# *Module 5: Environmental Monitoring*

5.2 Detection of Changes

## *Detection of Changes*

- Once the monitoring network is in place the data can be analyzed for:
  - long term means
  - long term variances
  - short term means over set periods of time (8 hour or 24 hour for example)
  - distribution shape

## *Detection of Changes*

- Once the data has been collected for a reasonable period of time, the data can also be analyzed for trends and for abrupt changes in the mean
- There are a number of different techniques to do this:
  - Expected trends suggest regression analysis
  - Expected changes in mean suggest paired t tests, two-sample t tests, or ANOVA



## *Detection of Changes*

- A need to detect a change or a trend quickly suggest Control and/or CUSUM charts
- A need to detect a change in distribution shape or location suggests Chi-Squared Tests or more sophisticated tests for distribution type



## *Detection of Changes*

- ANOVA
  - Use when you are looking for a difference in means
  - Advantages:
    - Well known technique
  - Disadvantages:
    - You must know or estimate at what time the change occurred. That works if some known event happened but usually that's not the case.



## *Detection of Changes*

- Regression Analysis
  - Use when you are looking for trends in time
  - Advantages:
    - Well known technique
  - Disadvantages:
    - You have to have quite a bit of data to detect a trend and often we have a need to detect these trends very quickly as they begin



# *Detection of Changes*

- Control Charts
  - Use when you have data in time and a need to detect a trend or change quickly (in real time)
  - Advantages:
    - Simple technique
  - Disadvantages:
    - You have to have a baseline of data to start with
    - Not widely used in environmental applications



# *Detection of Changes*

- Control Charts
  - Changes in the mean are detected in the sample mean chart
  - Changes in variability are detected using a range, variance or standard deviation chart
  - The idea is that you use the baseline data to lay out the charts and then you plot new sample statistics on the charts and look for excursions beyond the bounds
  - Excursions indicate possible shifts or trends



## *Control Chart Example*

- Procedure laid out in Manly (there are other ways to construct these charts but for simplicity we'll look at this way)
  - A baseline set of data of M samples each of size n is taken over a year.
  - For each sample, calculate the sample mean and sample range
  - The overall mean is the mean of the sample means (if they are all of size n) or just the mean of all of the data



## *Control Chart Example*

- Notation:

| | |
|---|---|
| $\overline{X}_i$ | the sample mean of the $i^{th}$ sample |
| $R_i$ | the sample range of the $i^{th}$ sample |
| $\hat{\mu}$ | the overall estimate of the mean of the means |
| $\overline{R}$ | the overall estimate of the mean of the ranges |
| $\hat{\sigma} = k(n)\overline{R}$ | the overall estimate of the standard deviation. k(n) is k as a function of n, NOT k*n. Use Table 5.5 in Manly (page 134). |



## *Control Chart Example*

- Mean control chart warning limits are set at

$$\hat{\mu} \pm 1.96\left(\frac{\hat{\sigma}}{\sqrt{n}}\right)$$

- Mean control chart action limits are set at

$$\hat{\mu} \pm 3.09\left(\frac{\hat{\sigma}}{\sqrt{n}}\right)$$



## *Control Chart Example*

Range control chart warning and action limits are set by multiplying $\overline{R}$ times the multipliers from Table 5.5 in Manly (page 134).

## *Control Chart Example*

- When the warning limits are violated, it's an indication of a *possible* shift or trend. Since this will occur 5% of the time when a real change has not occurred, the only action generally taken is increased attention. Sometimes sampling frequency is increased.
- When the action limits are violated, search for a cause or take other appropriate action. This will occur only 0.2% of the time if a real change has not happened.



## *Control Chart Example*

-

| Time | Sample Data (n=3) | | | Means | Ranges |
|---|---|---|---|---|---|
| 1 | 108.5 | 103.6 | 111.2 | 107.77 | 7.6 |
| 2 | 116.4 | 116.0 | 118.7 | 117.03 | 2.7 |
| 3 | 99.1 | 108.8 | 115.5 | 107.80 | 16.4 |
| 4 | 104.6 | 106.5 | 101.5 | 104.20 | 5.0 |
| 5 | 100.8 | 105.1 | 106.1 | 104.00 | 5.3 |
| 6 | 99.4 | 107.2 | 108.0 | 104.87 | 8.6 |
| 7 | 110.7 | 108.2 | 108.4 | 109.10 | 2.5 |
| 8 | 108.1 | 116.7 | 109.6 | 111.47 | 8.6 |
| 9 | 109.1 | 107.4 | 119.9 | 112.13 | 12.5 |
| 10 | 114.3 | 121.9 | 106.7 | 114.30 | 15.2 |

## *Sample Mean Control Chart Example*

| | | | | |
|---|---|---|---|---|
| Overall Mean = | | 109.27 | | |
| Mean Range = | | | 8.44 | |
| Stan. Dev. = | | 0.591*8.44 = | 4.99 | |
| Lower Warning Limit = | | 109.27-1.96*(4.99/sqrt(3)) = | | 103.62 |
| Upper Warning Limit = | | 109.27+1.96*(4.99/sqrt(3)) = | | 114.91 |
| Lower Action Limit = | | 109.27-3.09*(4.99/sqrt(3)) = | | 100.37 |
| Upper Action Limit = | | 109.27+3.09*(4.99/sqrt(3)) = | | 118.17 |
| | | | | |

To find the Stan. Dev. use Manly Table 5.5 for SD Factor (k) with n=3. NOTE, n=3 NOT M=10.



## *Sample Range Control Chart Example*

| | | | |
|---|---|---|---|
| R bar = Mean of Ranges = | | 8.44 | |
| Lower Warning Limit = | 0.18 * 8.44 = | | 1.52 |
| Upper Warning Limit = | 2.17 * 8.44 = | | 18.31 |
| Lower Action Limit = | 0.04 * 8.44 = | | 0.34 |
| Upper Action Limit = | 2.99 * 8.44 = | | 25.24 |

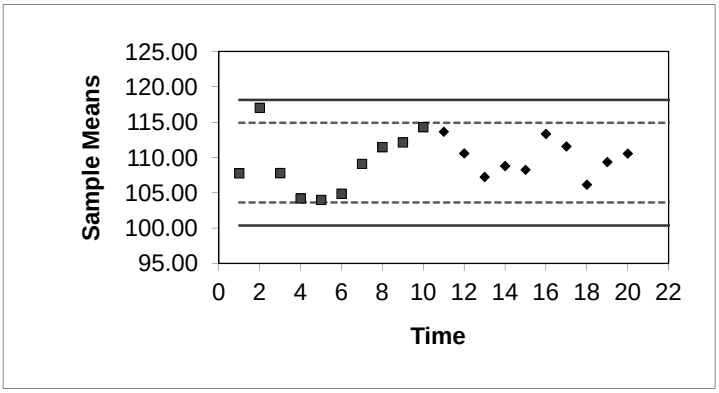
To find the multipliers for the warning and action limits, use Manly Table 5.5 with n=3.

## Control Chart Example – New Data

| Time | Sample Data | | | Means | Ranges |
|---|---|---|---|---|---|
| 11 | 110.7 | 108.2 | 122.1 | 113.67 | 13.9 |
| 12 | 105.9 | 115.8 | 110.0 | 110.57 | 9.9 |
| 13 | 110.0 | 103.8 | 108.0 | 107.27 | 6.2 |
| 14 | 108.6 | 111.8 | 105.9 | 108.77 | 5.9 |
| 15 | 110.1 | 107.3 | 107.3 | 108.23 | 2.8 |
| 16 | 108.8 | 112.1 | 119.2 | 113.37 | 10.4 |
| 17 | 115.7 | 118.7 | 100.3 | 111.57 | 18.4 |
| 18 | 104.5 | 109.7 | 104.2 | 106.13 | 5.5 |
| 19 | 111.2 | 104.3 | 112.5 | 109.33 | 8.2 |

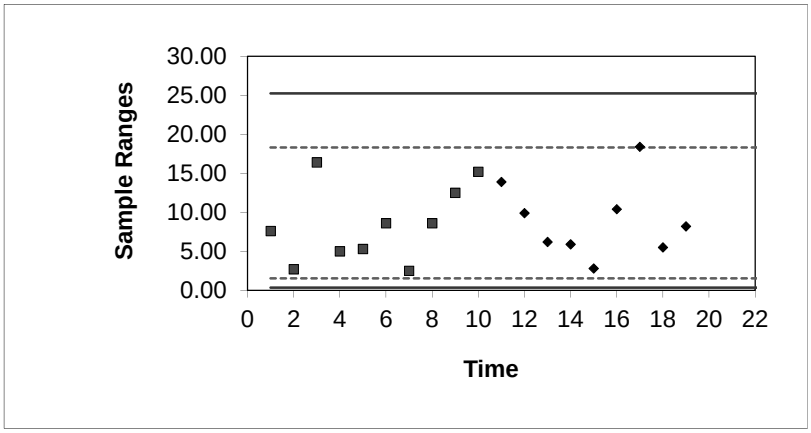


## Control Chart Example – Sample Means




Warning limits are shown as dotted blue lines and action limits as solid red lines.

## *Control Chart Example – Sample Ranges*






## *Detection of Changes*

- CUSUM Charts
  - Use when it is very important to detect small changes in the mean quickly.
  - Advantages
    - Very sensitive to trends or changes
  - Disadvantages
    - Not a particularly simple technique to construct or for managers to understand
    - Not widely known or used in environmental applications

# *Detection of Changes*

- Chi-Squared Tests
  - Use when you have a need for a screening test for changes in the mean or in distribution shape
  - Advantages
    - Easy to use
    - Doesn't require assumptions on data distribution type (normal for example)
  - Disadvantages
    - Not widely used in environmental applications