Section VI

Control

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Agenda

- ✓Pre-Control Considerations
- ✓Variables and Attributes Control Charts
- ✓Measurement System Analysis, Control Plan, and Project Closure
- ✓Introduction to Total Productive Maintenance

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Section VI, Lesson 1

Pre-Control Considerations

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Agenda

- ✓ Pre-Control Considerations
- ✓ Assessing the Results of Process Improvement
- ✓ Rational Subgrouping

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Pre-Control Considerations

- ✓A Six Sigma DMAIC project should move into the Control stage once the improvements have been validated in the Improve phase.
- ✓The process must exhibit a state of statistical control by the Improve phase.
- ✓Statistical validations of solutions must result in an increase in process capability or the performance of any other business measures.
- ✓All possible risks are understood and if there are any potential risks that could harm the process, preventive measures should be in place.
- ✓Post the toll-gate meeting, once the Black Belt and Champion agree to the improvement measures, the project can move into the Control stage.

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Assessing the Results of Process Improvement

✓It is important to understand the changes due to improvements compared to the inherent variation in the system. The results are assessed as follows:

- Compare the improvement measure data with the baseline data.
- Use appropriate formulas to compare 'before and after' performance.
- Compare moving average, median, spread, defect %, efficiency, waste, etc.
- Monitor the data for considerable number of days to ensure the improvements are sustainable over a period of time.

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Rational Subgrouping

- ✓**Rational Subgrouping** is the name given to the technique in which data is organized into subgroups for process control charts.
- ✓Usually, the subgroups should be chosen so that within a subgroup, variation is minimized.
- ✓The selection of rational subgroups should be consistent with the structure of the data from the process.
- ✓The selection of rational subgroups should allow the quick identification of potential corrective actions, once an out-of-control condition is identified.

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Summary

In this lesson we have learned:

- ✓ Pre-control considerations
- ✓ Assessing the results of process improvement
- ✓ Rational subgrouping

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Section VI, Lesson 2

Variables and Attributes Control Charts

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Agenda

- ✓Concepts of Variables Control Charts
- ✓Variables Control Charts
- ✓EWMA Charts
- ✓Cusum Charts
- ✓Attribute Control Charts

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Concepts of Variables Control Charts

Concepts:

- ✓Variables control charts to be used with variables data (input variable and output variable).
- ✓Xbar – R, also known as Mean – Range chart, to be plotted if subgroup sample size decided is between 2 and 9.
- ✓Xbar – S, also known as Mean – Sigma chart to be plotted if subgroup sample size decided is > 10.
- ✓I – MR chart, to be plotted if subgroup sample size is 1.
- ✓To plot I – MR chart, data must follow a normal distribution.
- ✓Xbar – R and Xbar – S charts are not dependent on normal data and control limits.
- ✓Basis of control charts are rational subgroups.
- ✓Rational subgroups mean subgroup of items produced under same conditions.

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Concepts of variables control charts

✓Control limits are calculated so that probability of having an average or range falling outside control limits is **rare.**

✓Control limits of all the variables charts are robust to **non-normality**.

✓Moderate departures from normality is accepted for drawing the range and Sigma control charts.

Control limits for range charts

✓Lower Control Limit (LCL) = $D_3 * R_{bar}$

✓Upper Control Limit (UCL) = $D_4 * R_{bar}$

✓Sigma = R_{bar}/D_4, where R_{bar} is the average of all the ranges, and D_3 and D_4 are chosen on the basis of the subgroup sample size.

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Concepts of Variables Control Charts (Contd.)

✓ **Control limits for average charts (using R_{bar})**

- LCL = X_{dbar} – ($A2$ * R_{bar})
- UCL = X_{dbar} + ($A2$ * R_{bar})

✓ Technically though, control limits are considered spaced at 3σ from the center line, considering that the probability of finding special causes of variation is 0.27%.

✓ Knowing the control chart constant formulas may not have a lot of practical significance, as specially designed computer packages do this calculation automatically.

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Concepts of Variables Control Charts (Contd.)

Example: For a given R_{bar} of 3, a subgroup sample size of 5, and average of averages as 10, calculate control limits for the averages and ranges chart.

Solution:

For range chart:

LCL = D3 * R_{bar} = 0 * 3 = 0

UCL = D4 * R_{bar} = 2.114 * 3 = 6.342

Thus, control limits for range chart are 0 and 6.342.

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Control limits for averages chart

LCL = X_{dbar} – (A2 * R_{bar})

UCL = X_{dbar} + (A2 * R_{bar})

From the control charts constants table,

A2 = 0.577

LCL = 10 - (0.577*3) = 8.26

UCL = 10 + (0.577*3) = 11.73

Thus, control limits for averages chart is 8.26 and 11.73.

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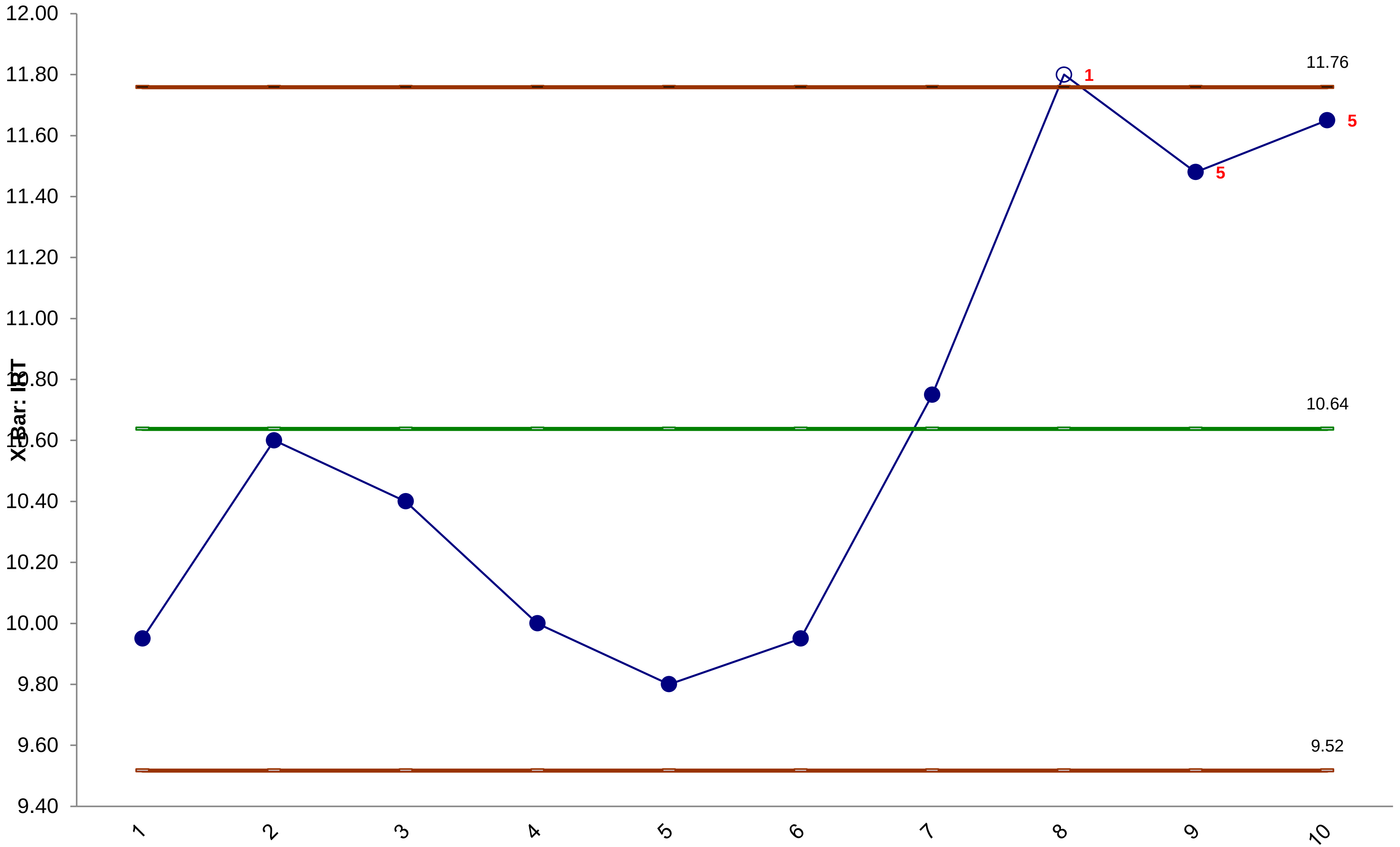
Variables Control Charts



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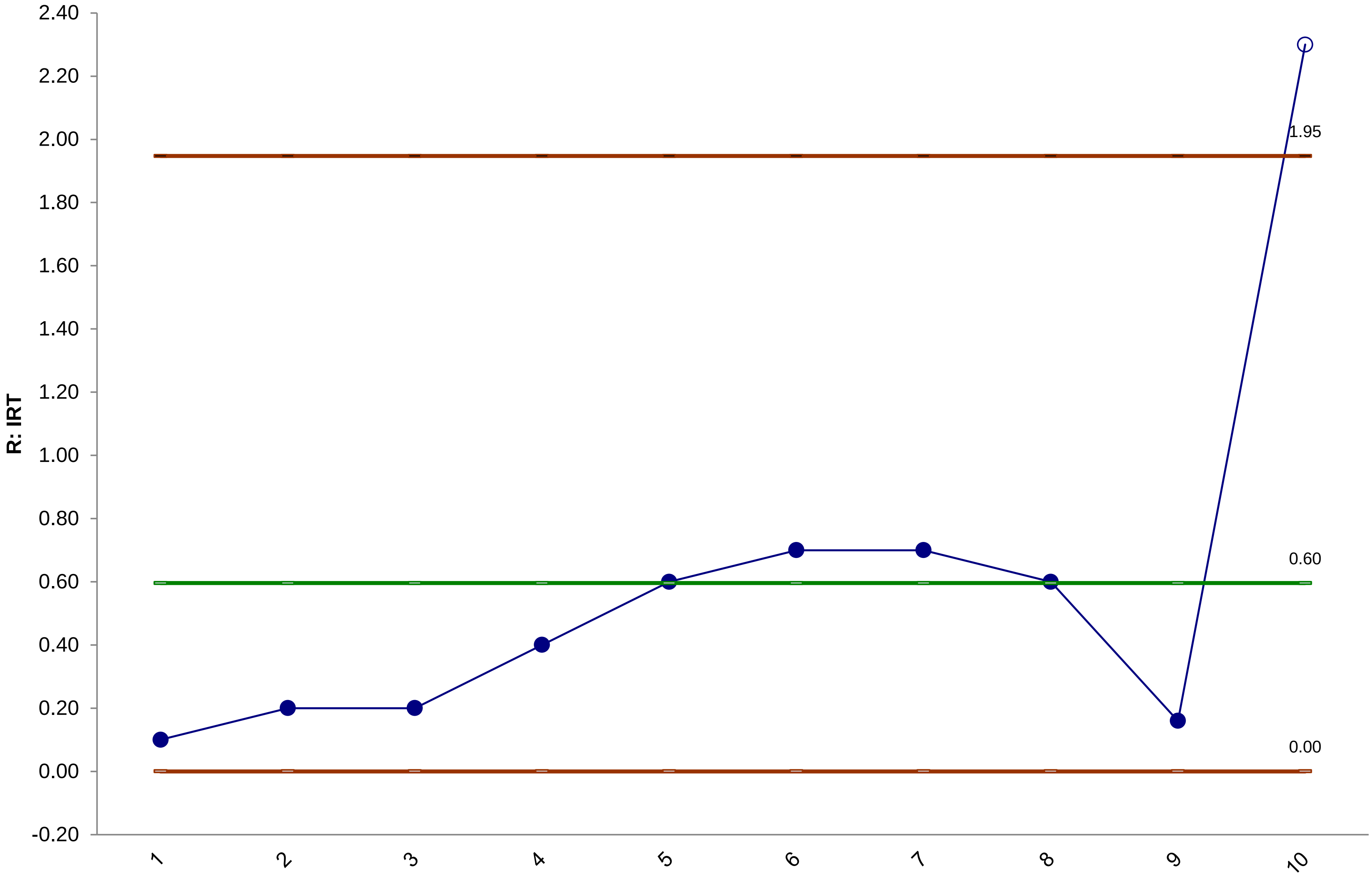
Variables Control Charts (Contd.)



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Interpretations

Interpreting both the charts, the average and the range chart, it is found that the process is still not in statistical control. Over a short run, the variations may be in control, but predicting long-term variations with such a process may not be easy.

In the control phase and in days to come, adequate efforts need to be taken to fix the defaulting points.

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Variables Control Charts (Contd.)

Control limits for Sigma chart

- ✓Use sample standard deviation formula to compute Sigma value of subgroups
- ✓s_{bar} = Sum of subgroup sigma/Number of subgroups
- ✓$LCL = B_3 * s_{bar}$
- ✓$UCL = B_4 * s_{bar}$

Control limits for averages chart

- ✓Xdbar = Sum of subgroup averages/Number of subgroups
- ✓$LCL = X_{dbar} - (A3 * R_{bar})$
- ✓$UCL = X_{dbar} + (A3 * R_{bar})$

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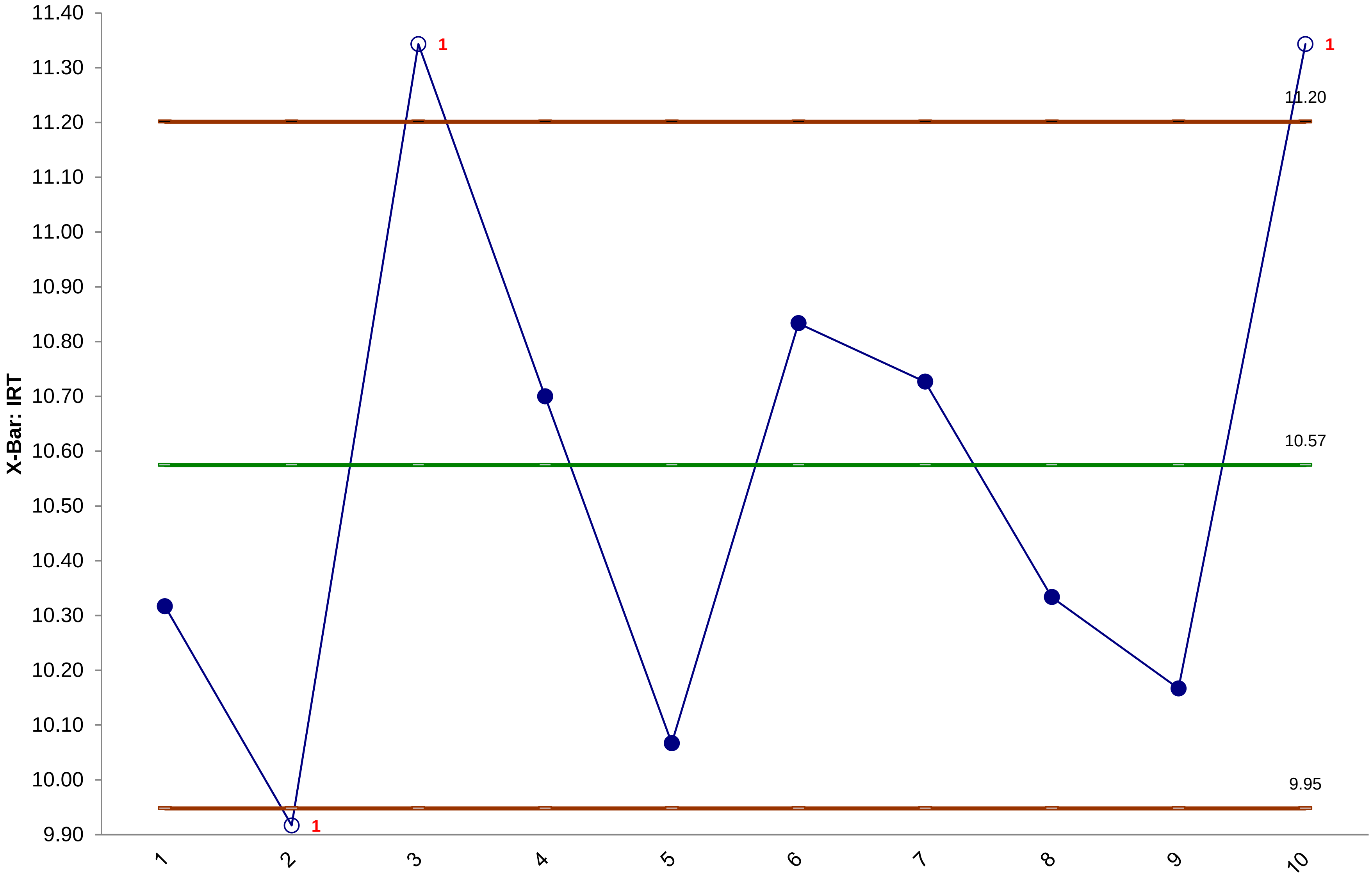
Variables Control Charts (Contd.)



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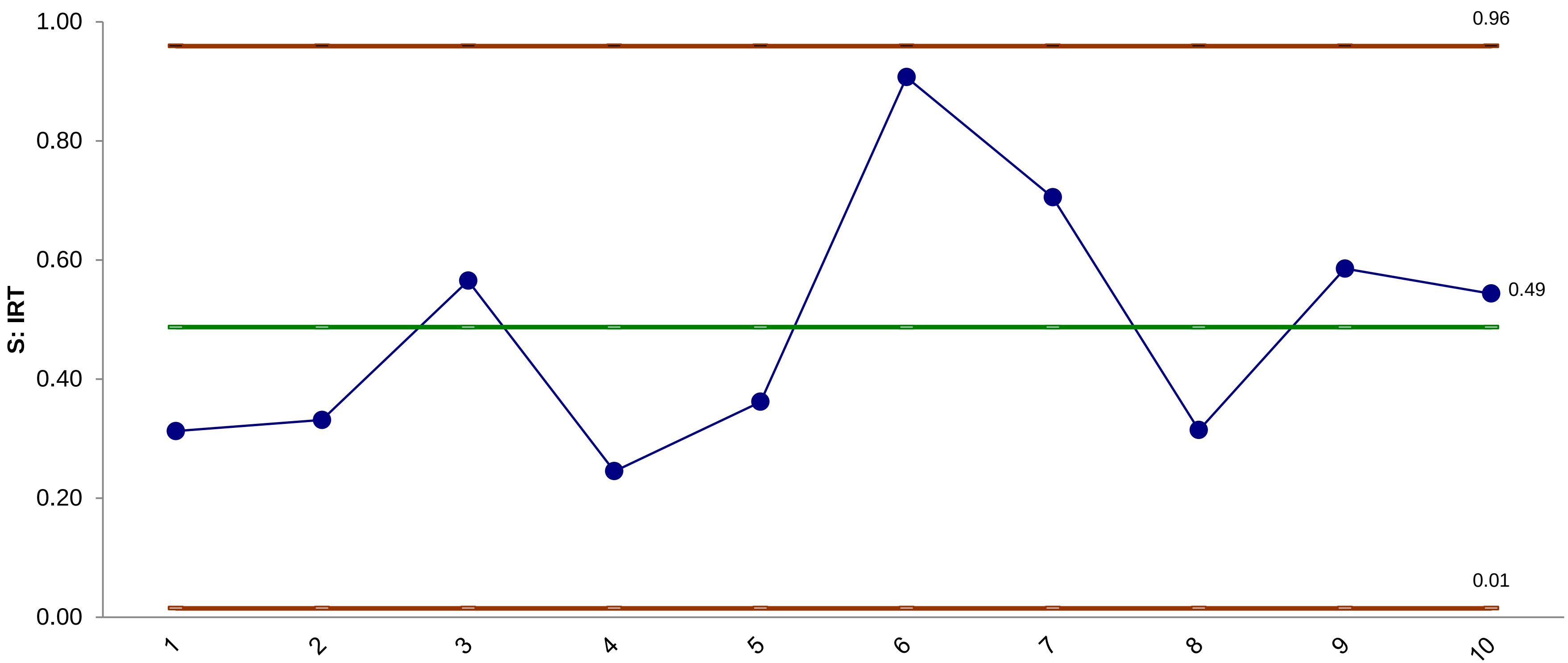
Variables Control Charts (Contd.)

Sigma chart



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Variables Control Charts (Contd.)

Interpretations

- ✓ Interpreting both the Average and the Sigma chart, it is found that the process is still not in statistical control. Over a short run, the variations may be in control, but predicting long-term variations with such a process may not be easy.

- ✓ In the control phase and in days to come, adequate efforts need to be taken to fix the defaulting points.

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Variables Control Charts (Contd.)

Individuals moving range charts are preferred over subgroup charts like Xbar – R and Xbar – S because:

- ✓Observations may at times be expensive to get;
- ✓Output of a process may be homogeneous over a short period of time, for example pH of a solution;
- ✓Production rate may be slow; and
- ✓Interval between successive observations is long.

In a batch-process in a typical chemicals manufacturing process, within group variability is too small compared to between groups variability. In such a scenario, using sub-group charts is not a logical option.

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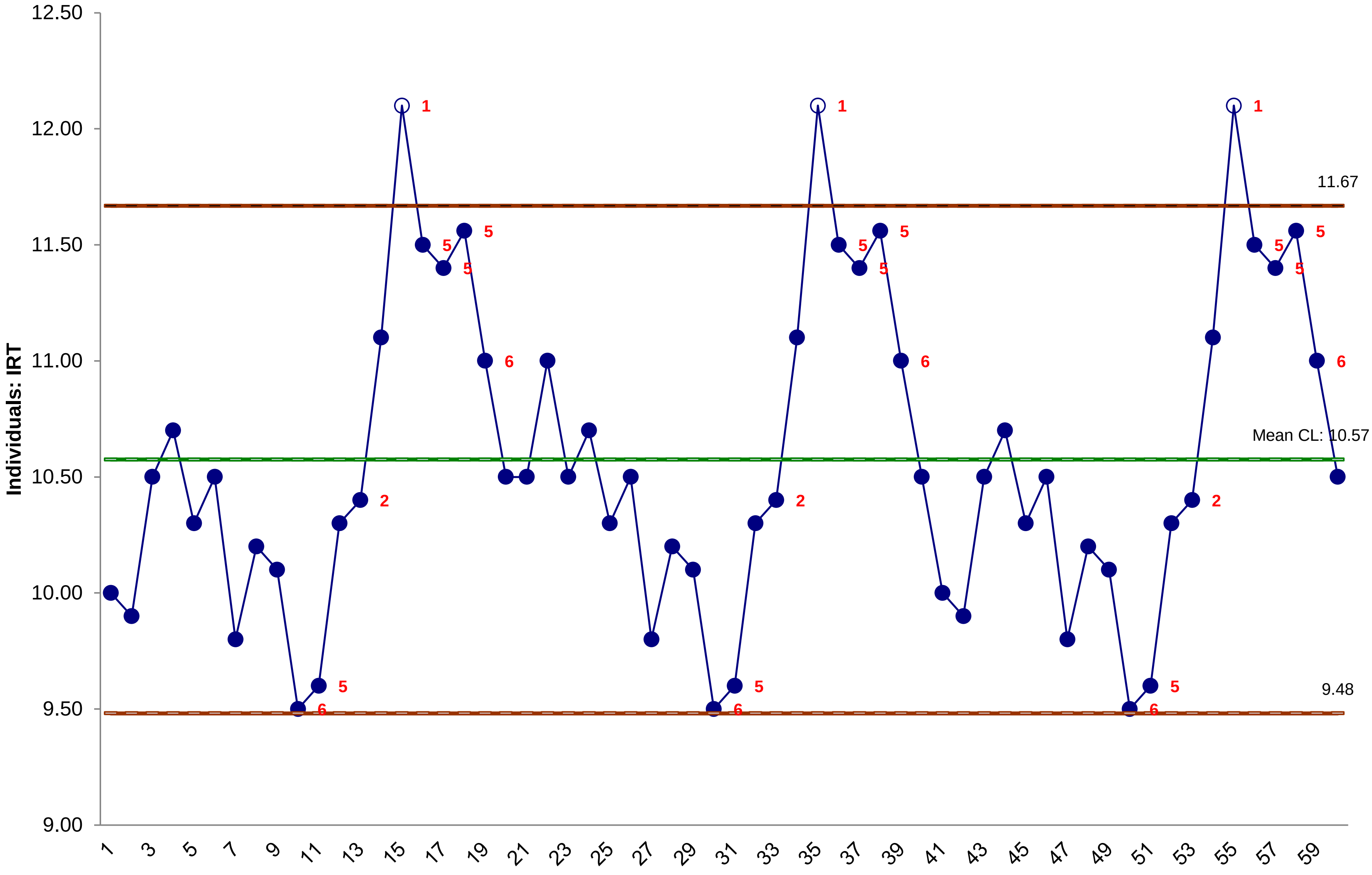
Variables Control Charts (Contd.)



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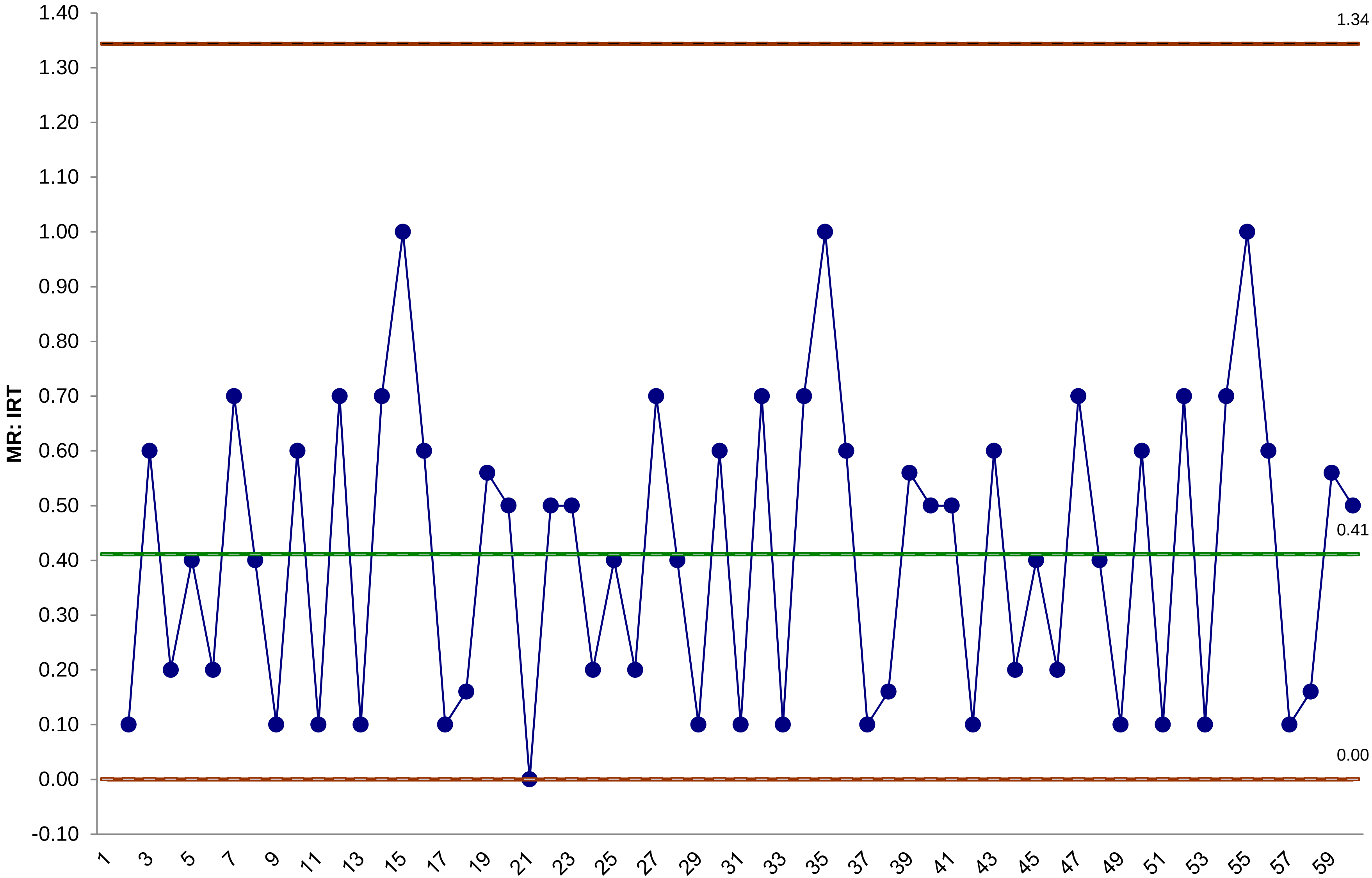
Variables Control Charts (Contd.)



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Variables Control Charts (Contd.)

Individuals and moving range chart interpretations

1. The moving range chart is in control.
2. The individuals chart is out of control, showing evidence of possible special causes of variation.
3. There are too many points out of control at a regular interval. Special causes don't occur frequently in a pattern, these have to be investigated further.
4. Basic assumption behind doing an I – MR chart is data should be normal.

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Variables Control Charts (Contd.)

Control chart patterns

1. Control charts provide an operational definition for special causes.
2. Generally, these special causes are defined as any points that cause an observation to go out of the control limits.
3. In addition to looking for points going out of control limits, the Black Belt must investigate drifts, freak patterns, and cycles.
4. These patterns indicate presence of non-special causes.
5. Computer packages will help the Black Belt in detecting such points.

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Variables Control Charts (Contd.)

Freak patterns

- ✓Freak patterns happen once in a while and are generally due to special causes.
- ✓Freak patterns show up as infrequent occurrences on the control charts, i.e., points moving out of the control limits.

Drifts

- ✓Drifts happen when current state of process is determined partly by its past state. For example, wear and tear of the tool. This would not come instantly.
- ✓When reasons for drifts are identified, actions should be taken to eliminate them.

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Cycles

- ✓Often identified as oscillatory patterns in a control chart.
- ✓Cycles occur due to the nature of the process.
- ✓Most of the times, they occur due to periodic changes in the process, or the inputs.
- ✓On identification of cycles, adjustment can be done by changing the periods, in order to smoothen out the graph.

Additional problems

- ✓When plotting a data set, one can expect to find different values.
- ✓Having repetitive values in the data set could be because of inadequate gage resolution.

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Variables Control Charts (Contd.)

Actions on control charts

1. Once control charts are plotted, differentiation should be done between caused (special cause) and un-caused variation (common cause).
2. If special causes are found, cause and effect diagram must be correlated with the control charts to find out what caused the observation to go out of control.
3. Remedial actions must be taken then to eliminate this special cause of variation, if undesirable.
4. Common causes or un-caused variation should be reduced as much as possible, evidence of which can be found from the CE diagram.
5. The main goal here is statistical association and not causal correlation.

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EWMA Charts

- ✓Stands for exponentially weighted moving average charts.
- ✓Plots moving averages of data and assign exponentially decreasing weights.
- ✓Helpful in detecting small process shifts as opposed to conventional variables charts that help in detecting large shifts due to special causes of variations.
- ✓The control limits (UCL and LCL) of an EWMA chart are not mandatory.
- ✓When fixed, the control limits vary exponentially in an EWMA chart.
- ✓On EWMA charts, any points out of control limit do not mean that it has special cause of variation.
- ✓These chart templates generated with QI Macros are found in process shifts charts in control toolkit.

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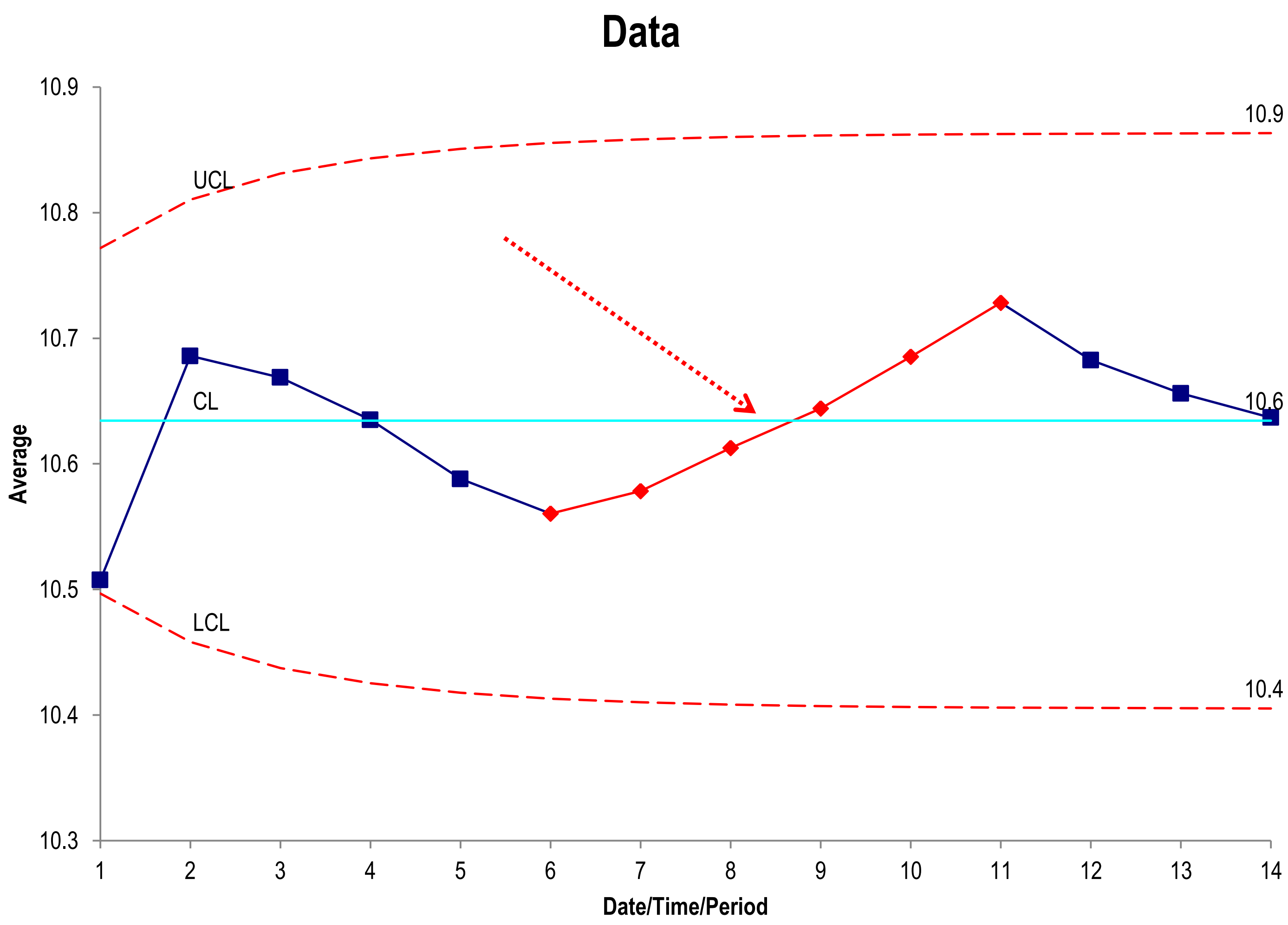
EWMA Charts (Contd.)



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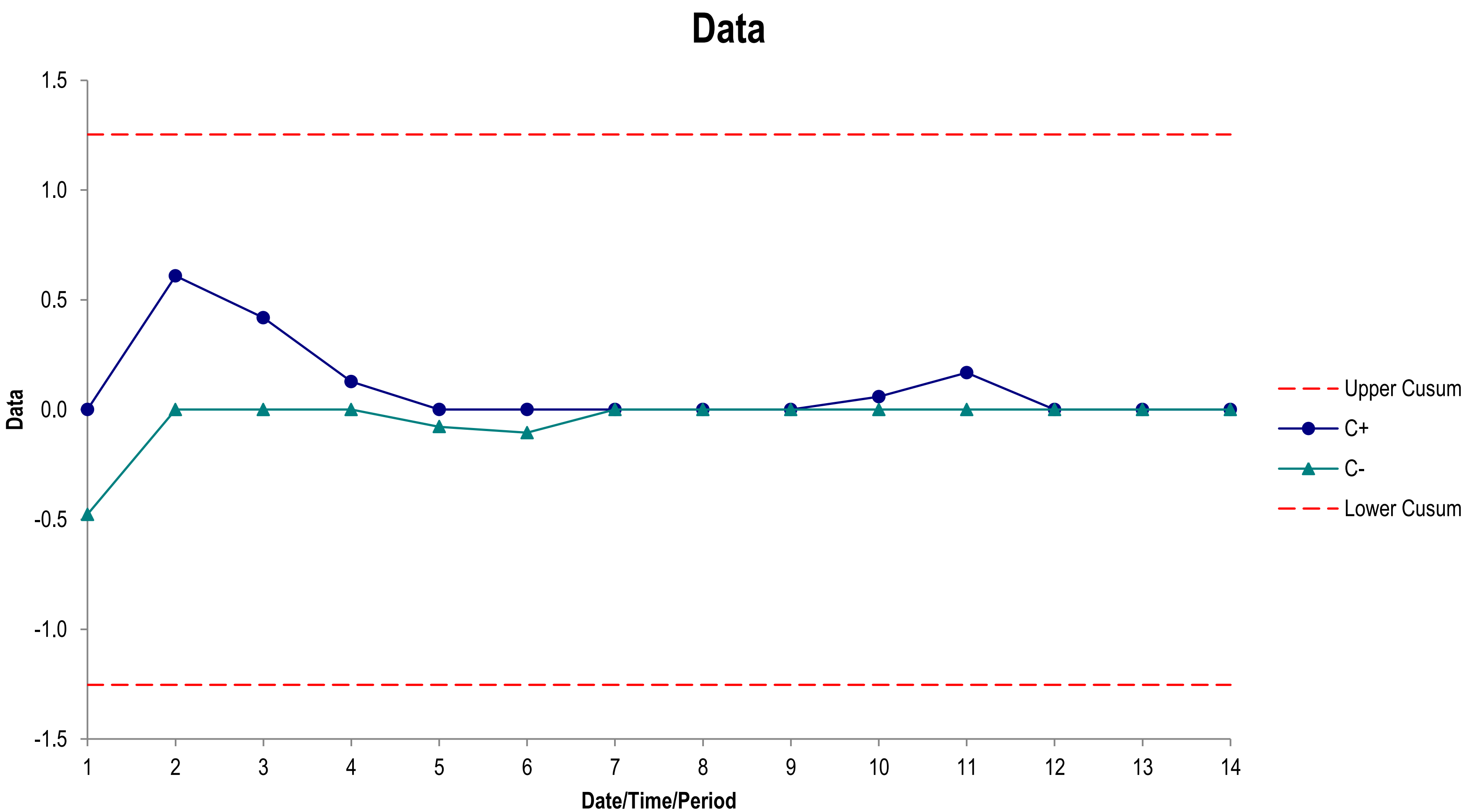
Cusum Charts

✓Cusum charts are another type of charts that detect small process shifts



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Attribute Control Charts

- ✓ Attribute charts are used with defects and defectives (discrete data)

Attribute	Chart	Process σ
Defective proportion	p	$\text{sqrt}(p_{bar}(1-p_{bar})/n)$
Number of defectives	np	$\text{sqrt}(np_{bar}(1-p_{bar}))$
Defects per unit	c	$\text{sqrt}(c_{bar})$
Av defects per unit	u	$\text{sqrt}(u_{bar}/n)$

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Attribute Control Charts (Contd.)

Control limits for p charts

LCL = $p_{bar} - 3 * sqrt(p_{bar}(1-p_{bar})/n)$

UCL = $p_{bar} + 3 * sqrt(p_{bar}(1-p_{bar})/n)$

p chart is used for varying sample size, and to find out proportion defectives.

Control limits for np charts

LCL = $np_{bar} - 3 * sqrt(np_{bar}(1-p_{bar}))$

UCL = $np_{bar} + 3 * sqrt(np_{bar}(1-p_{bar}))$

Where pbar = np_{bar}/n, where n is the number of sub-groups.

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Attribute Control Charts (Contd.)

Control limits of u – chart

LCL = u_{bar} – 3 * sqrt(u_{bar}/n)

UCL = u_{bar} + 3* sqrt(u_{bar}/n)

Use u – chart if the sample size is varying.

Control limits of c – chart

LCL = c_{bar} – 3 * sqrt(c_{bar})

UCL = c_{bar} + 3* sqrt(c_{bar}), where c_{bar} = sum of subgroup occurrences/number of sub-groups.

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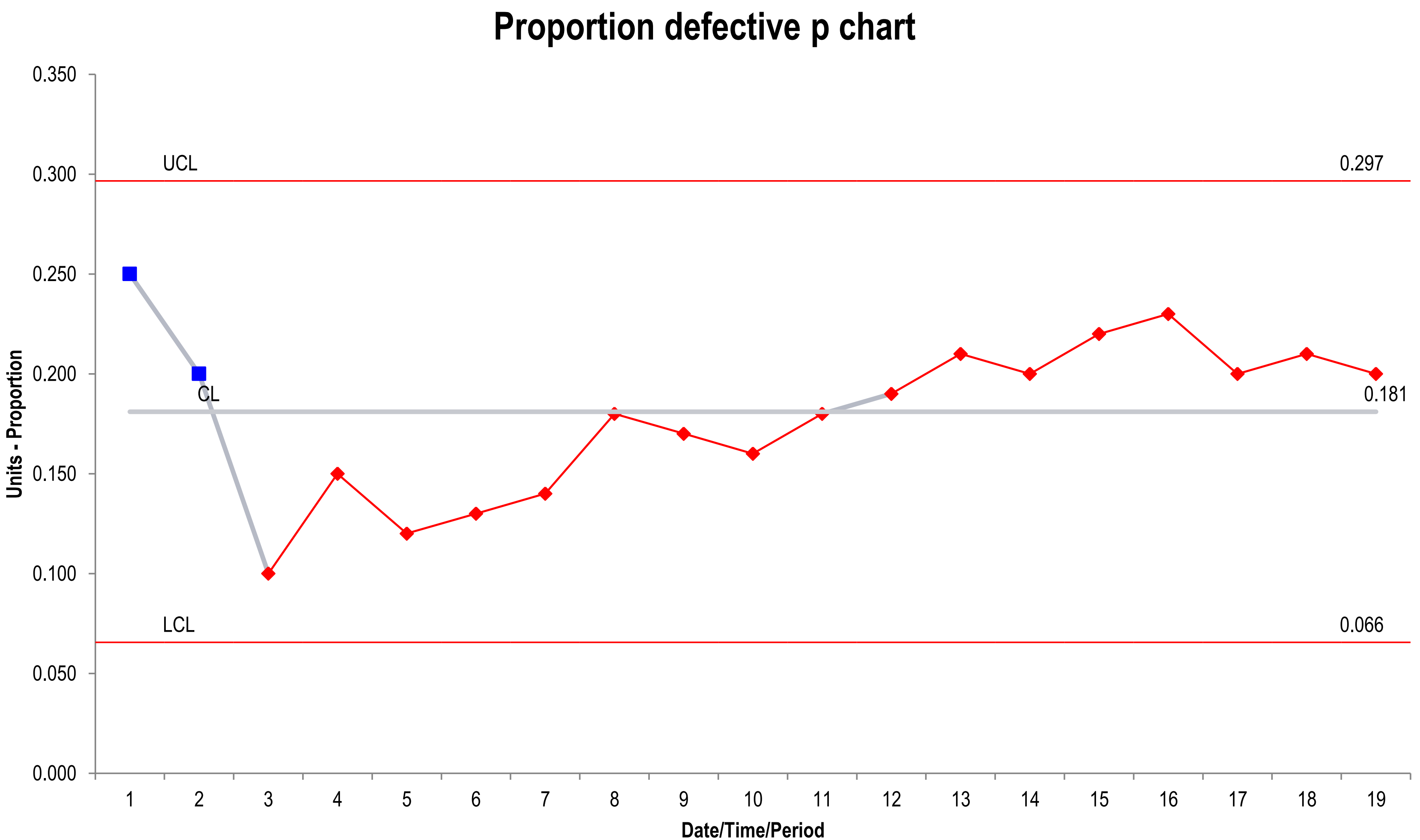
- p – chart on sample data



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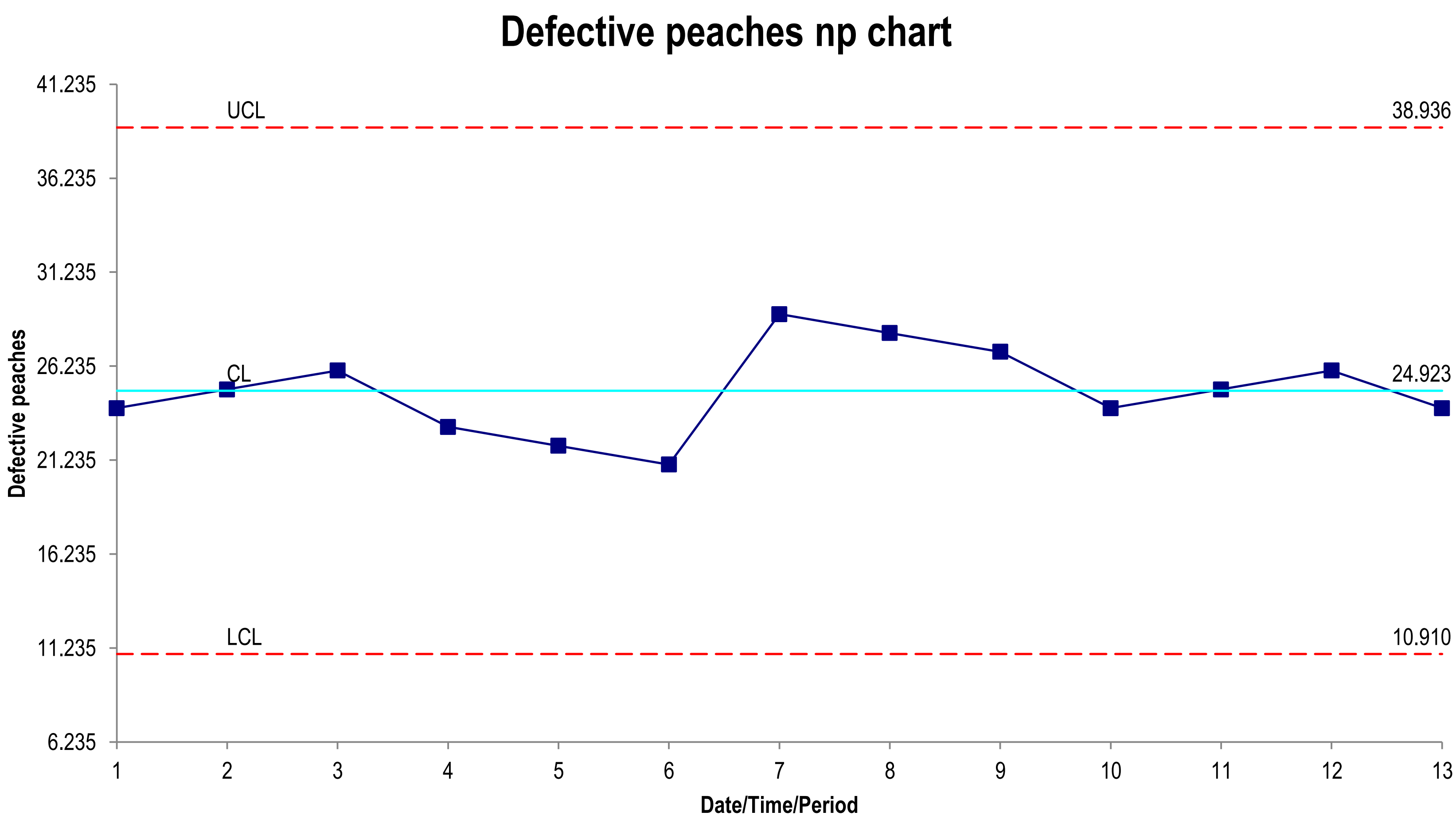
✓ np chart for sample data



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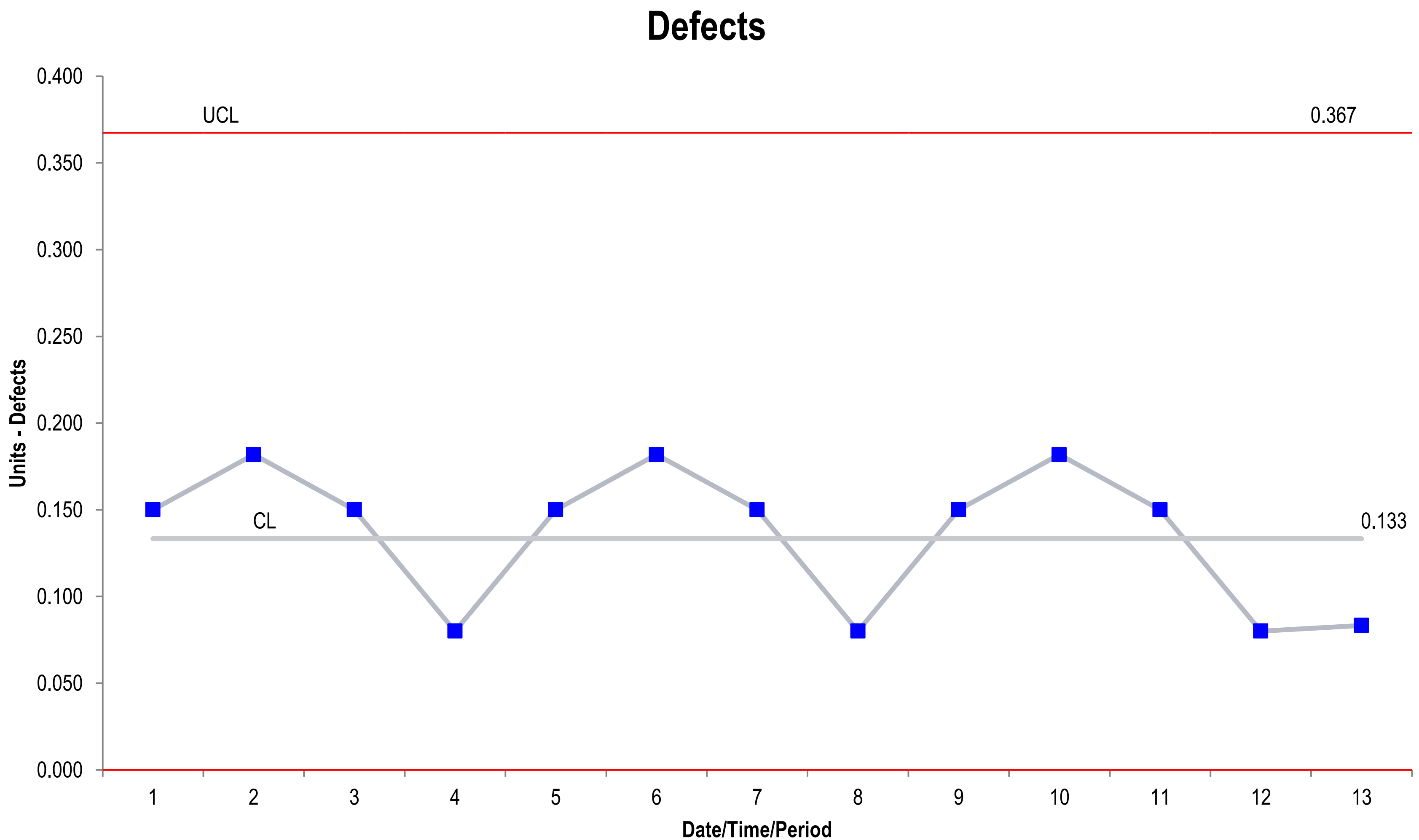
- u chart for sample data



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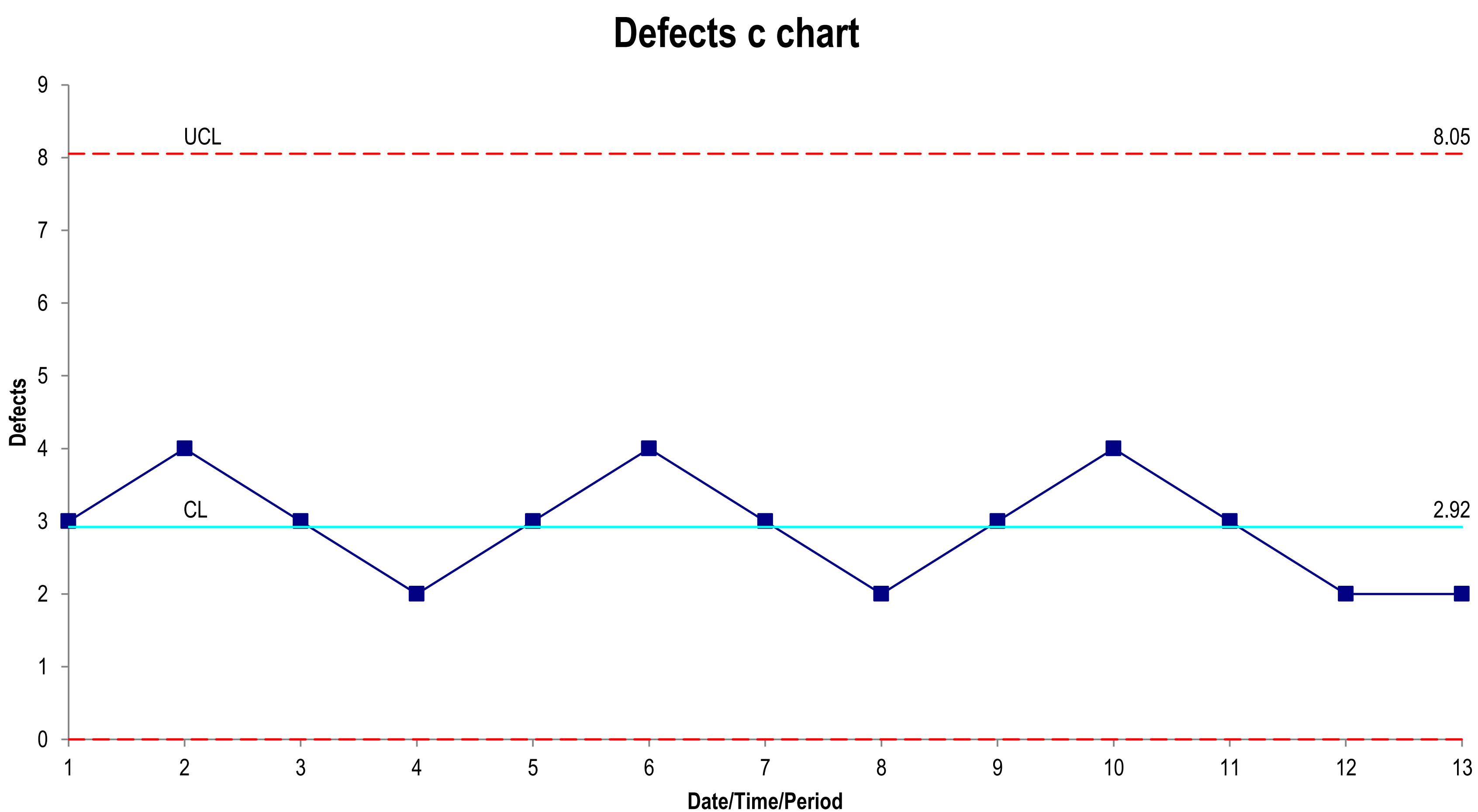
✓ c chart for sample data



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Summary

In this lesson, we have learned:

- ✓ Concepts of attribute and variables charts
- ✓ Xbar – R
- ✓ Xbar – S
- ✓ I – MR
- ✓ EWMA
- ✓ p chart, np chart, u chart, and c chart

In addition, we have also learned how to calculate control limits for different charts manually.

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Section VI, Lesson 3

Measurement System Analysis, Control Plan, and Project Closure

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Agenda

- ✓Measurement Systems Analysis
- ✓Control Plan
- ✓Project Closure

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Measurement System Analysis

- ✓Measurement system analysis is done in the Measure phase to validate the measurement system and check if the data to be collected is valid and reliable.
- ✓MSA in the measure phase is also done to re-compute baseline data.
- ✓In the Control phase, measurement system analysis is done to check if measurement system has adequate resolution to measure data with **reduced variability.**
- ✓MSA re-analysis is important because in the long run, the measurement system must be adequate and effective enough to measure reduced variability data seamlessly.

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Control Plan

- ✓Control plan is the official document and part of the knowledge transfer mechanism across teams.
- ✓To be updated by the Six Sigma team, checked by the Black Belt, and approved by the project Champion.
- ✓Control plan will also provide details on document archiving, and should be archived along with the other documents.

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Control Plan (Contd.)

- ✓ A process control plan assures that a well thought-out reaction plans are in place, in case an out-of-control condition occurs. It provides a central vehicle for documentation and communication of control methods.
- ✓ Special attention is typically given to potential failures with high RPNs and those characteristics that are critical to the customer.
- ✓ A control plan deals with the same information explored in an FMEA plus more.
- ✓ The major additions to the FMEA needed to develop a control plan are:
  - Identification of the control factors;
  - The specifications and tolerances;
  - The measurement system;
  - Sample size;
  - Sample frequency;
  - The control method; and
  - The reaction plan.

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Control Plan (Contd.)

- ✓ Where to use it: To ensure that the problem solutions are permanently effective.
- ✓ Three questions are addressed:
  - What has been done to prevent the process problems?
  - How is it known when problems occur; and what will be done when problems, in fact, do occur?
  - What are the written descriptions of the systems for controlling parts and processes?

Control plan to be updated is attached as part of the toolkit.

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Control plan snapshot

							Current Control Plan				
Process Step	Input	Output	Process Spec (LSL, USL, Target)	Cpk / Date (Sample Size)	Measurement System	%R&R or P/T	Current Control Method (from FMEA)	Who	Where	When	Reaction Plan

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Project Closure

A project is considered closed only after:

a. An increase in capability and performance indices is noted;
b. Process remains in statistical control;
c. Future risks and preventive solutions are identified;
d. Corresponding reduction in DPMO levels are noted;
e. Increase in bench Sigma levels is noted;
f. RPN reduces for failure modes;
g. Project storyboard and other documentation are completed and approved; and
h. Control plan is completed, checked, and approved.

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Summary

In this lesson we have learned:

✓ Measurement system analysis;

✓ Control plan and document archiving; and

✓ Project closure are the last activities that need to be done in a control phase.

Once these activities are done, the project is considered closed and the Six Sigma team can submit a formal project closure document to the Champion.

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Section VI, Lesson 4

Introduction to Total Productive Maintenance

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Agenda

- ✓Total Productive Maintenance (TPM) Overview
- ✓How to Implement TPM
- ✓8 Pillars of TPM
- ✓Overall Equipment Effectiveness (OEE)
- ✓Total Effective Equipment Performance (TEEP)

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Total Productive Maintenance (TPM)

Total productive maintenance

- ✓Better utilization and maintenance of production resources result in improved process capability.
- ✓Unreliable uptime is due to machine breakdowns, which further impacts productivity and flow.
- ✓Operators and teams of a company are the best to seek and identify the problems in equipment, before they assume damaging proportions.

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Total Productive Maintenance (TPM) (Contd.)

- ✓Originated in Japan in 1951, as part of preventive maintenance.
- ✓Toyota embraced TPM first as part of TPS in 1960.
- ✓Nippondenso, a part of Toyota, mandated the principle of autonomous maintenance due to the high degree of automation in their company.
- ✓Total productive maintenance (TPM) have 3 major goals:
  - Zero product defects;
  - Zero equipment unplanned failures ;*and
  - Zero accidents.

* A scheduled system downtime is not factored by TPM as detrimental.

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Total Productive Maintenance (TPM) (Contd.)

How to implement TPM

1) Gap analysis on historical product (defects/accidents/failures)
2) Physical investigation on equipment (Genchi Genbutsu and Jijutsu)
3) Corrective and incremental actions

8 pillars of TPM

- ✓ Focused improvement (Kobetsu Kaizen)
- ✓ Autonomous maintenance (Jishu Hozen)
- ✓ Planned maintenance
- ✓ Training and education
- ✓ Early phase management
- ✓ Quality maintenance (Hinshitsu Hozen)
- ✓ Office TPM
- ✓ SHE

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Total Productive Maintenance (TPM) (Contd.)

OEE, TEEP, and TPM

- ✓OEE and TEEP are the key KPIs of TPM
- ✓OEE — Overall equipment effectiveness
- ✓TEEP — Total effective equipment performance

Both the above metrics show how well facilities in a site are utilized

- ✓OEE = Availability * Performance * Quality

A P Q

Availability = How much time of the total time are the equipment available

Performance = How well do the equipment perform

Quality = What is the defect rate out of the equipment

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Total Productive Maintenance (TPM) (Contd.)

Availability calculations

- ✓Available production time per day = 480 mins
- ✓Scheduled break time = 30 mins
- ✓Scheduled production time = 450 mins
- ✓Scheduled downtime = 60 mins
- ✓Available production time = 390 mins
- ✓Availability = 87%

Performance calculations

- ✓Performance = (Products produced*ideal cycle time)/available time
- ✓Number of parts = 100
- ✓Time per part = 3 mins
- ✓Performance = (100 *3)/390 = 77%

Performance calculations doesn't factor quality

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Total Productive Maintenance (TPM) (Contd.)

Quality calculations

Quality = Number of good units/Total units

Hypothetically here,

Quality = 90/100 = 90%

OEE = 87% * 77% * 90% = 60.21%

Industry OEE benchmark is 85%

Room for improvement

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Total Productive Maintenance (TPM) (Contd.)

TEEP = Loading * OEE

Loading = Scheduled time/Calendar time

Calendar time = 7 days and 24 hours

Scheduled time = 5 days and 24 hours

Loading = 71.4%

TEEP = Loading * OEE

= 71.4% * 60.21%

= 42.98%

Since only 43% of the total effectiveness of the equipment is visible, there is room for improvement.

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Summary

In this lesson, we have learned:

- ✓ An overview of TPM
- ✓ The implementation of TPM
- ✓ The 8 pillars of TPM
- ✓ The concept of OEE
- ✓ The concept of TEEP

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Tools to Refer

- ✓ Control charts constants – PDF file
- ✓ Xbar R template – Excel file
- ✓ Xbar S template – Excel file
- ✓ p chart template – Excel file
- ✓ np chart template – Excel file
- ✓ u chart template – Excel file
- ✓ c chart template – Excel file
- ✓ Glossary for useful terms in Lean and Six Sigma – Excel file

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Quiz

1. Freak patterns happen due to:

a) Special cause

b) Common cause

c) Human error

d) Non-value add activity

2. TPM stands for:

a) Total preventive maintenance

b) Total productive maintenance

c) Toyota production and manufacturing

d) Tight process map

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Quiz

3. Cusum charts are used to detect:

a) Small process shifts

b) Special Cause

c) Freak Patterns

d) Cumbersome Process

4. Control plan is used for:

a) Process Control

b) Plan Control and Execution

c) Knowledge transfer

d) Official Six Sigma closure

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Answers

1. a) Special cause. Freak patterns happen once in a while and are generally due to special causes.
2. b) Total productive maintenance.
3. a) Small process shifts. Cusum charts are used to detect small process shifts
4. c) Knowledge transfer. Control plan is the official document and part of the knowledge transfer mechanism across teams.

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Thank you

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