

CQI-26

SPC Short Run Supplement

1st Edition

»» Insight

»» Expertise

»» Results

The **Catalyst** for Peak Performance



ABOUT AIAG

Purpose Statement

Founded in 1982, AIAG is a globally recognized organization where OEMs and suppliers unite to address and resolve issues affecting the worldwide automotive supply chain. AIAG's goals are to reduce cost and complexity through collaboration; improve product quality, health, safety, and the environment; and optimize speed to market throughout the supply chain.

AIAG Organization

AIAG is made up of a board of directors, an executive director, executives on loan from member organizations, associate directors, a full-time staff, and volunteers serving on project teams. Directors, department managers, and program managers plan, direct and coordinate the association's activities under the direction of the executive director.

AIAG Projects

AIAG promotes objectives primarily by publishing standards and offering educational conferences and training. Member companies donate the time of volunteers to work at AIAG in a non-competitive, open forum that is intended to develop recommendations, guidelines and best practices for the overall good of the industry. A listing of current projects can be found at www.aiag.org

AIAG PUBLICATIONS

An AIAG publication reflects a consensus of those substantially concerned with its scope and provisions. An AIAG publication is intended as a guide to aid the manufacturer, the consumer and the general public. The existence of an AIAG publication does not in any respect preclude anyone from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the publication.

DISCLAIMER

The Publisher does not make any representation or warranty, express or implied in relation to any information from this publication, and the Publisher does not assume any legal liability for the accuracy, completeness, or usefulness of any information from this publication.

CAUTIONARY NOTICE

AIAG publications are subject to periodic review and users are cautioned to obtain the latest editions.

MAINTENANCE PROCEDURE

Recognizing that this AIAG publication may not cover all circumstances, AIAG has established a maintenance procedure. Please refer to the Maintenance Request Form at the back of this document to submit a request.

Published by:

Automotive Industry Action Group
26200 Lahser Road, Suite 200
Southfield, Michigan 48033
Phone: (248) 358-3570 • Fax: (248) 358-3253

APPROVAL STATUS

The AIAG Quality Steering Committee and designated stakeholders approved this document for publication on February, 2016.

AIAG COPYRIGHT AND TRADEMARK NOTICE:

© 2016 Automotive Industry Action Group, except that copyright is not claimed as to any part of an original work prepared by a U.S. or state government officer or employee as part of the person's official duties.

Except as noted above, all rights are reserved by AIAG and no part of these materials may be reproduced, reprinted, stored in a retrieval system, or transmitted, in any form or by any means, electronic, photocopying, recording, or otherwise, without the prior written permission of Automotive Industry Action Group. Copyright infringement is a violation of federal law subject to criminal and civil penalties.

AIAG and Automotive Industry Action Group are registered service marks of the Automotive Industry Action Group. Automotive Industry Action Group makes no claim to any trademark of a third party. Trademarks of third parties included in these materials are the property of their respective owners.

© 2016 Automotive Industry Action Group

ISBN#: 978 1-60534 333 4

CQI-26

SPC Short Run Supplement

Version 1, Issued 2/2016



FOREWORD

The *SPC Reference Manual, 2nd Edition*¹ was developed by the Statistical Process Control (SPC) Work Group, sanctioned by the FCA US LLC/Ford/General Motors Supplier Quality Requirements Task Force, and under the auspices of the Automotive Industry Action Group (AIAG). This manual is an introduction to statistical process control. *It is not intended to limit evolution of SPC methods suited to particular processes or commodities.* While these guidelines are intended to cover normally occurring SPC system situations, there will be questions that arise.

This *SPC Short Run Supplement* is a guideline developed to address one such situation – short run production, which is identified by processes which do not have the production volume to readily apply the approaches identified in the *SPC Reference Manual, 2nd Edition*.

The purpose of the *SPC Short Run Supplement* is to provide an approach with examples to short run SPC. Through discussion of the fundamental tools and advocacy of a back-to-basics approach, this document presents the subject matter in a straightforward manner to benefit a majority of applications.

This document is not intended to supplant the *SPC Reference Manual* but to supplement and simplify its contents when a short run application is called for.

¹ FCA US LLC, Ford Motor Company, and General Motors, *Statistical Process Control (SPC)*, 2nd Edition, AIAG: July 2005

ACKNOWLEDGEMENTS

AIAG would like to recognize and thank the member organizations and work group members responsible for this document:

Tom Firestine -----	Toyota Motor Engineering & Manufacturing North America Inc., Co-Chair
Greg Gruska -----	Omnex Inc., Co-Chair
Karen Meldrum -----	Minitab Inc.
Jim Verhanovitz -----	Nexteer Automotive
Patricia White-Johnson -----	Ford Motor Company
Stanley Zhou -----	FCA US LLC
Jan Tucker -----	ASQ
John Boulahanis -----	JAMA Consulting, LLC

TABLE OF CONTENTS

ABOUT AIAG	1
FOREWORD	3
ACKNOWLEDGEMENTS	4
TABLE OF CONTENTS.....	5
TABLE OF FIGURES	7
1 GETTING STARTED – SHORT RUN PROCESSES.....	9
DNOM CHART.....	10
STANDARDIZED CHART ($\bar{X}$ CHART)	10
EXAMPLE	11
2 SHORT RUN CONTROL CHARTS WITH EQUAL VARIANCES	21
DNOM $\bar{X}$ & R CHARTS.....	21
A. Multiple Characteristics on Same Part	25
B. Multiple Characteristics on Multiple Parts	28
TARGET $\bar{X}$ & R CHART	30
C. Target not at process specification nominal	30
D. Unilateral specification case	32
3 SHORT RUN CONTROL CHARTS WITH UNEQUAL VARIANCES	35
STANDARDIZED $\bar{X}$ & R CHARTS	35
A. Standardized Short Run $\bar{X}$ & R Chart Development	35
B. Proper Usage of Standardized Short Run $\bar{X}$ & R Charts	36
C. Using Historical or Target values in Standardized Control Charts.....	37
EXAMPLE STANDARDIZED SHORT RUN $\bar{X}$ & R CHARTS	37
SHORT RUN $\bar{X}$ & S CHART	47
EXAMPLE STANDARDIZED TARGET SHORT RUN $\bar{X}$ & S CHARTS	49
4 ATTRIBUTE CHARTS FOR SHORT RUNS.....	51
A. REVIEW OF THE STANDARD TYPES OF ATTRIBUTE CONTROL CHARTS.....	51
B. TRANSLATION OF DATA FOR SHORT RUN ATTRIBUTE CONTROL CHARTS	51
C. EXAMPLE OF TRANSLATING THE DATA (C CHART).	51
D. TABLE FOR TRANSLATING ATTRIBUTE CONTROL CHARTS TO STANDARDIZED ATTRIBUTE CONTROL CHARTS	54
E. ATTRIBUTE DATA EXAMPLE: COMPOSITE P-CHARTS	54
F. ATTRIBUTE DATA EXAMPLE: NP-CHARTS	57
G. ATTRIBUTE DATA EXAMPLE: U-CHARTS	58
APPENDICES.....	60
APPENDIX A: SAMPLE DATA SETS	61
Getting Started.....	61
DNOM $\bar{X}$ & R Charts.....	63

CQI-26

SPC Short Run Supplement

Version 1, Issued 2/2016



Multiple Characteristics on Same Part.....	64
Multiple Characteristics on Multiple Parts.....	66
Standardized $\bar{X}$ & R Charts.....	67
Multiple Characteristics on Same Part.....	68
Single Characteristics on Multiple Parts.....	69
Multiple Characteristics on Multiple Parts.....	70
Target $\bar{X}$ & S Chart.....	72
Composite P-Charts.....	73
C Chart	74
NP Chart.....	75
U Chart.....	76
APPENDIX B	77
Table of Constants and Formulas for Control Charts	77
MAINTENANCE REQUEST FORM	78

TABLE OF FIGURES

FIGURE 1. TABLE WITH COMPARISON BETWEEN NORMAL AND SHORT RUN PROCESSES	9
FIGURE 2. EXAMPLE OF AN I – MR CHART	13
FIGURE 3. PROCESS CAPABILITY REPORT FOR MONTH 1 DATA	14
FIGURE 4. I – MR CHART OF PROCESS AFTER ADJUSTMENT.....	15
FIGURE 5. PROCESS CAPABILITY REPORT FOR MONTH 2 DATA AFTER ADJUSTMENT	15
FIGURE 6. I – MR CHART FOR FIRST 3 MONTHS AFTER ADJUSTMENT	16
FIGURE 7. I – MR CHART FOR FIRST 3 MONTHS AFTER ADJUSTMENT WITH SIGMA ZONES	17
FIGURE 8. PROCESS CAPABILITY REPORT OF ADJUSTED PROCESS	17
FIGURE 9. I – MR CHART USING PROCESS PARAMETERS.....	18
FIGURE 10. I – MR CHART OF PRODUCTION USING PROCESS PARAMETERS	19
FIGURE 11. EXAMPLE OF A TRADITIONAL X-BAR – R CHART	22
FIGURE 12. DISTRIBUTIONS OF EXAMPLE PROCESSES	24
FIGURE 13. EXAMPLE OF A DNOM $\bar{X}$ & R CHART WITH MULTIPLE PART NUMBERS	25
FIGURE 14. SKETCH OF A VALVE BODY WITH MULTIPLE CHARACTERISTICS	26
FIGURE 15. EXAMPLE OF A DNOM I CHART WITH MULTIPLE CHARACTERISTICS ON SAME PART	26
FIGURE 16. EXAMPLE OF A DNOM $\bar{X}$ & R CHART WITH MULTIPLE CHARACTERISTICS ON SAME PART	27
FIGURE 17. INTERMEDIATE STEERING SHAFT ASSEMBLY.....	28
FIGURE 18. EXAMPLE OF A DNOM I CHART WITH MULTIPLE CHARACTERISTICS ON MULTIPLE PARTS	29
FIGURE 19. EXAMPLE OF A DNOM $\bar{X}$ & R CHART WITH MULTIPLE CHARACTERISTICS ON MULTIPLE PARTS.....	30
FIGURE 20. TABLE WITH EXAMPLE PART PARAMETERS	31
FIGURE 21. TARGET $\bar{X}$ & R CHART.....	32
FIGURE 22. TABLE FOR UNILATERAL EXAMPLE PARAMETERS.....	32
FIGURE 23. EXAMPLE OF A TARGET $\bar{X}$ & R CHART FOR UNILATERAL CASE	33
FIGURE 24. TABLE FOR PORTION OF DATA FOR CHARACTERISTICS 1 FROM PART A	38
FIGURE 25. EXAMPLE OF A SHORT RUN X-BAR – R CHART WITH ACTUAL VALUES	39
FIGURE 26. EXAMPLE OF THE SHORT RUN X-BAR CHART WITH STANDARDIZED VALUES	39
FIGURE 27. EXAMPLE OF THE SHORT RUN X-BAR CHART WITH STANDARDIZED VALUES FOR TWO CHARACTERISTICS	40
FIGURE 28. EXAMPLE OF THE SHORT RUN RANGE CHART WITH STANDARDIZED VALUES FOR TWO CHARACTERISTICS.....	41
FIGURE 29. EXAMPLE OF THE SHORT RUN X-BAR CHART WITH STANDARDIZED VALUES FOR MULTIPLE PARTS ON THE SAME CHARACTERISTICS	42
FIGURE 30. EXAMPLE OF THE SHORT RUN RANGE CHART WITH STANDARDIZED VALUES FOR MULTIPLE PARTS ON THE SAME CHARACTERISTICS	43
FIGURE 31. EXAMPLE DATA FROM MULTIPLE PARTS AND CHARACTERISTICS.....	44
FIGURE 32. PLOTTING POINTS FOR EXAMPLE DATA FROM MULTIPLE PARTS AND CHARACTERISTICS	45
FIGURE 33. EXAMPLE OF A SHORT RUN X-BAR CHART WITH STANDARDIZED VALUES	45
FIGURE 34. EXAMPLE OF A SHORT RUN RANGE CHART WITH STANDARDIZED VALUES	46
FIGURE 35. EXAMPLE OF A SHORT RUN AVERAGE CHART WITH STANDARDIZED VALUES	47
FIGURE 36. EXAMPLE OF A SHORT RUN AVERAGE AND STANDARD DEVIATION CHART WITH STANDARDIZED VALUES.....	49
FIGURE 37. TABLE OF HISTORICAL AVERAGES FOR CURRENT PRODUCTION DATA.....	52
FIGURE 38. TABLE SHOWING CALCULATION EXAMPLES FOR CURRENT PRODUCTION DATA.....	52
FIGURE 39. EXAMPLE OF A SHORT RUN C – CHART	53
FIGURE 40. TABLE FOR TRANSLATING ATTRIBUTE CONTROL CHARTS TO STANDARDIZED ATTRIBUTE CONTROL CHARTS.....	54
FIGURE 41. TABLE OF DATA FROM PRODUCTION SAMPLE	56
FIGURE 42. COMPOSITE P-CHART FROM PRODUCTION SAMPLE	56
FIGURE 43. EXAMPLE OF A NP CHART.....	57
FIGURE 44. EXAMPLE OF A U CHART.....	59

CQI-26

SPC Short Run Supplement

Version 1, Issued 2/2016



1 GETTING STARTED – SHORT RUN PROCESSES

When getting started in applying process control to any process, the goal is to move from the analysis of the process to the maintenance (process control) as quickly as possible by applying the tenets of “CQI-25 SPC Quick Start Guide”.

Because a short run process does not have the production volume to readily apply the approach in the CQI-25, the question becomes “how do I make this transition with a limited production?”

For long run production volumes we can determine the process location and spread (mean and standard deviation) from the significant production run. For short run processes we need to find a substitute for this information to set up process control parameters until we can produce a sufficient volume of parts to calculate them directly from the process.

	(Long Run Process)	Short Run Process
Development of Initial Process parameters	Use Pre-Production Activities	Use surrogate process or target parameters
Control Limits	Applied after the collection and analysis of 20+ subgroups of data	Applied immediately, developed from target information
Recognizing instability	Standard rules apply	Deeper investigation needed for indication of special causes

Figure 1. Table with Comparison between Normal and Short Run Processes

For the process mean the only alternative is to establish a process target. If a target is not specified for the characteristic, it is most often taken to be the nominal or midpoint of the process specifications.

For the process variation, two choices are available:

- Use the variation of a documented surrogate process
- Determine a standard deviation from a target performance

$$\text{Target } P_p = \frac{USL - LSL}{6 \sigma_{P-\text{Target}}}$$

$$\therefore \sigma_{\text{Process}} = \sigma_{P-\text{Target}} = \frac{USL - LSL}{6 * \text{Target } P_p}$$

- To calculate the control chart parameters, the underlying assumption for a DNOM (Difference or Deviation from Nominal) Chart is that all the process standard deviations need to be statistically the same. Consequently use the following:

$$\bar{R}_{calc} = d_2 \sigma_{process}$$

Where d_2 is based on the subgroup size.

These values will be used for determining the control limits for the DNOM chart or the plot points and the control limits for the standardized chart:



DNOM Chart

$$\text{plotpoint} = x_i - \mu_{\text{target}}$$

$$\text{Centerline} = 0$$

For $n \geq 2$

$$UCL_{\bar{x}} = 0 + A_2 \bar{R}_{calc} \quad LCL_{\bar{x}} = 0 - A_2 \bar{R}_{calc}$$

For $n = 1$

$$UCL_x = 0 + E_2 \bar{R}_{calc} \quad LCL_x = 0 - E_2 \bar{R}_{calc}$$

For the Range Chart:

$$UCL_R = \bar{R}_{calc} D_4 \quad LCL_R = \bar{R}_{calc} D_3$$

Standardized Chart ($\bar{X}$ Chart)

$$\text{plotpoint} = \frac{\bar{x}_i - \mu_{\text{target}}}{\bar{R}_{calc}}$$

$$\text{Centerline} = 0$$

$$UCL_{\bar{x}} = 3 \quad LCL_{\bar{x}} = -3$$

Standardized Chart (Range Chart):

$$\text{plotpoint} = \frac{R_i}{\bar{R}_{calc}}$$

$$\text{Centerline} = 1$$

$$UCL_R = D_4 \quad LCL_R = D_3$$



Use of these charts would follow the same rules as given in the Quick Start Guide (CQI-25). However, since the parameters are based on historical or target values, caution should be taken in interpreting the charts.

Example

Scenario: The supplier has a contract to produce a specialty widget for a limited production vehicle for the next year. The total volume will be 120 units paced over the year.

Design analysis (including DFMEA and p-diagrams²) has identified function A as a significant requirement. This is associated with the product characteristic PC-A which has been designated as a special characteristic. To assure that this characteristic is on target with acceptable variation, it was decided to use short run control charts to monitor and control the process.

The specification for PC-A is 50 ± 1 with a target Pp, Ppk of 1.67. Since this is the first time the supplier is using this process they do not have any historical or surrogate products to use as a basis for the charts. The control chart was based on the target values:

$$\text{Centerline} = 0$$

$$\text{Target } P_p = \frac{USL - LSL}{6 \sigma_{P-\text{Target}}}$$

$$\therefore \sigma_{\text{Process}} = \sigma_{P-\text{Target}} = \frac{USL - LSL}{6 * \text{Target } P_p} = \frac{2}{6 * 1.67} = 0.1996 = 0.2$$

$$\text{Since the sigma of the process is equal to } \sigma_{\text{process}} = \frac{\bar{R}_{calc}}{d_2}$$

² FCA US LLC, Ford, GM, *Potential Failure Mode & Effects Analysis*, 4th Edition, AIAG, June 2008

It was decided to use an Individuals and Moving Range Chart (i.e., $n_x = 1$ and $n_{MR} = 2$):

$$\therefore \bar{R}_{calc} = d_2 \sigma_{process} = 1.1284 * 0.2 = 0.22568$$

With:

$$\text{Centerline} = 0$$

$$UCL_x = 0 + E_2 \bar{R}_{calc} \quad LCL_x = 0 - E_2 \bar{R}_{calc}$$

$$UCL_x = 0 + 2.660 * 0.22568 = 0.6003$$

$$LCL_x = 0 - 2.660 * 0.22568 = -0.6003$$

$$UCL_R = \bar{R}_{calc} D_4 \quad LCL_R = \bar{R}_{calc} D_3$$

$$UCL_R = 0.22568 * 3.267 = 0.7373 \quad LCL_R = 0$$

and

$$\text{plotpoint} = x_i - 50$$

Unknown to the team, the actual process $P_p = 2$ and process average = 49.65.

When production started, the team began plotting the measurement results on the I-MR chart based on the target values. Since the points were inside the control limits the production continued without adjustment.

The results of the first month's production were:

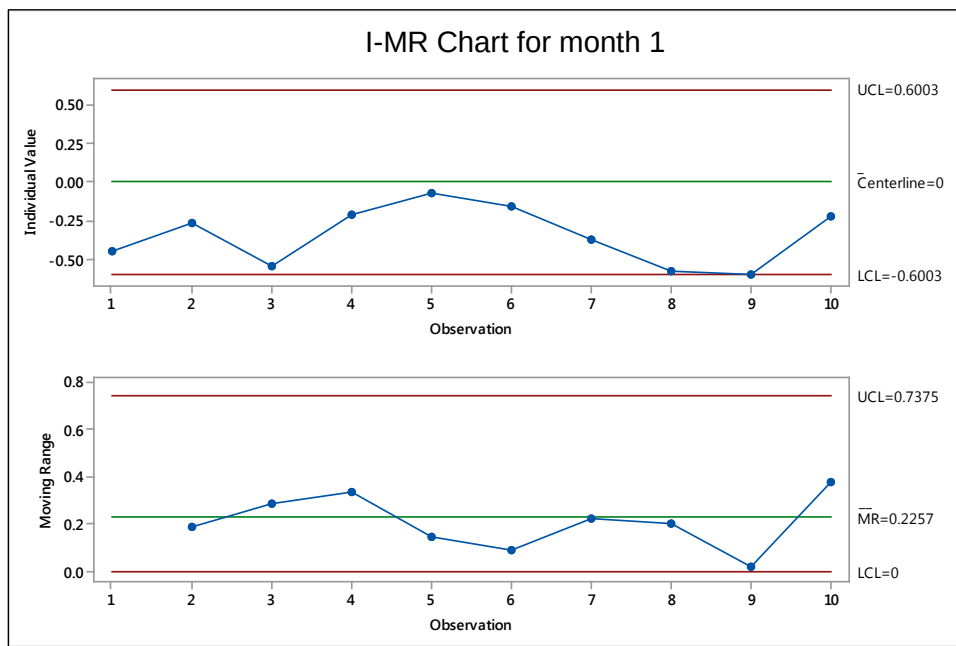


Figure 2. Example of an I – MR Chart

Digging Deeper

Analysis of the results show that the process is off target but appears to have acceptable variability

Even though the sample size is small, a capability analysis was performed:

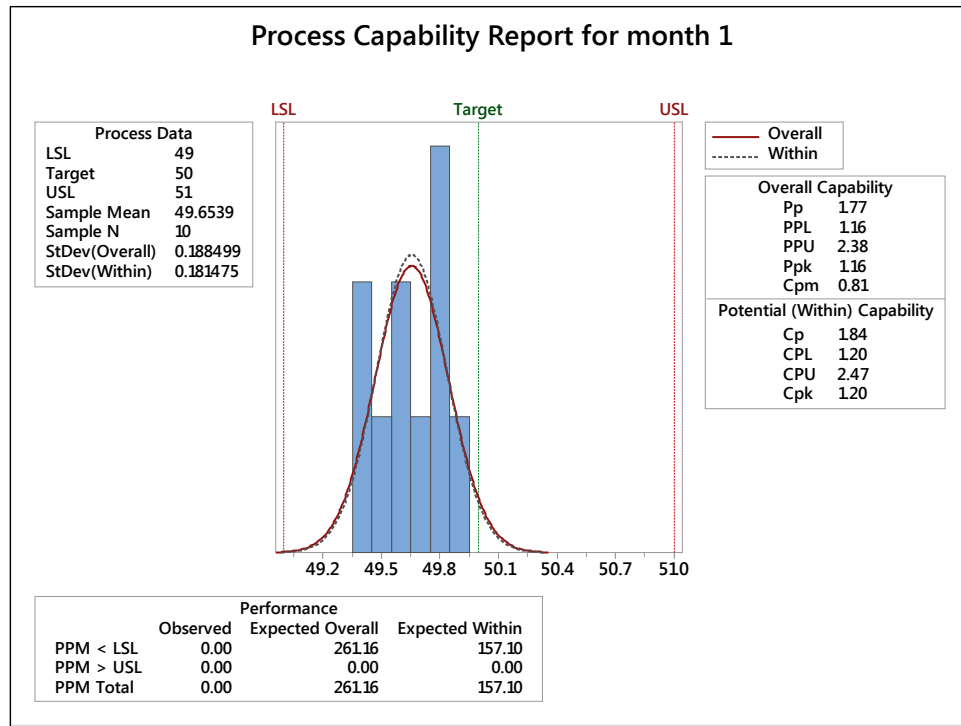


Figure 3. Process Capability Report for Month 1 Data

This reinforced the conclusions arrived at from the control charts.

The team adjusted the center of the process by 0.35 for the second month's production and got the following results:

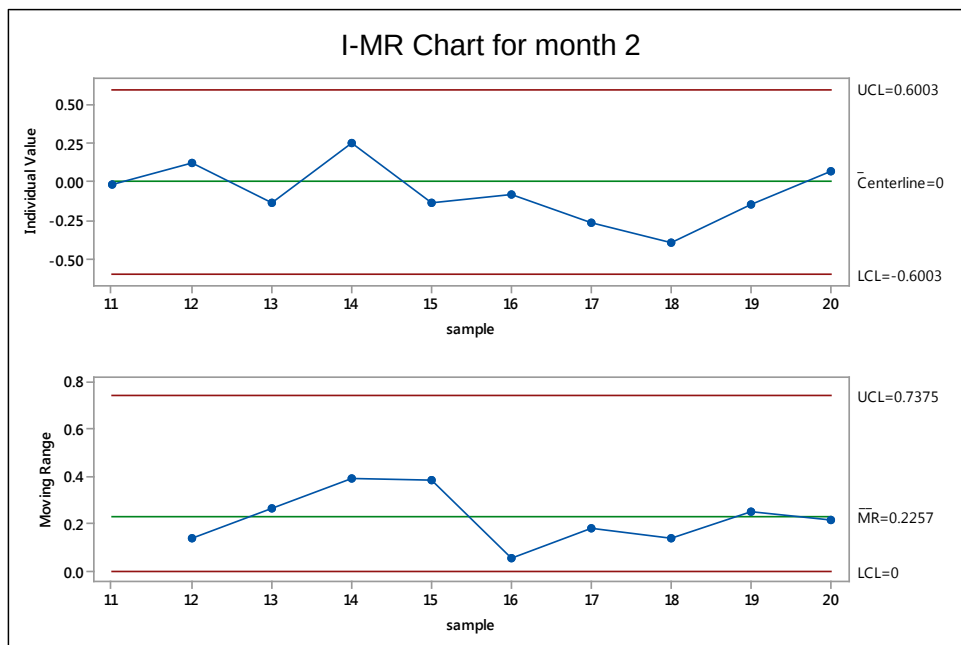


Figure 4. I – MR Chart of process after adjustment

With the capability analysis of the same data showing:

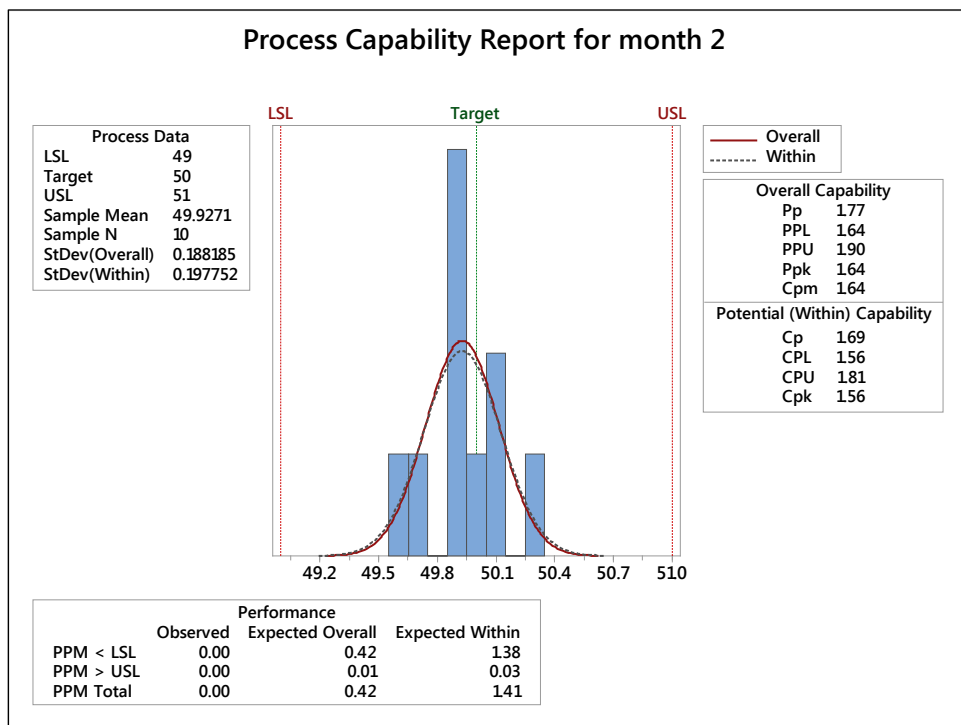


Figure 5. Process Capability Report for Month 2 data after adjustment

Some team members were concerned that the estimated indices were much better than the first month's results. They were reminded that the confidence interval for a sample of size 10 is large and that this estimate is only an initial indicator of the process capability.

Since the control chart indicated an acceptable process the team kept the current target for subsequent production.

Over the next 2 months the data collected showed:

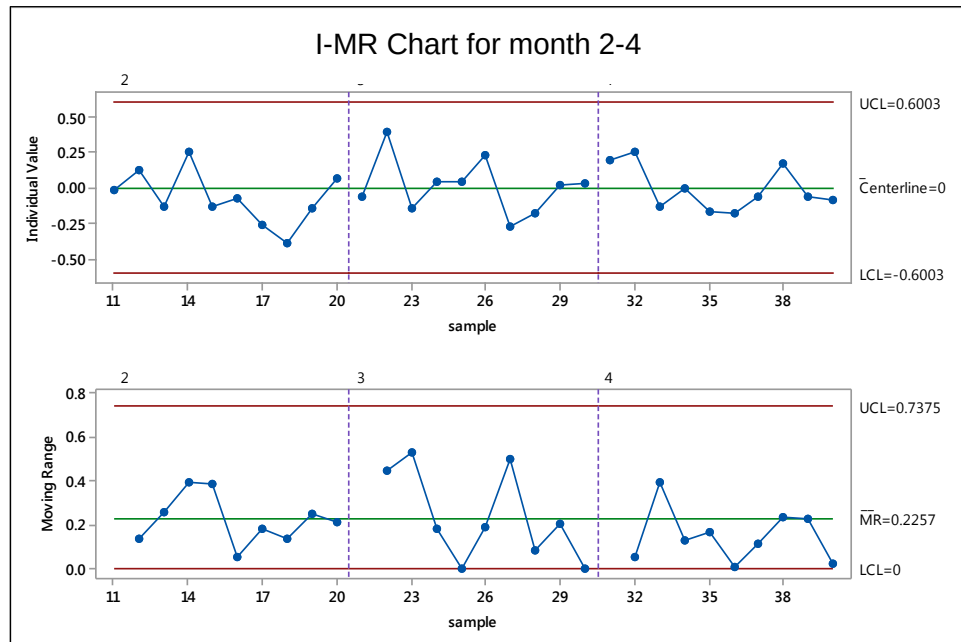


Figure 6. I – MR Chart for first 3 months after adjustment

The control chart for individuals shows that the plotted values are “hugging” the centerline; e.g. no points are located in the 2 – 3 sigma bands of the control chart.

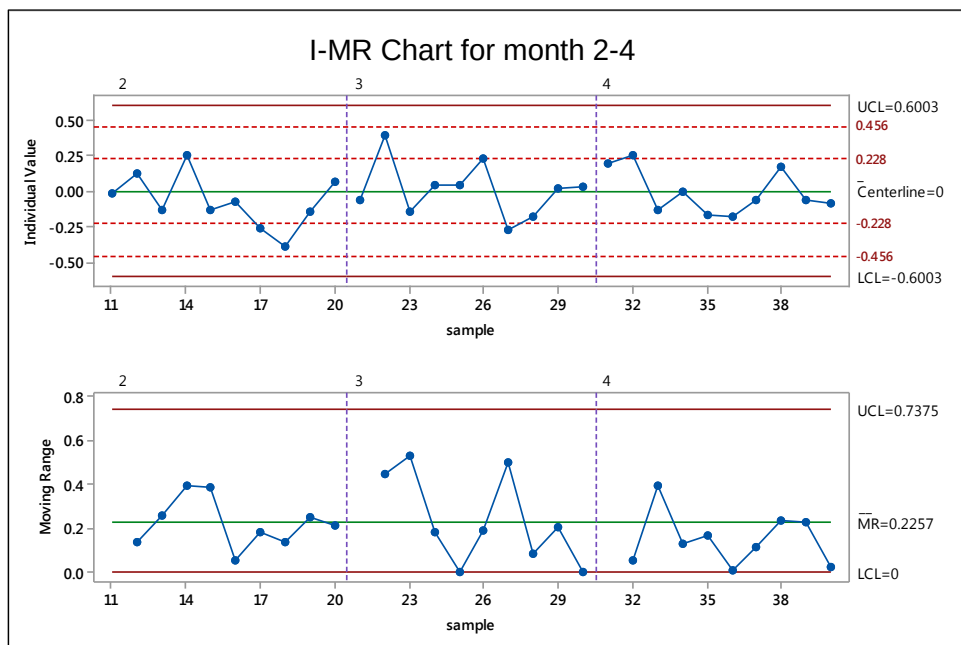


Figure 7. I – MR Chart for first 3 months after adjustment with sigma zones

The capability analysis shows the process capability exceeds the target capability of 1.67.

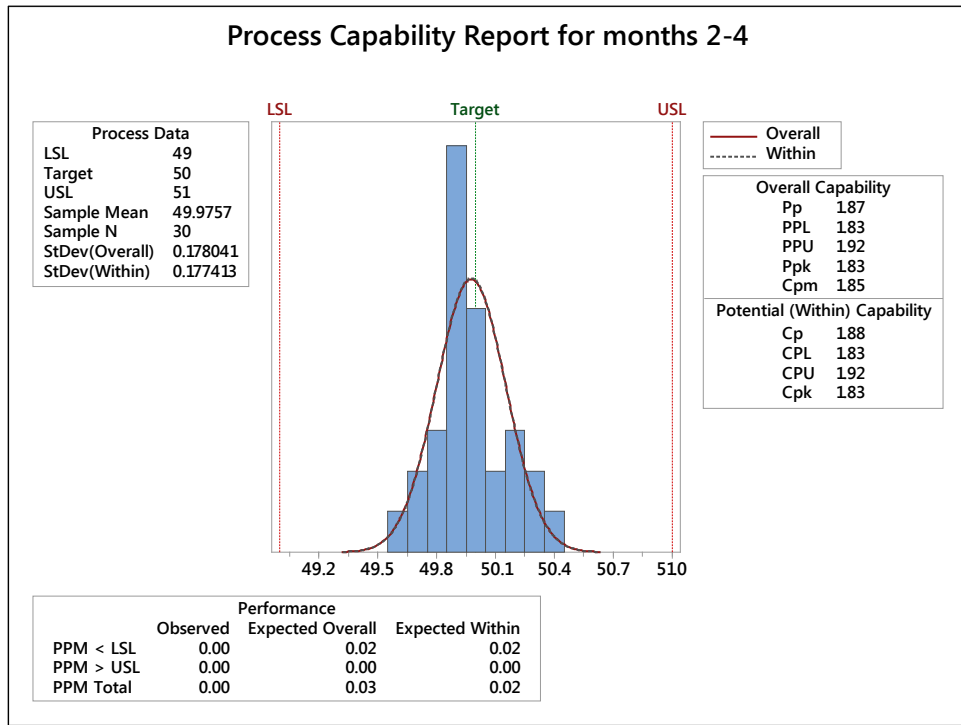


Figure 8. Process Capability Report of adjusted process

This means that the indication of an “out of control” signal is caused by the fact that the control limits were based on estimated values not actual

values. However the team now has sufficient samples to use the data to calculate the control limits. This yielded the following analysis.

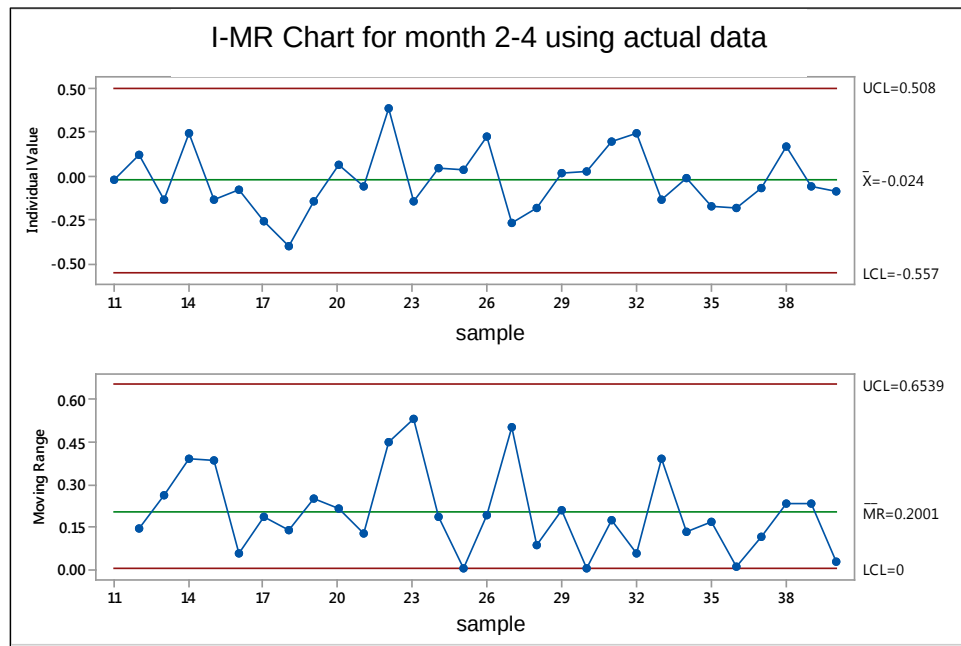


Figure 9. I – MR Chart using process parameters

The data now “fills” the control limits as expected. So the team will continue with these control limits. Below is the result after 6 months of production

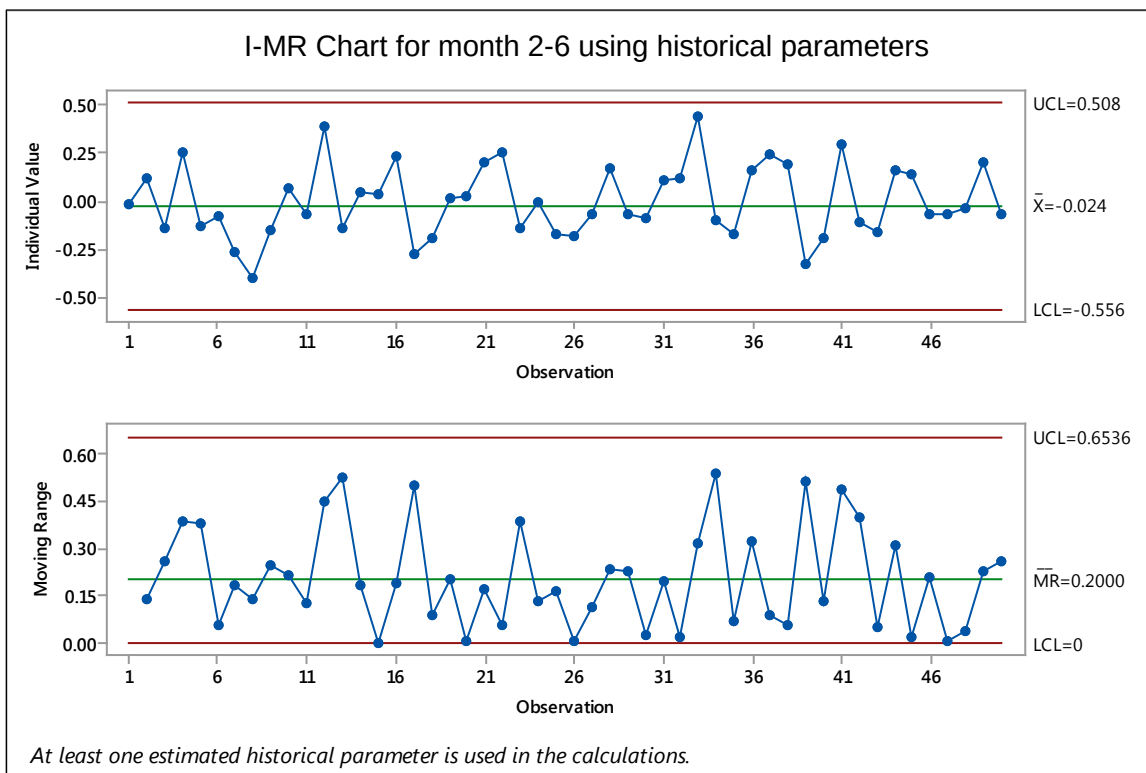


Figure 10. I – MR Chart of production using process parameters

Note that caution must be used when identifying out of control signals when using Short Run Charts, especially if the parameters are based on target information. Control charts were developed to assist in differentiating between common and special causes of variation. As seen above, by using target information this differentiation may not be straightforward.

Once we have shown that the process we want to control is stable for a single part, we can use the DNOM Chart for ongoing control of multiple parts.



Remember, once the control limits have been established, they should be changed only if the process is improved through improvement actions.

CQI-26

SPC Short Run Supplement

Version 1, Issued 2/2016



2 SHORT RUN CONTROL CHARTS WITH EQUAL VARIANCES

DNOM $\bar{X}$ & R Charts

Another Short Run SPC situation to consider is an application for J.I.T. inventory which results in small lot sizes with frequent changeovers to support the O.E.M.s who have many part numbers for similar types of product run over the same equipment at a supplier. The usual approach for a supplier was to have a control chart for each part number when they were running large lots of material for extended periods of time.

However, with small lot sizes run over the same machine, this process control monitoring method is not the most effective and efficient way to evaluate the real time performance of the process. One method that can be used in order to reduce the number of control charts is to have just one control chart for all of the various part numbers run on the machine. Since the different part numbers could have different nominal values, the resulting scale on the traditional $\bar{X}$ & R Control Chart would have to be constructed to accommodate all of these values.

As you can see in the following graph, it appears that we have numerous instances of the process being out of control if the actual average part value is plotted. Also note that the Range Chart shows that the process variation is stable for all of the part numbers.

Copyright Automotive Industry Action Group
Provided by IHS Markit under license with AIAG
No reproduction or networking permitted without license from IHS

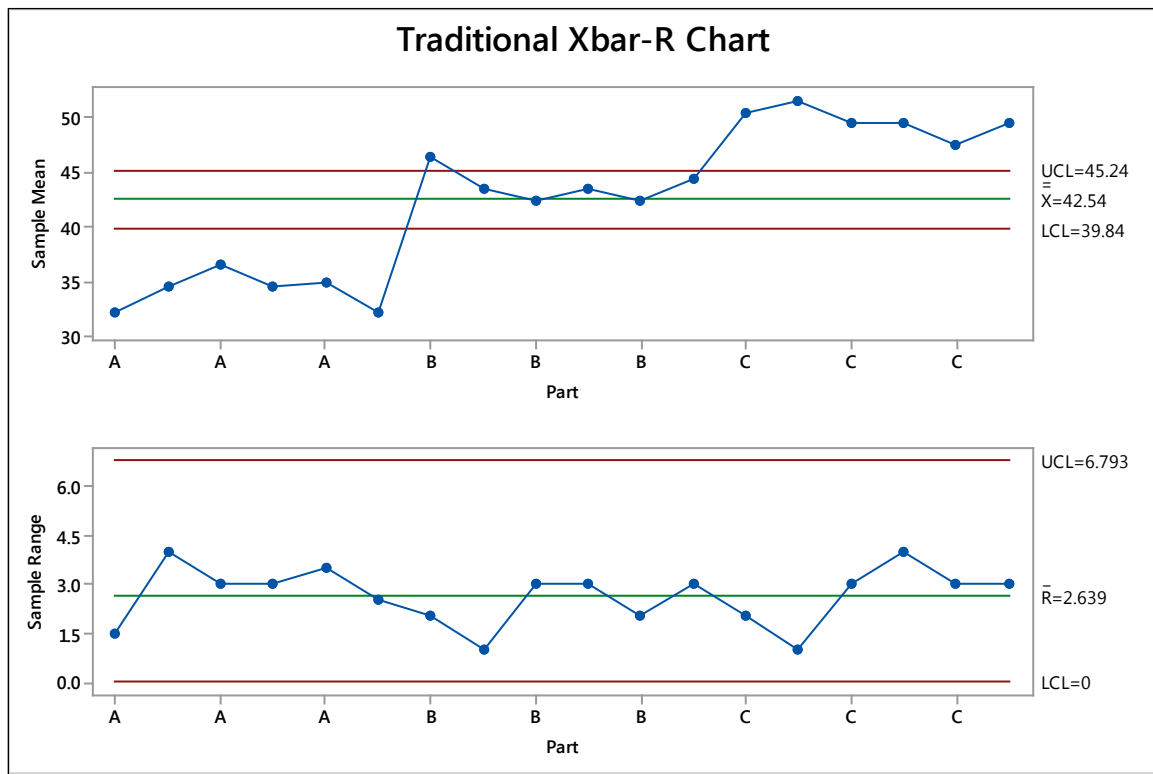


Figure 11. Example of a traditional X-bar – R Chart

The DNOM $\bar{X}$ & R Chart was developed to help solve the potential problem when parts with different nominal values are plotted on the same chart. The DNOM $\bar{X}$ & R Chart is best used when the following conditions are met:

- The subgroup size is constant;
- The Average Range of the different part numbers are similar;
- The nominal print specification is the target for each distribution process center.

With the DNOM $\bar{X}$ & R Chart we are able to still monitor the process with a single Control Chart as we changeover to the different part numbers. This is accomplished by translating the average of the subgroup data as the difference from the part nominal value. Thus the part specification nominal value becomes the zero value on the DNOM $\bar{X}$ control chart. If we take the data from figure 11 and translate the data into the difference of each sub-group average actual data value from its nominal print specification value, the resulting chart would look like the following DNOM $\bar{X}$ & R (figure 13).

$$\text{plotpoint} = \bar{x}_i - \text{nominal}$$

$$\text{Centerline} = \begin{cases} 0, & \text{when getting started} \\ \text{average of plotpoints,} & \text{ongoing control} \end{cases}$$

Where the average of plotpoints comes from the initial study which shows the process is stable.

For $n \geq 2$

$$UCL_{\bar{x}} = \text{centerline} + A_2 \bar{R} \quad LCL_{\bar{x}} = \text{centerline} - A_2 \bar{R}$$

$\bar{R}$ = Average Range over all the subgroups

However, before we analyze the different part numbers on the same chart for statistical control, we must check that process variation for all of the part numbers are approximately equal. All the parts displayed on the same DNOM Chart must have the same (similar) variation. If one of the part numbers has a large difference in the variation then we need to exclude it from the DNOM Chart. (Other options will be discussed later)

A quick check of the variation for the part number is to compare the ratio of the R-Bar from this part number to the overall R-Bar for all of the part numbers including the suspected part number.

If the ratio for the suspected part number is less than 1.3 we can consider that the variations are statistically the same and can include those part numbers on the DNOM $\bar{X}$ & R Chart ³.

For example: Let's calculate the ratio for each of the above part numbers⁴ and check to see if we need to exclude that part number from the DNOM $\bar{X}$ & R Chart.

Part	Mean	R-Bar	N
A	34.11	2.917	18
B	43.83	2.333	18
C	49.67	2.667	18

$$\text{Ratio for } \bar{R}_A = 2.917/2.639 = 1.11$$

$$\text{Ratio for } \bar{R}_B = 2.333/2.639 = 0.88$$

$$\text{Ratio for } \bar{R}_C = 2.667/2.639 = 1.01$$

Conclusion: All of the ratios do not exceed 1.3; hence we can plot the part numbers on one chart.

If the ratio is greater than 1.3, we have the following options:

- 1) Reduce the process variation for that part number such that the ratio will be less than 1.3;

³ Ellis R. Ott, *Process Quality Control: Troubleshooting And Interpretation of Data*, McGraw Hill Higher Education (1975)

⁴ See Appendix A for the data set