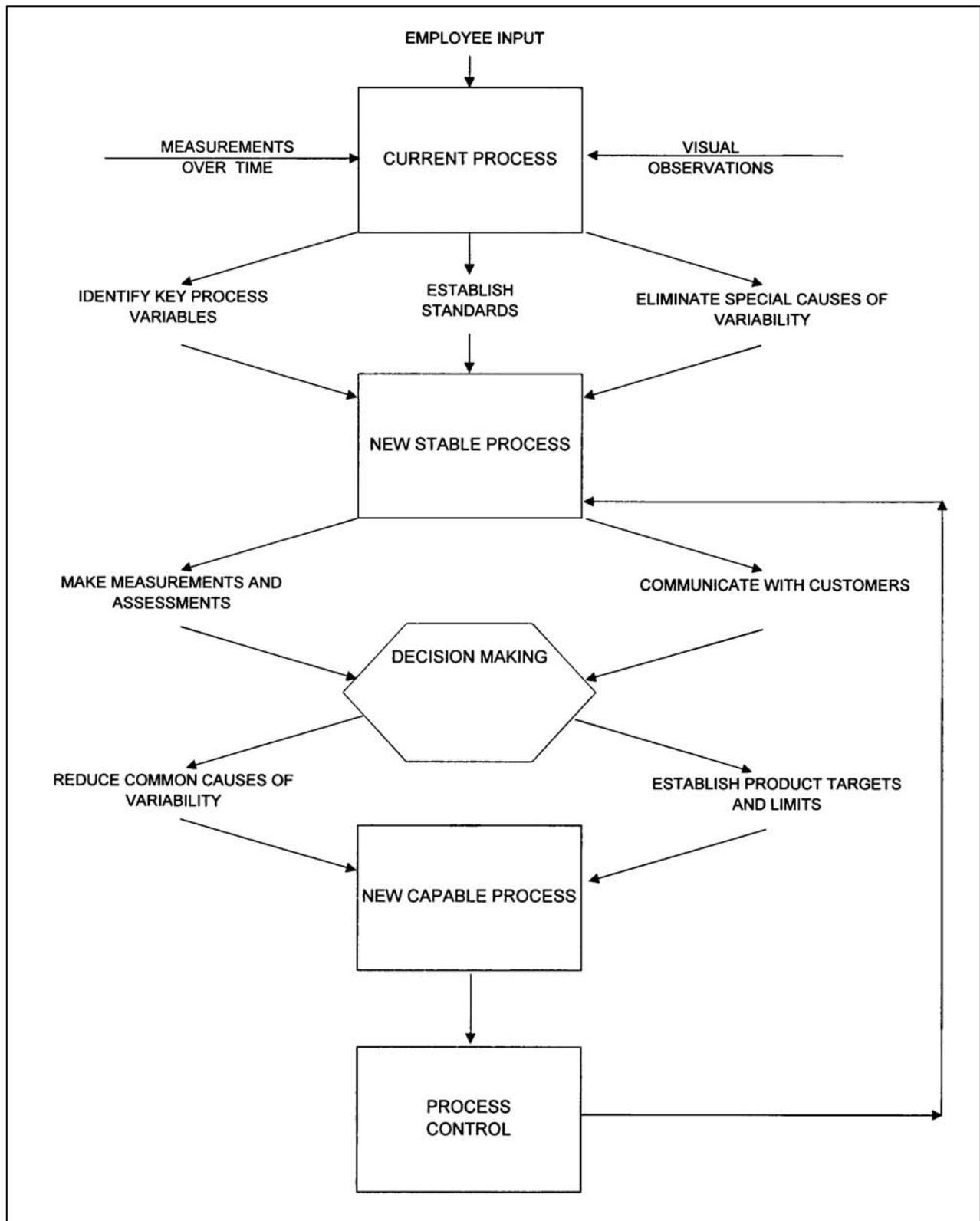


Figure 6-11. Steps for Managing Quality