Manual of Petroleum Measurement Standards
Chapter 23.1

Reconciliation of Liquid Pipeline Quantities

SECOND EDITION, 202X

Introduction

In the ideal world, every drop of liquid received into a pipeline system and every drop delivered out of the system, as well as all liquid inventory within the system, would be measured and accounted for precisely, and a comparison of all receipts and all deliveries—adjusted for inventory changes—would be exactly the same. The system would never experience a loss or a gain. Unfortunately, this ideal pipeline balance seldom exists in the real world.

Most pipeline systems typically experience some degree of loss or gain over time. This represents the normal loss/gain performance for a system. From time to time, losses or gains greater than normal may occur for a variety of reasons. Excessive or unexplained loss/gain often leads to contention between participating parties, sometimes requiring monetary settlements to adjust for abnormal loss/gain. In such cases, it is necessary to be able to (1) identify abnormal loss/gain as quickly as possible, (2) determine the magnitude of abnormal loss/gain, and (3) institute corrective actions.

Sometimes losses or gains are real, and adjustments shall be made to correct shipper batches and/or inventories. Most of the time, though, there are no physical losses or gains. The loss/gain that occurs in day-to-day operation is usually small (a fraction of a percent) and is caused by small imperfections in a number of measurements in a system.

In a sense, loss/gain is an indicator of the ability to measure within a system. Loss/gain should be monitored for any given system at regular intervals to establish what is normal for that system and to identify any abnormal loss/gain so that corrective action can be taken.

Reconciliation of Liquid Pipeline Quantities

1 Scope

1.1 General

Chapter 23.1 provides methodologies for monitoring liquid hydrocarbon pipeline loss/gain and for determining the loss/gain performance level range for any such pipeline system.

This document does not establish industry standards for loss/gain performance level range because each system has its own characteristics and exhibits its own loss/gain level range and/or patterns.

Provides operational and statistically based tools for identifying when a system has deviated from normal, the magnitude of the deviation, and guidelines for identifying the causes of those variations. Troubleshooting suggestions are also presented.

1.2 Field of Application

The primary application of this publication is in custody transfer liquid pipeline systems in which there is provision for measuring all liquids that enter the system and exit the system, as well as liquid inventory within the system. The application is not intended for nonliquid or mixed-phase systems.

The applications and examples in this document are intended primarily for custody transfer pipeline systems, but the principles may be applied to any system that involves the measurement of liquids into and out of the system and possibly, inventory of liquids within the system. Such systems may include pipelines, marine terminals, marine voyages, bulk loading or storage terminals, tank farms, and rail and trucking systems.

2 Normative References

There are no normative references in this document.

3 Terms and Definitions

For the purposes of this document, these specific definitions apply.

3.1 Definitions

3.1.1
action limits
Lines on a control chart that represent a boundary between taking or not taking action to modify a process.

3.1.2
control chart
A graphical method for evaluating whether a process is in or out of a state of statistical control by using warning and action limits determined by statistical analysis of the process data.

3.1.3
control chart loss/gain
A graphical method for evaluating whether L/G and/or meter proving operations are in or out of a “state of statistical control.”

3.1.4
control limits
Lines on a control chart used to evaluate whether or not a process is in statistical control.

3.1.5
loss/gain system

L/G
L/G is the difference between deliveries and receipts, adjusted for changes in inventory, experienced by a system over a given time period (e.g., day, week, month) or over a single (or multiple) product movement(s).

NOTE Often referred to as gain / loss, or G/L.

3.1.6
natural gas liquids
NGL
Those hydrocarbons liquefied at the surface in field facilities or in gas processing plants. Natural gas liquids include ethane, propane, butanes and natural gasoline.

3.1.7
repeatability
Measurement precision under a set of repeatable conditions of measurement.

3.1.8
standard deviation
Positive square root of the variance.

3.1.9
statistical control
The data on a control chart are in a state of statistical control if the data hover in a random fashion around a central mean value, and at least 99 % of the data are within the three standard deviation control limits, and the data do not exhibit any trends with time.

3.1.10
tolerance limits
Control limits that define the action and conformance boundaries for variations to indicate when an audit or technical review of the facility may need to be conducted to determine sources of errors and changes that may be required to reduce variations.

3.1.11
standard deviation limits
Control limits equal to one, two and/or three standard deviations from the arithmetic mean of the set.

3.1.12
warning limits
Control limits applied to a control chart to indicate when equipment, operating conditions or computations should be checked because one or more data points were outside pre-established limits. Warning limits are normally based on 90-95 percent confidence levels.

3.1.13
line fill
The quantity of liquid contained in a segment of pipeline.

4 Measurement Data Analysis

4.1 General

Data may be presented in the form of control charts, trending charts, or cumulative charts. Guidelines on such charts may include control limits and trending lines. Charts used for monitoring measurement systems should be living documents and should be updated whenever new data is available.

Accumulating data for some period of time and periodically updating charts (e.g., semi-annually) serves no useful purpose. Charts and monitoring procedures can be effective only if charts are current and used as constructive tools.

4.2 Loss/Gain (L/G) Analysis

4.2.1 Loss/Gain Equations

Losses and gains may be physical issues (e.g., leaks, evaporation, theft, shrinkage, unmeasured or unaccounted liquid is added to the system etc.) or apparent issues (e.g., errors in measurement, tickets, procedures, etc.). More often, there is no actual physical loss or gain, just simply small measurement inaccuracies or accounting discrepancies. The combination of these may result in a system being outside of normal or acceptable limits.

L/G analysis typically involves collecting data, calculating L/G, and plotting L/G on any of several different types of control charts. These control charts may include control limits or other analytical guides that are derived from some simple statistical tools as per the equations described in the following sections. The tools described in this document may be used by anyone and may not require an understanding of statistics.

The two basic L/G equations (not all inclusive) are shown below. One expresses a loss as a negative value and the other expresses the loss as a positive value.

It is important to keep in mind which convention is being used to correctly decide whether the L/G values represent losses or gains.

Loss expressed as a negative number can be calculated with Equation 1:

$$\frac{L}{G} = \left(CI + D\right) - \left(OI + R\right) \tag{1}$$

Loss expressed as a positive number can be calculated with Equation 2:

$$\frac{L}{G} = \left(OI + R\right) - \left(CI + D\right) \tag{2}$$

Loss or gain of the system to be reconciled may also be provided as an absolute value to express relative distance of the variance from zero as shown in Equation 3:

$$\frac{L}{G} = \left|\left(CI + D\right) - \left(OI + R\right)\right| \tag{3}$$

System Gain: If (CI + D) > (OI + R)
System Loss: If (OI + R) > (CI + D)

In such case, loss or gain is always an absolute value, where

CI	is the closing inventory in the system at the end of the time period,
D	is the sum of deliveries out of the system during the time period,
OI	is the opening inventory in the system at the start of the period,
R	is the sum of receipts into the system during the time period, and
$\frac{L}{G}$	may be reported in units of volume (e.g., barrels, gallons or kiloliters) or mass (e.g., pounds or metric tons)

When expressed in percent, the actual L/G quantity is divided by the quantity of total receipts for a receipt-based system or by the quantity of total deliveries for a delivery-based system and multiplied by

100. Receipt based systems typically have consistent receipt volumes and delivery-based systems typically have consistent delivery volumes.

For Receipt-based systems, see Equation 4:

$$\frac{L}{G}\% = \left(\frac{L}{G} \div R\right) \times 100 \qquad (4)$$

For Delivery-based systems, see Equation 5:

$$\frac{L}{G}\% = \left(\frac{L}{G} \div D\right) \times 100 \qquad (5)$$

For Average-based systems, see Equation 6:

$$\frac{L}{G}\% = \left(\frac{L}{G} \div \left(\frac{(R+D)}{2}\right)\right) \times 100 \qquad (6)$$

NOTE In the equations above, variables shall be expressed in like units of measure. Variables calculated under the same conditions (mass, or gross standard volume [GSV] and net standard volume [NSV]), will yield the most meaningful information. (Reference API MPMS Ch. 12.1.1, *Calculation of Static Petroleum Quantities, Part 1—Upright Cylindrical Tanks and Marine Vessels*, Ch. 12.1.2, *Calculation of Static Petroleum Quantities, Part 2—Calculation Procedures for Tank Cars*, and Ch. 12.2, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors*)

4.2.2 Factors to account for in the L/G equations

4.2.2.1 Change in line fill: Opening Inventory (OI) and Closing Inventory (CI)

Change in line fill volume may contribute significantly to system inventory. If possible, line fill should be corrected for temperature, pressure and density. Pipelines should be completely empty or completely full at the beginning and end of the time period.

Line fill may be considered static, but depending on the line fill volume and throughput it may impact L/G.

The potential impact of line fill change can be estimated by performing the following calculation provided in Table 1. When the throughput of the system is considered, it clearly shows the impact reduction with increased throughput.

	Calculation	Opening	Closing	Opening	Closing	Opening	Closing
	Formulas / Units	NO CTS & CPS	NO CTS & CPS	With CTS & CPS	With CTS & CPS	Differ-ence	Differ-ence
Average Temp	Temp., °F	70.0	75.0	70.0	75.0	-	-
Average Pressure	Pressure, psi	100.0	150.0	100.0	150.0	-	-
Weighted Avg. API	°API Gravity	35.0	35.0	35.0	35.0	-	-
Weighted Avg. S&W %	S&W Vol%	0.500 %	0.500 %	0.500 %	0.500 %	-	-
GOV	Gross line fill, Barrels	100,000	100,000	100,000	100,000	-	-
Pipe ID	Inches	-	-	16	16	-	-
Wall Thickness	Inches	-	-	0.50	0.50	-	-

CTL	CTL @ Temp. & °API	0.99526	0.99289	0.99526	0.99289	-	-
CPL	CPL @ Temp & °API	1.00052	1.00079	1.00052	1.00079	-	-
CTPL	CTL * CPL	0.99578	0.99367	0.99578	0.99367	-	-
CPS	1 + (PD/Et)	1.00000	1.00000	1.00011	1.00016	-	-
CTS	1 + (T – 60) g	1.00000	1.00000	1.00019	1.00028	-	-
CCF	CTPL * CPS * CPS	0.99578	0.99367	0.99607	0.99411	-	-
GSV Volume	GOV * CCF	99,578	99,367	99,607	99,411	29	44
Net Volume	GSV – (GSV * S&W %)	99,080	98,870	99,109	98,914	29	44
Throughput	Volume, Barrels	500,000		500,000		-	-
Line fill change % of Through-put	%	-0.042 %		-0.039 %		-	-
Throughput	Volume, Barrels	5,000,000		5,000,000		-	-
Line fill change % of Through-put	%	-0.004 %		-0.004 %		-	-

Table 1—Line Fill volume change with and without Temperature and Pressure effects on steel pipe.

For a better estimation, the following pipeline corrections may be applied.

To correct for the effect of pressure on steel of pipe (CPS), use Equation 7:

$$\text{12-month average } \% = \left(\frac{\sum \text{last 12-months } \dfrac{L}{G} \text{ volume}}{\sum \text{last 12-months } \left(\text{receipts, deliveries, or average}\right)} \right) \times 100 \tag{7}$$

Where,

P is internal pressure, psig

D is internal diameter, inches

t is wall thickness of pipe, inches, and

E is modulus of elasticity for pipe (E = 3.00E+07 for mild steel)

To correct for the effect of temperature on steel of pipe (CPS), use Equation 8:

$$CTS = 1 + \left(T - 60\right) g \tag{8}$$

Where,

T is temperature in ˚F (fluid temperature), and

g is coefficient of cubical expansion per ˚F of pipe material (1.86E-05 for mild steel)

4.2.2.1.1 Factors to account for in the L/G equations

Several additional factors may impact loss / gain equations, including:

- Cavern inventory (generally salt caverns are not included in L/G systems)
- Line fill volume may change due to a project or maintenance work
- Slack line

NOTE See API MPMS Chapter 17.6, *Guidelines for Determining the Fullness of Pipelines Between Marine Vessels and Shore Facilities*, for determination of pipeline fullness

4.2.2.2 Deliveries (D) and Receipts (R)

The following are factors which can influence loss / gain on deliveries or receipts:

4.2.2.2.1 Meters or Custody tank transfer

Perhaps the most common errors occurring on manually calculated measurement tickets are arithmetic errors and wrong correction factors applied.

Tickets that do not get into the accounting process on time will cause an apparent loss or gain in the current accounting period and an offsetting gain or loss in the following period.

4.2.2.2.2 Sump tank

Sumps collect drips and drains from several sources and may add a bias to a system loss or gain if the sumps are emptied by pumping into a pipeline system without being measured. Usually, sump volumes are small enough to not impact the overall L/G for the system. However, the volumes may be significant if sumps accumulate large volumes, such as frequent drain downs from provers or pig traps.

4.2.2.2.3 Unmetered Volumes

Factors to consider when unmetered volumes are present in the system or are estimated:

- Pipeline relief events and/or unmetered product flaring
- Pigging
- Line emptying
- Project work
- Chemical Additive injection
- Theft
- Tank evaporation
- Product growth or shrinkage

NOTE See API MPMS Ch. 12.3, *Volumetric Shrinkage Resulting from Blending Light Hydrocarbons With Crude Oils*

4.2.2.3 Once the reconciliation of the system (or a part of the system) is complete, its results shall be compared to the criteria and limits established by the operator. If the system's Loss or Gain meets the established criteria (see Section 4.3), and there are no known issues associated with the system's performance during the timeframe being evaluated, then no further action may be required. It is a good practice to always develop control charts to conduct further data analysis to ensure that all components of the system were in control, and no special cause variations were present, which could mask a potential issue with either equipment or processes. Detailed analysis (segmenting system into smaller segments) may be desirable on the complex systems with multiple inlets and outlets and with multiple parties in the system. The overall Loss or Gain may stay well within the acceptable limits, but some segments can show larger variances which can seriously affect the involved parties.

If the system’s Loss or Gain is found outside of the established criteria, then further data analysis and investigation of the excessive variances should be conducted. Various control charts and other troubleshooting tools and techniques included in this document can help operator to identify the cause of the problem and work on necessary corrections.

NOTE 1 See Section 5 and Annex D for troubleshooting suggestions and techniques.

NOTE 2 For additional information on line fill refer to GPA Midstream Guideline PFPDM-23, *Guidelines for Pipeline Fill, Pack, and Determination Methodology*.

4.3 Control Charts

4.3.1 General

To ensure accurate measurement, it's essential to continuously monitor measurement results to determine if systems, or equipment and procedures, perform as expected and operate within acceptable limits. Utilizing control charts can facilitate this process.

Control limits are often determined by historical performance of the system. In other cases, the control limits are set on an established value (e.g., contractual limits). Due to inherent issues (built in biases, etc.) with both of those models, consideration should be given to establishing control limits based on the capabilities of the equipment in the L/G system. Statistical analysis of the uncertainties of the measurement equipment (i.e., meters, prover, etc.) and procedures (verification/calibration frequencies, tolerances, etc.) can also be utilized to establish control limits. See Annex B for one such method for establishing control limits. Control charts are the most common method of ascertaining system L/G performance. Control charts display a collection of data over some period of time and include the control limits. Control charts help to define normal trends of a system and may indicate when something has changed. Typical L/G charts, as shown in Figure 1, indicate a system’s performance based on a percentage of throughputs over time. Typically, because accounting systems encompass a 30-day period, monthly evaluations of a system are commonly used to evaluate performance. Control charts may be prepared for any time span (e.g., weekly or daily) if adequate data are available.

Control charts may be maintained for entire systems or for individual segments of a system if measurement and records are available at the junctures of segments. The limits of the control charts will depend on the accuracy of the available measurement systems.

The data on control charts should remain near or around a target value and can be represented by a horizontal line on the chart. This target value is generally based on the anticipated or expected L/G of the system (typically at or near 0 %). The control chart also includes UCLs and LCLs that may be:

1) Defined statistically as two and three standard deviations above and below the target value or

2) Defined as engineering, historical or contractual limits, which are values based on experience or performance objectives

Standard deviation is a statistical measure of the spread of a data set with respect to the mean value of the set the specific number of deviations as determined by the user(s). Procedures for calculating statistical quantities are shown in Annex A.

Figure 1 shows the example of a typical control chart.

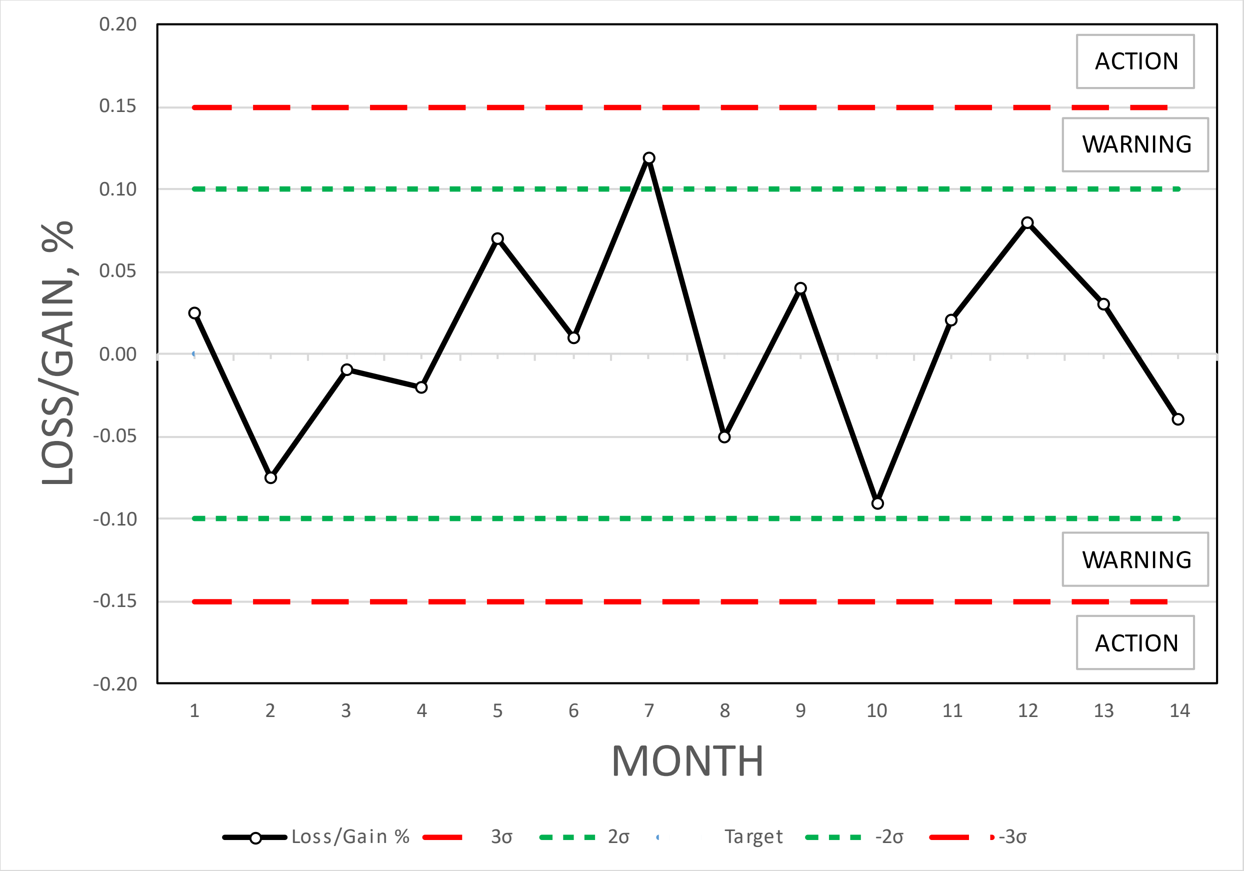


Figure 1 – Sample Control Chart

The data shall be representative of the expected performance of the system, as the control limits will be used to predict near-future performance. Any data point that is known to be the result of a special cause should be shown on the control chart but should not be included in the calculation of target, standard deviation, or control limits, and the number of data points shall be adjusted accordingly. A special cause is an event (e.g., meter failure, late run ticket, line displacement with water for hydrostatic pressure test, etc.) that results in mismeasurement for a given period of time but is not a part of the normal operation of the system.

Charts can be used to determine system stability, cyclical trends, or step changes in performance. One of the most important benefits of using charts to assess performance is the instant visual representation it provides.

The adage “a picture paints a thousand words” best summarizes the effectiveness of control charting.

NOTE For further information on control charts and their interpretation, refer to Annex B “Interpreting Control Charts”.

4.4 Pipeline System Control Charts

4.4.1 A useful tool for monitoring pipeline systems is the control chart that shows L/G as percent of throughput over time. Total receipts are used for throughput in receipt-based systems, and total deliveries are used for delivery-based systems.

For historical performance-based control limits to be statistically significant, a minimum of 30 data points is required. For practical purposes, control limits for a pipeline system that is monitored monthly will often be based on monthly L/G data. For our purposes, the 24 data points are acceptable. It is common practice to set limits at the beginning of each calendar year based on the prior history. These limits are carried forward for the calendar year unless there is a change in the process that would require new limits. Until enough data is collected to establish historically performance-based control limits, reasonable control limits should be established and applied by the system operator.

NOTE When calculating limits based on historical data, pay careful consideration to outliers. Outliers are data points that are notably different from other data points, and they can cause problems in statistical procedures. There are several statistical outlier tests that can be used to remove biases caused by outliers.

4.4.2 Setting fixed limits for L/G, without regard to actual data, may be required for contractual reasons. Whenever possible, it is more practical to set limits based on historical data. Care should be taken to avoid bias conditions or outliers affecting the control limit calculations. A pipeline system tends to operate at a level of performance that is dictated by, but not limited to, physical configuration, equipment, procedures, maintenance practices, environmental conditions, and employee training. All these factors combine to produce a natural randomness and, sometimes, a natural bias in a system. For systems that have other constraints, it may be desirable to include a second set of limits. See Annex A for tolerance calculations.

Figure 2 shows the L/G data for two years. This data may be used to set control limits for the following year.

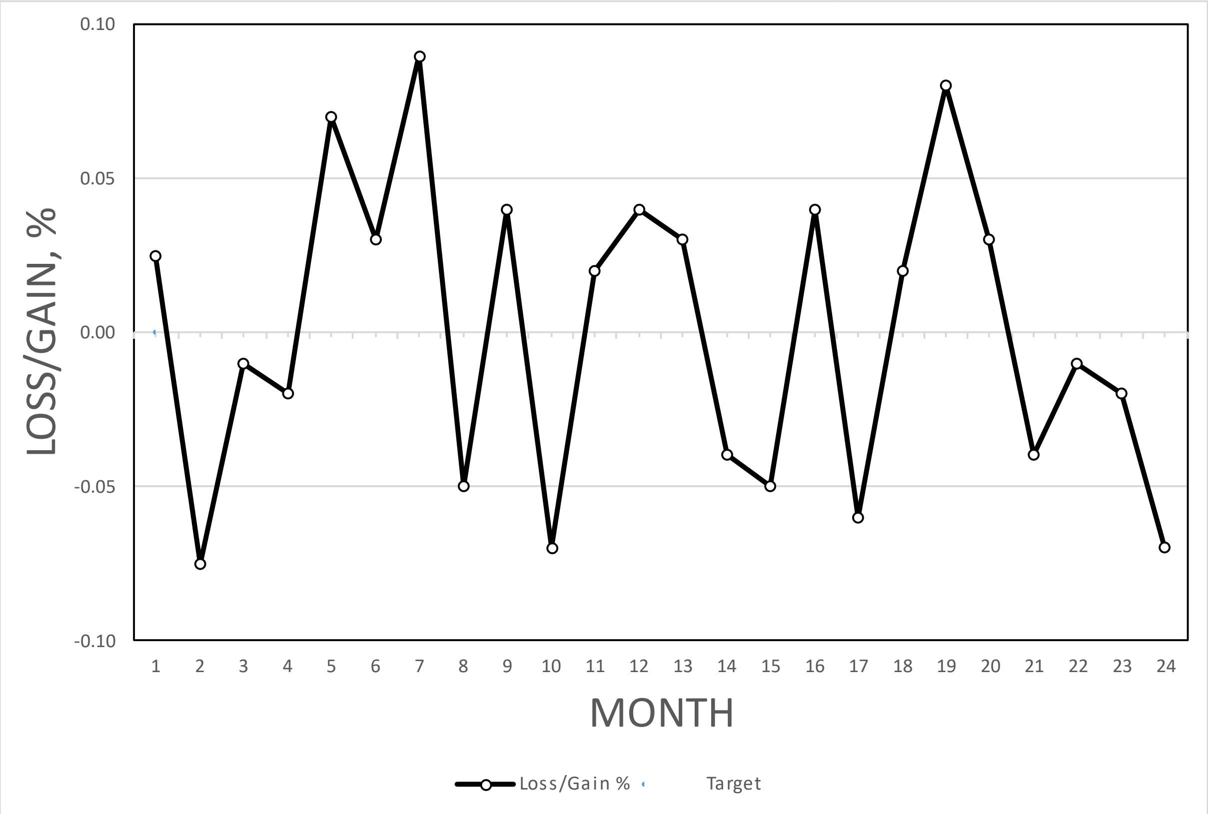


Figure 2 – Two Years of Data for Control Limits

Figure 3 shows the first three-month data compared with the two-year historical control limits.

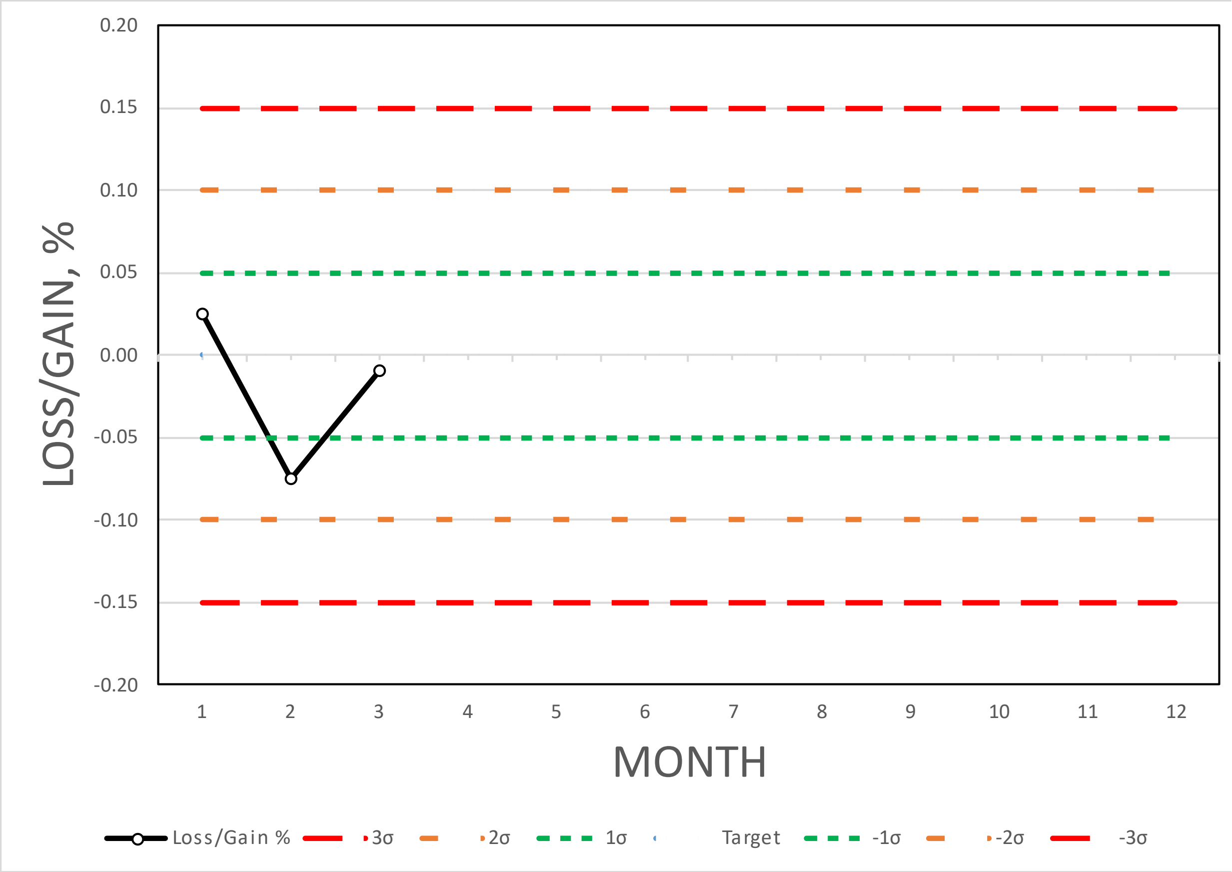


Figure 3 – Control Chart for the Following Year

4.4.3 Users should determine whether a system is stable and in control. A system is said to be stable if the data exhibit only random fluctuations around the mean without trends. A system is generally considered to be in control if the data are all within control limits that have been established from the data. Data points outside the control range indicate poor control.

4.4.4 When physical or operational changes are made to a system, the L/G pattern for the system will often change. When this happens, the prior two-year history may not be suitable for setting the control limits. In such cases, a moving range chart may be used until sufficient history is developed to define the system's new pattern. In a moving range chart, the mean and standard deviation are recalculated each time new data are available using all data since the change. The resulting mean and control limit lines on the control chart may exhibit an immediate step change to a new level of control or may change gradually for some period of time until the system stabilizes at a new level of control.

4.5 Meter Factor Control Charts

4.5.1 Control charts can be used for tracking various things. Meter factors are an example.

4.5.2 Control charts may also be used to monitor meter performance, in which case meter factor is plotted as a function of either time or volume throughput.

NOTE For additional guidance on uncertainties in meter data, see API MPMS Ch. 13.2, *Methods of Evaluating Meter Proving Data*.

4.6 Trending Charts

4.6.1 Trending charts may be used when data exhibit a definite upward or downward trend and may not hover around a simple horizontal mean value. Such charts may be shown as a trending run chart merely to show a trend in the data or may resemble a control chart with lines representing average performance (similar to “mean”) and control limits that follow the upward or downward trend of the data.

4.6.2 12-month rolling average charts are often trending charts that can assist in identifying process issues as shown in Figure 4. 12-month rolling average control chart tolerance should be tighter than monthly control charts because normal monthly fluctuations should smooth out over a 12-month period. As shown in Figure 4, the 12-month tolerances are 50 % of the monthly tolerances.

The calculation of the 12-month rolling average is not the average of the L/G % averaged over the previous 12 months. Depending on whether the system is receipt-based, delivery-based or average-based, it is calculated as follows in Equation 9:

$$\text{12-month average \%} = \left(\frac{\sum \text{last 12-months } \frac{L}{G} \text{ volume}}{\sum \text{last 12-months } \left(\text{receipts, deliveries, or average}\right)} \right) \times 100 \qquad (9)$$

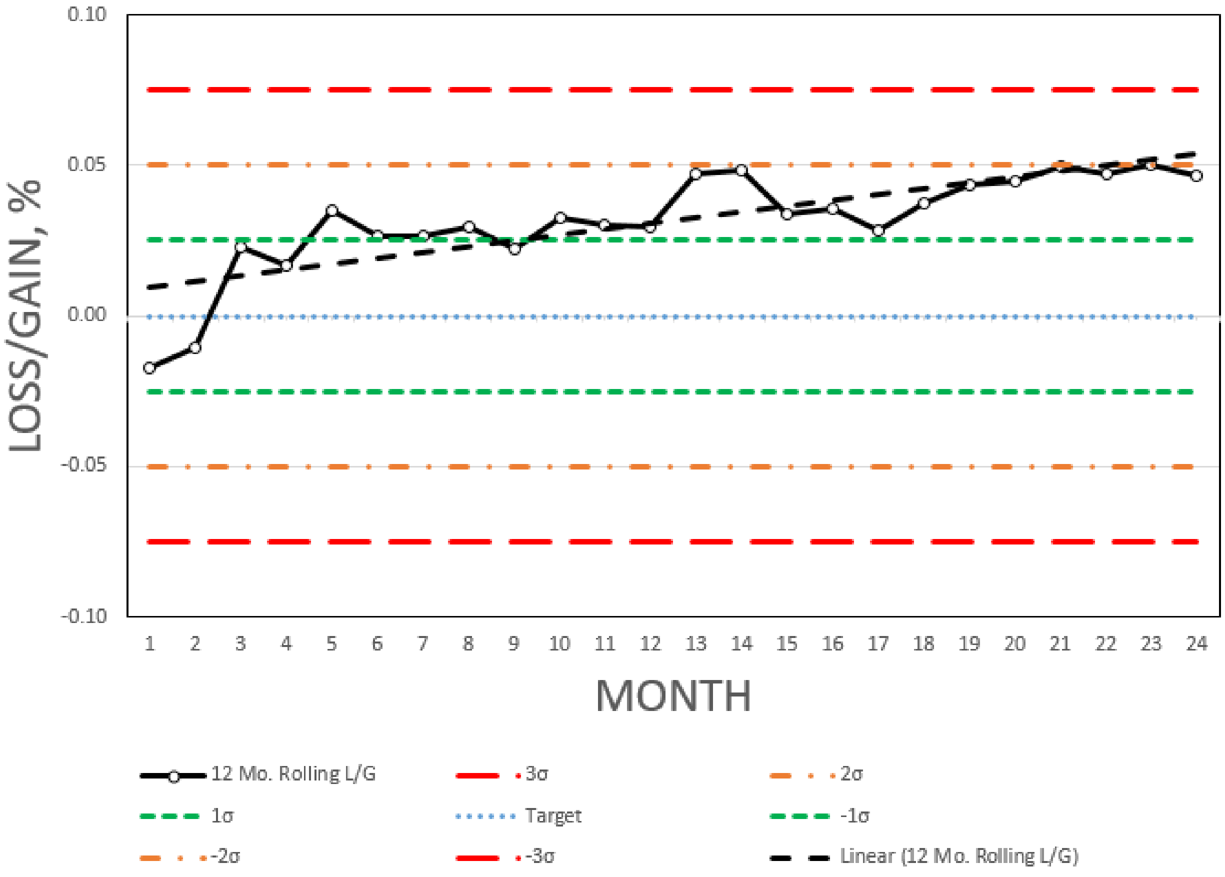


Figure 4 – 12 month Rolling Average

4.7 Cumulative Charts

4.7.1 Cumulative charts are similar to trending charts but plot the cumulative values of some variable such as L/G vs time. The cumulative value is obtained by arithmetically (i.e., keeping the plus and minus signs) adding the value of each data point to the sum of all the data points preceding it in a sequence of data.

4.7.2 The data in cumulative charts do not hover around a central mean value. They exhibit an upward or downward trend. The shape of the curve is the main characteristic of cumulative charts, and changes in shape or general trend are very important.

4.7.3 L/G data may be plotted on cumulative charts. In Figure 5, the L/G quantities are measured in barrels, but other volume or mass quantities may be used as appropriate.

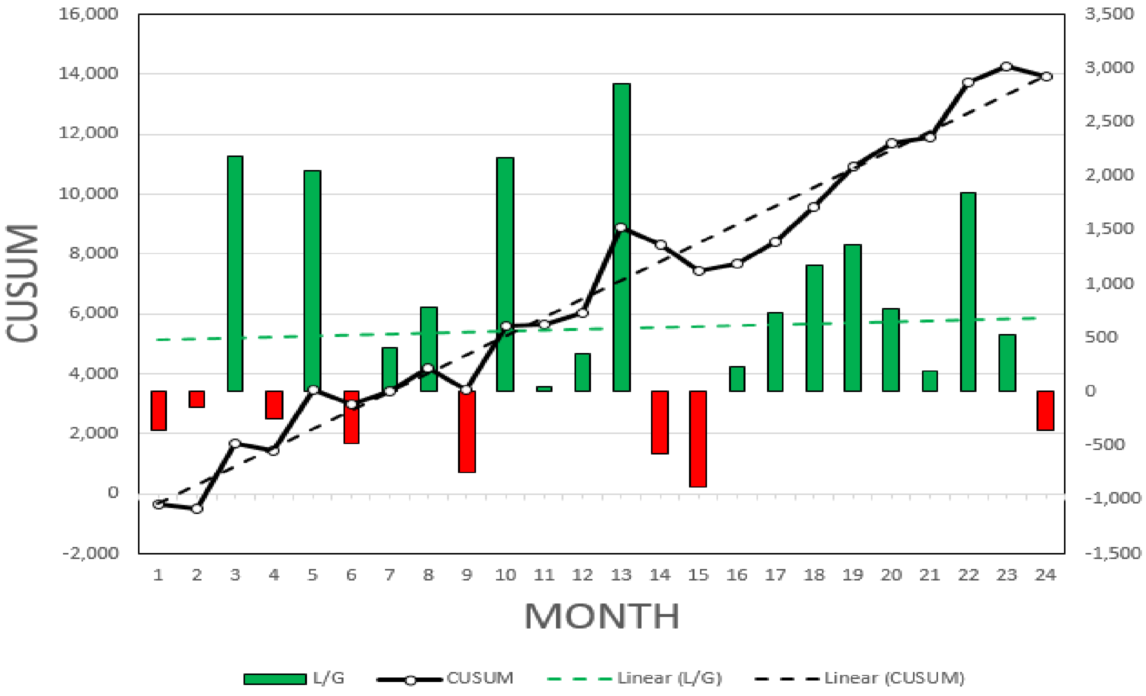


Figure 5 – Cumulative Chart – CUSUM vs L/G

4.7.4 Cumulative L/G charts can be informative to the practiced eye. They often indicate the onset of a trend before it is evident on a conventional control chart. A system that is performing normally will generally exhibit a steady trend. A sudden shift in the pattern or a definite change in the rate of trend (change in general slope of the data) usually indicates that something abnormal happened.

4.7.5 The cumulative chart can also be useful for visually demonstrating the quality of sediment and water (S&W) measurement in a crude liquid system by plotting GSV and NSV on the same chart as shown in Figure 6. In this chart, the first eight months are typical of a system with consistent S&W measurement. The NSV line may be a bit below the GSV. However, if the two lines are close together and essentially parallel, S&W measurement is consistent and uniform. If, on the other hand, the two lines diverge, as shown during the last eight months in Figure 6, S&W measurement is not consistent and/or is not uniform. This could signal an opportunity to improve S&W measurement in the system. Figure 6 depicts a potential issue with the delivery S&W measurement and Figure 7 depicts a potential issue with the receipt S&W measurement.

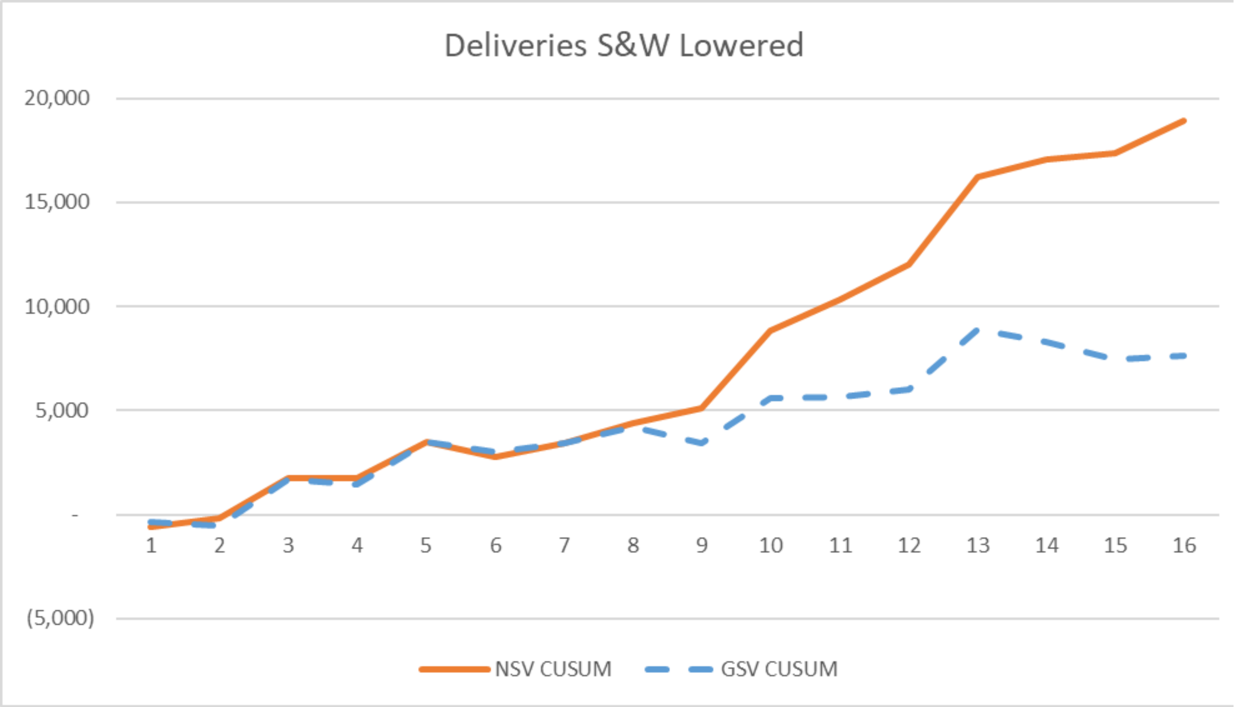


Figure 6 – Cumulative NSV versus GSV

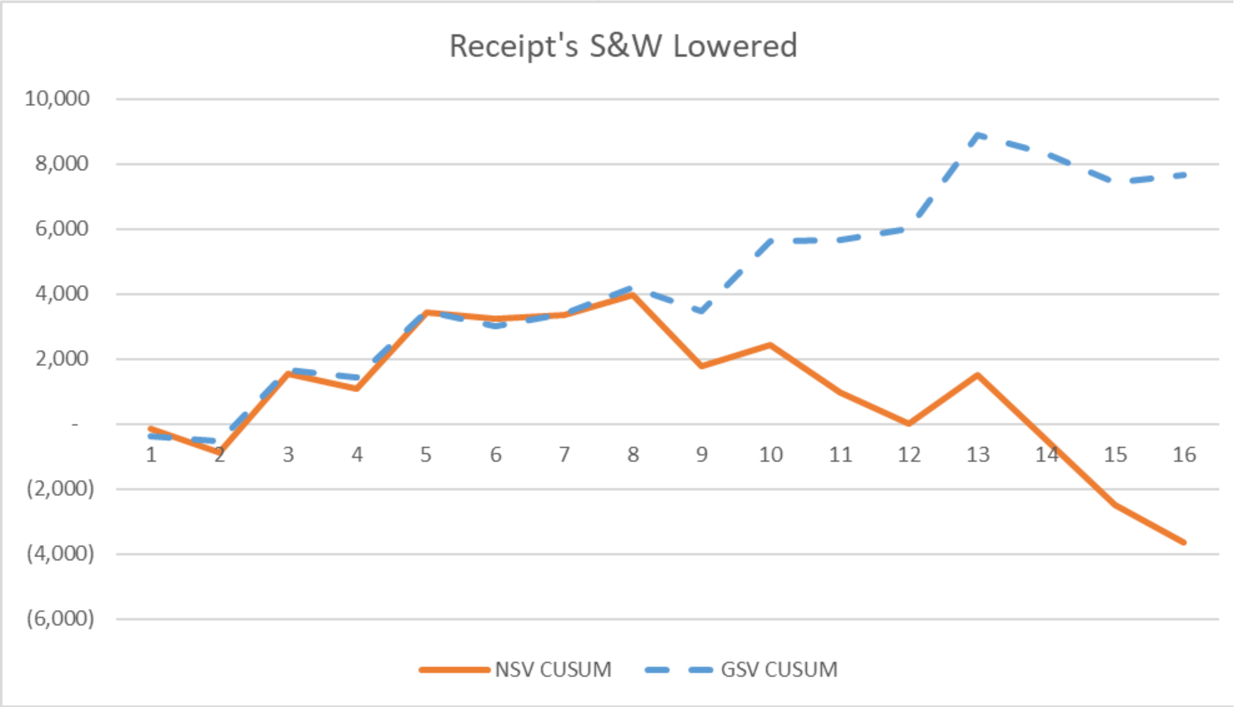


Figure 7 – Cumulative NSV versus GSV

4.7.6 S&W content is the composite of sampling equipment type and installation, frequency of sampling, stream mixing ahead of the sampler, withdrawing the laboratory portion of sample from the field sample container, maintaining the integrity of the sample between the field and the laboratory, handling and remixing in the laboratory, and the S&W measurement process. Inexactitude in any part of the chain of events will lead to an erroneous answer. Individual companies may set acceptable tolerances based on experience for use in their operations.

NOTE For further information on control charts and their interpretation, refer to Annex B “Interpreting Control Charts”.

5 Troubleshooting

5.1 General

One of the challenges of today’s pipeline measurement personnel is troubleshooting pipeline losses and gains. Whenever losses or gains exceed established limits, an investigation should be initiated to determine the cause and whether adjustments are required to bring a system into balance.

Troubleshooting pipeline losses involves an understanding of the L/G process and may require collecting and analyzing data, interviewing personnel, and visiting facilities to assess equipment performance and witness measurement activities. Ultimately, loss investigations should include a conclusion of the findings along with recommendations for correction and improvements.

5.2 The Troubleshooting Process

5.2.1 General

Investigating pipeline losses can often be challenging if not frustrating. It is not uncommon for the process to take as long to resolve as it does for losses to appear. With a keen eye for detail, some losses can be resolved in minutes, whereas some may take weeks, months, or even longer. (See Annex D for a Troubleshooting Guide for Pipeline Measurement Operations.)

5.2.2 Analyzing Measurement Data

The first step in identifying losses involves a review of the measurement data. An L/G report is usually the red flag that signals that a system is out of control. Start by carefully reviewing the report and ensure that input data were accurate and timely. Computer generated reports are only as good as the data entered. It is important to first understand the data entry process and then the integrity of the data used to populate the report.

With the increasing number of automatic data acquisition and processing tools and options, the data validation is an extremely important step of each reconciliation process. The risks associated with data manipulation, built-in biases and errors shall be recognized. All tools and systems from the source through the final report should be validated and included into the troubleshooting process.

5.2.3 Looking for the Obvious

Custody measurement records such as tickets, proving reports, and meter performance logs can be obtained and reviewed from the office environment. Reviewing measurement calculations is an easy way to check for measurement error. Often, human error, equipment failure, or software glitches can quickly be identified.

Reviewing records and historical data is of key importance. Look for patterns, often hidden among the noise caused by large month-to-month variations. Look for step changes linked to operational changes at the facility. There are many possible operational changes that can affect reported losses. Some items that should be investigated are as follows:

- personnel,
- procedures,

- facility operating conditions,
- pigging operations,
- variables associated with DRA injection,
- product flaring, vaporization, or vapor recovery,
- software/calculations,
- missing data (e.g., run tickets),
- weather conditions,
- security, data security,
- physical theft or data theft

For additional troubleshooting guidance refer to Annex D.

5.2.4 Interviewing Personnel

The best method of identifying change is by interviewing the personnel responsible for the system(s). This includes the measurement technician, gauger, or operator, other technicians and relevant personnel performing work at the sites. The key to obtaining useful information from field personnel is to establish a dialogue that is nonconfrontational. Sharing ownership of the problem, as well as the credit for the resolution, is often the best approach.

5.2.5 Reviewing the Facility

Another step in the process is to conduct a field assessment and investigate the causes of the excessive losses or gains. This may involve a visit to the facilities to review the equipment and the measurement procedures/documentation. Determine if the proper procedures are being followed in accordance with company and industry guidelines. Observe piping details, equipment placement, and other visual records that may be indicators to or influence the measurement performance. It is important to be able to discuss the facility and its operation with the measurement personnel who conduct day-to-day activities. They usually know the facility much better than the investigator and can often provide a detailed history of changes for a facility.

5.3 Inaccuracies and Uncertainties

5.3.1 General

Many everyday things can cause inaccuracy or uncertainty in measurement and, thereby, contribute to losses and gains in a system.

When a measurement of a quantity is conducted, the result obtained is not the actual true value of the quantity but only an estimate of the value. This is because no instrument is perfect; there will always be a margin of doubt about the result of any measurement. The uncertainty of a measurement is the size of this margin of doubt.

To fully express the result of a measurement three numbers are required:

1) The measured value. This is simply the figure indicated on the measuring instrument.
2) The uncertainty of the measurement. This is the margin or interval around the indicated value inside which you would expect the true value to lie with a given confidence level.
3) The level of confidence attached to the uncertainty. This is a measure of the likelihood that the true value of a measurement lies in the defined uncertainty interval. In industry, the confidence level is usually set at 95 %.

Often the terms “inaccuracy” and “uncertainty” are confused and used interchangeably. As provided above, uncertainty is the margin of doubt associated with a measurement. Inaccuracy (or error) is the difference between the measured value and the true value.

NOTE For further details on uncertainty and the statistical calculations associated with uncertainly refer to Annex A.

5.3.2 Meters and Meter Proving

Users should refer to API MPMS Ch. 4.1, *Section 1—Introduction*, Ch. 13.2, *Methods of Evaluating Meter Proving Data*, and Ch. 13.3 *Measurement Uncertainty*, for the uncertainties of Flow Metering and Meter Proving as appropriate.

NOTE Additionally, refer Annex D of this chapter, *Troubleshooting Guide for Liquid Pipeline Measurement Operations*

5.3.3 Tanks

The physical closing tank gauge reading from the previous period should match the physical opening tank gauge reading for the current period.

Tanks that are gauged for inventory and that are active at the time of gauging should be allowed to rest long enough to be gauged without liquid moving in or out.

Accurate month-end inventory gauges are especially important because they are used to balance and close out pipeline and/or terminal inventories and to issue customer and billing reports. Multiple customers may share the same storage in a fungible tank, and L/G offsets from month to month can be difficult to allocate.

Users should refer to API MPMS Ch. 3.1A, *Standard Practice for the Manual Gauging of Petroleum and Petroleum Products*, for information on uncertainties relating to tank measurement.

NOTE Additionally, refer Annex D of this chapter, *Troubleshooting Guide for Liquid Pipeline Measurement Operations*

5.3.4 Explainable L/G and Biases

Certain L/G inaccuracies can be explained and quantified, whereas others can be explained but not quantified. Likewise, minor meter imbalances or recurring hourly shortages/overages can be the result of many factors.

NOTE 1 Refer to Annex C for specifics associated with NGL quantity reconciliations.

NOTE 2 Refer to Annex D for the examples of explainable Losses and Gains.

5.3.4.1 The size of a tender (batch, parcel, movement, shipment) is a factor in the overall loss or gain in the tender. Fewer/larger tenders for the same period of time may help with better L/G performance.

5.3.4.2 Equipment that is not calibrated, certified, or verified such as thermometers, hydrometers, temperature gauges, gauge tapes, and centrifuge tubes may be inaccurate. If so, this will add a bias to the system L/G.

5.3.4.3 Common errors occurring on manually calculated measurement tickets include arithmetic mistakes, data entry mistakes, and pulling wrong correction factors from tables.

5.3.4.4 Tickets that do not get into the accounting process on time will cause an apparent loss or gain in the current accounting period and an offsetting gain or loss in the following period.

5.3.4.5 Timing discrepancies, period to period, in closing meter readings and inventory information can be a major factor in properly establishing L/G for an accounting period.

5.3.4.6 The closing tank gauge reading from the previous period should match the opening tank gauge reading for the current period.

5.3.4.7 Accurate month-end inventory gauges are very important because they are used to balance and close out pipeline and/or terminal inventories and to issue customer reports and billing. Multiple customers may share the same storage in a fungible tank, and L/G offsets from month to month can be difficult to allocate. Month-end gauges are also useful to identify trends that may reveal a bias (e.g., a systematic error).

5.3.4.8 Sumps collect drips and drains from a number of sources and may add a bias to a system L/G if the sumps are emptied by pumping into a pipeline system without being measured. Usually, sump volumes are small enough to be significant. However, the volumes may be significant if sumps accumulate large volumes, such as frequent drain downs from provers or scraper traps.

5.3.4.9 Wax may deposit on pipe walls when a waxy crude liquid is cooled below the cloud point. Wax changes volume by a measurable amount when it changes from the liquid state to the solid state. This can affect line fill volume and, thereby, affect L/G. Even if wax does not deposit on the inside of pipe walls, the change from liquid to suspended microcrystalline solids results in a volume change in the overall liquid, and there may be a measurable difference between pipeline receipt volumes and delivery volumes.

5.3.4.10 Correction for the temperature of the liquid (CTL). The physical characteristics of given liquid(s) may not be accurately represented by the applicable volume correction tables, including API MPMS Chapter 11.1 or Chapter 11.2.4.

Examples of some additional system biases include, but are not limited to, the following:

- Inconsistent sampling techniques and/or containers (i.e., single cavity vs. piston cylinders)
- Methods of analysis (i.e., S&W by centrifuge vs. other methodologies)
- Variations between test results from different Labs
- Inconsistent product composition applied to various points of the system
- Inconsistent pressure in different line segments due to pumping capabilities or pipeline elevation profile
- Different types of meters used within same system
- Meter proving procedures
- Meter proving frequency
- Measurement systems - tanks vs. meters
- Mixing systems (i.e., static vs. powered)
- Temperature units (i.e., Fahrenheit vs Celsius)
- Pressure units (i.e., psia vs psig, or psi vs kPa)
- Liquid properties
- Viscosity

NOTE 1 Refer to Annex C for specifics associated with NGL quantity reconciliations.

NOTE 2 Refer to Annex D for the additional information on system biases and the examples of explainable Losses and Gains.

6 Reporting

6.1 Resolving the Loss/Gain

6.1.1 A loss investigation is successful when the cause has been identified and appropriate actions are taken to resolve or correct the problem. A key role of the loss investigator is to thoroughly document the findings from background to resolution so there is a clear understanding of the problem, how the problem lead to a loss (or gain), and, most important, what is required to resolve the problem and prevent reoccurrence. Investigative reports should provide detailed recommendations and responsibility assignments to ensure complete resolution.

6.1.2 Sometimes, due to any number of issues regarding measurement systems, the measurement reading will not be accurate and an adjustment for the measurement period in question should be made until the measurement system is either repaired or replaced. Such adjustments can be made based on the available secondary measurement systems, such as tank gauging or meter information from upstream or downstream of the inaccurate measurement system. The adjustments should be agreed upon by the affected parties and properly documented.

6.1.3 To troubleshoot the out-of-tolerance gains or losses, it is generally a good practice to collect and analyze all difference trend data available between primary and secondary measurement data. For example, a comparison of metered volumes with the corresponding shore tank received or delivered volumes on both ends of line. The trend will often show a change in deviation, which will indicate where to begin further investigation.

6.1.4 Once the cause of an excessive loss or gain has been identified and resolved, in certain cases it may be possible to go back and correct measurement tickets for the period of time affected by the inaccurate measurement. If the adjustments are agreed by all affected parties and follow the agreed upon procedures, contractual obligations, and the established rules and regulations (such as pipeline tariffs, etc.), tickets may be revised.

Two sets of data are often available for stock balances:

- **"Accounting month"** includes all transactions that entered the books during the month including adjustments, corrections, and late tickets from prior months.
- **"Current month"** includes only actual receipts, deliveries, and inventory changes that occurred during the month. It does not include late tickets or adjustments from prior months.

It is desirable to look at current month data because that data set tells us the most about the physical operation of a system. It tends to highlight the fundamental accuracy of a system, equipment malfunctions, and procedural errors.

Analysis of accounting month data can help to identify problems in ticket preparation and handling and other accounting type problems. It may not be necessary to be concerned about the occasional bobble, but recurring problems need to be identified and corrected.

7 Calculating System Uncertainties

7.1 It is useful to determine the uncertainty of the system to understand the capability of the overall gain/loss analysis.

7.2 The uncertainty of the system is calculated as follows:

First, the Loss/Gain of the system is defined as Equation 10:

$$L/G_{system} = Stock_{Initial} + Inputs - Outputs - Stock_{Final} = \Delta Stock + Inputs - Outputs \tag{10}$$

The second step is to calculate the uncertainty of the system as shown in Equation 11:

$$U_{LG\ System} = \sqrt{U_{\Delta S}^2 + \Sigma_i U_{Input_i}^2 + \Sigma_{Output_j}^2} \tag{11}$$

where,

$U_{\Delta S}$ is the uncertainty of the variation in the inventory/stock measurement

U_{Input} is the uncertainty of the input measurements

U_{Output} is the uncertainty of the output measurements

7.3 System conditions may vary during the measurement process. Understanding those variations is important to determine their contribution to the overall uncertainty.

7.4 If the calculations of the uncertainty are too difficult to determine for the system (no instrument information, complex process, etc.), analysis of historical data should be performed. Care should be taken using historical data because biases and structural issues can become normalized.

7.5 If the scatter in data is already known for a given operation, then the uncertainty limits will be known, and any measurement that falls outside the limits corresponding to 95 % probability should be rejected. When only two measurements are available, and their difference exceeds the repeatability, then both measurements may be suspect. It should be stressed, however, that measurements should never be discarded freely. An attempt shall be made to find a reason for the extreme values, after which corrective action can be taken.

7.6 Estimating overall uncertainty of the system and making the calculations available for all parties is essential for communications. A consistent basis of estimating uncertainty can help to avoid disputes and dispel delusions on the accuracy of the activities.

7.7 Reviewing the loss/gain and understanding the uncertainty of the system can provide insight into the level of improvement that can be achieved by investing into it (technology, procedures, training, etc.).

NOTE Refer to Annex A for the additional information on system uncertainty calculations.

8 Improving System Performance

This section is intended to provide guidance that could be used to improve system performance.

8.1 Almost all measurement systems can be improved in one form or another. Improvements typically have associated operational expenses, which are decided on the basis of some acceptable level of system performance, or, in other words, the quantity of the losses. It is important to understand that the uncertainties of a particular system are limited to the capabilities related to measurement.

8.2 Individual measurement uncertainties are related to a particular point in time. Monthly reconciliations tend to reduce random errors, making bias visible for the measurement professional.

8.3 The uncertainty depends on the equipment and procedures in place.

8.4 An analysis of the measurement system can be used to define the current capability and the improvement that might be accomplished with upgraded equipment and procedures. Installing more accurate measurement equipment, using improved operational procedures, and instituting an ongoing training and witnessing program for measurement or operations personnel should improve system performance.

8.5 Pipeline measurement accuracy may take several months, or even years, to reach a performance level acceptable to the pipeline organization.

Annex A
(informative)

Statistical and Uncertainty Calculations

This informative annex will present several ways to determine control limits to the L/G of a system using statistical or uncertainty calculations as a tool.

A.1 Calculation of Tolerances for a pipeline system based on uncertainties

This model is based on the determination of the uncertainty of the complete measurement system. The model encompasses all measurement systems involved in the transfer of the product. This is shown in Equation A.1:

$$Tolerance_{Batch} = \pm\sqrt[2]{U_{Input}^2 + U_{Output}^2} \tag{A.1}$$

Where,

U_{Input} and U_{Output} are the uncertainties of the two measurement systems involved in a simple transfer.

This tolerance applies independently to each batch transfer through the pipeline.

If the measurement system is more complex, for example a pipeline with two or more inputs and one or more outputs, the equation can be expressed as follows in Equation A.2:

$$Tolerance_{Batch} = \pm\sqrt[2]{\sum_{i=0}^{n} U_i^2} \tag{A.2}$$

Where,

n corresponds to the number of measurement systems involved in the transfer system.

To determine a tolerance for a certain period of time (for example, a month), Equation A.3 can be applied:

$$Tolerance_{Period} = \pm\frac{Tolerance_{Batch}}{\sqrt[2]{n}} \tag{A.3}$$

Where,

n is the number of batches transferred in the considered period.

To calculate the monthly product quantity balance by product we may use the following equation A.4:

$$\text{Accumulated Difference} = \sum \text{Input Volume} - \sum \text{Output Volume} \tag{A.4}$$

To measure by tolerance index, use Equation A.5:

$$IT\% = \left(\frac{\sum \text{Input Volume} - \sum \text{Output Volume}}{\sum \text{Input Volume}}\right) \bullet 100\% \tag{A.5}$$

Where,

IT is the Tolerance Index for the measurement system.

A.1.1 Calculation of Uncertainties for each batch

For control of quantities, a monthly tolerance for the balance in a pipeline is recommended. This monthly tolerance is based on the computed uncertainties of the measurement system. The measurement system in this scenario is defined as:

- Product Input (U_I: Input Measurement Uncertainty)
- Product Output (U_O: Output Measurement Uncertainty)

In this case, both systems have the same characteristics and operate under the same conditions, and it may happen that the same system is used for both the Input and Output measurements.

A.1.1.1 Determination of U_I and U_O

The input and output volumes of the pipeline are based on the Quantity Certificate or Meter Ticket agreed between the parties involved in the transfer, these reports are generated by the Flow Computer of the measurement system adjusted to 15 °C and 1 atmosphere (atm).

In the case of multi-product pipelines, we should consider the calculation of the amount of product in the interface between batches of different products, except if a physical separator or "pig" is used to prevent the mixture between the two products, therefore Product A and Product B can be expressed with Equation A.6:

$$Vol.A_{Input} = Vol.BatchA_{Input} + Vol.BatchA_{InitialInterface} + Vol.A_{FinalInterface}$$

(A.6)

$$Vol.A_{Input} = Vol.BatchA_{Input} + Vol.A_{InitialInterface} + Vol.A_{FinalInterface} \tag{A.6}$$

Where,

$Vol.BatchA_{Input}$	is the volume of Product A that enters the Pipeline excluding the content in the Interface
$Vol.BatchA_{InitialInterface}$	is the Volume of Product A in the Initial Interface, and
$Vol.A_{FinalInterface}$	is the Volume of Product A in the Final Interface

The same analysis corresponds to the measurement of the pipeline outlet ($Vol.A_{Out}$).

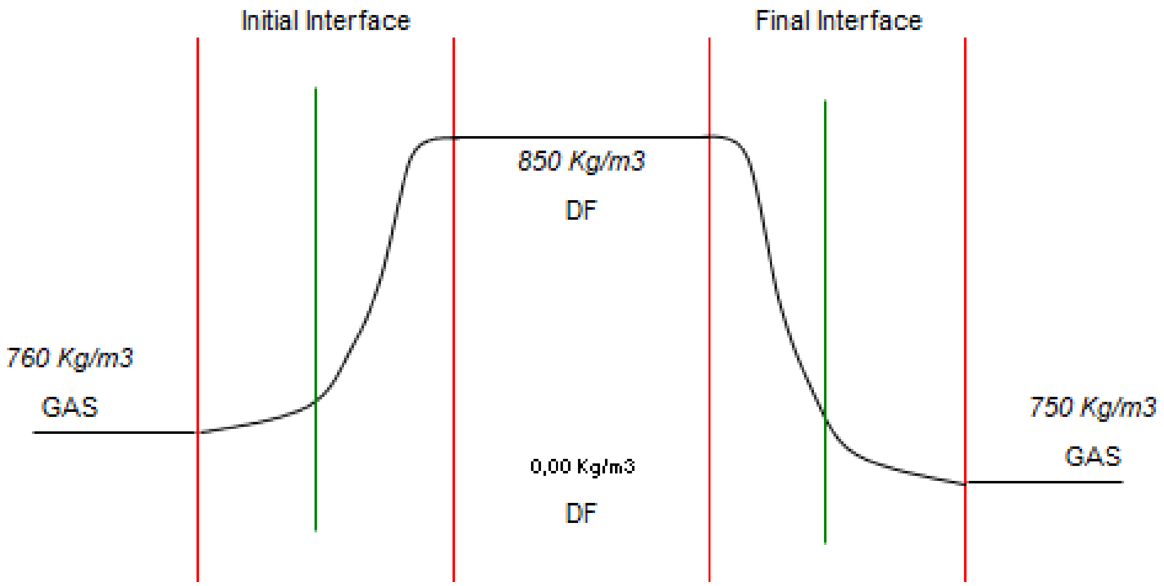


Figure A.1 – Example of interface volumes using Gasoline (GAS) and Diesel Fuel (DF)

NOTE In the present example, the stocks inside the Pipelines were not considered as they don't affect the calculation.

A.1.1.2 Determination of Uncertainties of interfaces

For the measurement of the Input and/or Output volumes excluding the Interfaces, use Equation A.7:

$$V_{15°,1atm} = \frac{P}{K_f} \times MF \times CTLm \times CPLm \tag{A.7}$$

The typical pipeline procedure for cutting an interface uses the following equations. These equations show the sources of uncertainty of interfaces. For product measurement in the Initial Interface see Equation A.8:

$$Vol.A_{\text{Initial Interface}} = \frac{Vol_{\text{Initial Interface}}\left(\rho_{\text{Initial Interface}} - \rho_B\right)}{\rho_A - \rho_B} \tag{A.8}$$

If this is the equation for the initial interface volume, then the uncertainty is a function of 3 sources (Volume of the interface, Product A density, and Product B density). For product measurement in the Final Interface see Equation A.9:

$$Vol.A_{\text{Final Interface}} = \frac{Vol_{\text{Final Interface}}\left(\rho_{\text{Final Interface}} - \rho_B\right)}{\rho_A - \rho_B} \tag{A.9}$$

If this is the equation for the final interface volume, then the uncertainty is a function of 3 sources (Volume of the interface, Product A density, and Product B density).

A.1.1.3 Uncertainty Calculations Assumptions

The following assumptions are used in the below calculations. Users should review the suitability of these assumptions as it relates to the equipment in the field.

- Linear approximation in the correction factors for temperature effects is sufficient.

- The meter is calibrated and traceable to national or international Standards, in perfect condition, properly maintained, is properly installed, and is used within its operating range.

In steps we determine first the sources of uncertainty, estimate the standard Uncertainty of each source, calculate the combined standard uncertainty and finally determine the expanded Uncertainty.

A.1.1.4 Measurement Uncertainty of a Batch

Table A.1 below shows an example of calculation measurement uncertainties in a single batch of product.

No	Source	Description	Origin Uncertainty		Distribution
1	Meter Pulse Generated	API 21.2 – 8.1.3 => ±2 in 200.000 pulses	2.00 pulses		R
2	Meter Factor (MF)				
	Stability	Manufacturer Specifications (±0.05 %)	± 0.0005		N; k=2
	Linearity	Manufacturer Specifications (±0.15 %)	± 0.0015		R
	Meter Calibration	5 runs – 0.05 %	± 0.00027		N; k=2
3	Compressibility Factor	API 11.1 - 4 => ±6.5% at 95 % of confidence	± 0.0000065 bar^{-1}	± 0.00000065 psi^{-1}	N; k=2
4	Density at 15°C	API 9.4	± 3.0 Kg/m3	± 0.5°API	R
5	Meter Temperature				
	Stability T°	Statistical data and experience:	± 0.10 °C	±0.2°F	N; k=2
	Thermometer Resolution	API 7.4	± 0.05 °C	±0.05°F	R
	Thermometer Calibration	API 7.4 - 10.5.2	± 0.10 °C	±0.2°F	N; k=2
6	Meter Pressure				
	Pressure Stability	Statistical data and experience:	± 0.10 bar	± 1.45 psi	N; k=2
	Pressure Meter Resolution	Manufacturer Specifications	± 0.05 bar	± 0.73 psi	R
	Pressure Meter Calibration	It is adopted by experience: 0.25 % of the reading	± 0.023 bar	± 0.33 psi	N; k=2

Table A.1 – Measurement uncertainty of a batch from several sources

A.1.1.5 Interface measurement uncertainty

No	Source	Description	Origin Uncertainty		Distribution
1	Meter Pulse Generated	API 21.2 => ±2 in 200.000 pulses	2.00 pulses		R
2	Meter Factor (MF)				
	Stability	Manufacturer Specifications (± 0,05%)	± 0.0005		N; k=2
	Linearity	Manufacturer Specifications (± 0,15%)	± 0.0015		R
	Meter Calibration	5 runs – 0.05%	± 0.00027		N; k=2
3	Compressibility Factor	API 11.1 - 4 => ±6.5% at 95% of confidence	± 0.0000065 bar^{-1}	± 0.00000065 psi^{-1}	N; k=2
4	Interface Density	API 9.4	± 3.0 Kg/m3	± 0.5°API	R
5	Product A Density (DF)	API 9.4	± 3.0 Kg/m3	± 0.5°API	R
4	Product B Density (GAS)	API 9.4	± 3.0 Kg/m3	± 0.5°API	R

6	Meter Temperature				
	Stability T°	Statistical data and experience	± 0.10 °C	±0.2°F	N; k=2
	Thermometer Resolution	API 7.4	± 0.05 °C	±0.05°F	R
	Thermometer Calibration	API 7.4 10.5.2	± 0.10 °C	±0.2°F	N; k=2
7	Meter Pressure				
	Pressure Stability	Statistical data and experience	± 0.10 bar	± 1.45 psi	N; k=2
	Pressure Meter Resolution	Manufacturer Specifications	± 0.05 bar	± 0.73 psi	R
	Pressure Meter Calibration	It is adopted by experience: 0.25% of the reading	± 0.023 bar	± 0.33 psi	N; k=2

Table A.2 – Measurement uncertainty of an interface from several sources

A.1.1.6 Expression of Uncertainty U_E and U_S

The U_E (expanded uncertainty) of the measurement of the volumetric meters ±0.181 % was calculated by multiplying the U_S (combined standard uncertainty) ±0.092 % by a coverage factor k 1.97, with an approximate confidence level of 95.45 % and a distribution t with "v" 233 degrees of freedom.

The U_E of the interface measurement ±1.394 % was calculated by multiplying the U_S ±0.709 % by a coverage factor k 1.97, with an approximate confidence level of 95.45% and a t distribution with "v" 402 degrees of freedom.

Although applicable to all transportation systems, in the pipelines particular case we have the final uncertainty of the system as the quadratic sum of the uncertainty of the measurement of the initial interface, the final interface and the volumetric meter resulting in Equations A.10 and A.11:

$$U_{SYSTEM} = \sqrt{\left(U_{InitialInterface} \times Vol_{InitialInterface}\right)^2 + \left(U_{FinalInterface} \times Vol_{FinalInterface}\right)^2 + \left(U_{Vol.Meter} \times Vol_{Batch}\right)^2} \quad \text{(A.10)}$$

$$U_E\left[\%\right] = \frac{U_{SYSTEM}\left[lts\right]}{Vol_{InitialInterface} + Vol_{FinalInterface} + Vol_{Batch}} \quad \text{(A.11)}$$

The contribution of interfaces can be analyzed as shown in Table A.3:

% Interface / Total Volume	**Uncertainty (Meter + Interface)**	**Uncertainty (Meter + Interface) / Uncertainty Vol. Meter**
0.5 %	0.181 %	100 %
1.0 %	0.181 %	100 %
1.5 %	0.182 %	100 %
2.0 %	0.183 %	100 %
2.5 %	0.184 %	101 %
3.0 %	0.186 %	102 %
3.5 %	0.189 %	104 %
4.0 %	**0.192 %**	105 %
5.5 %	**0.203 %**	112 %
6.5 %	**0.213 %**	117 %
7.5 %	**0.224 %**	123 %
8.5 %	**0.236 %**	130 %

9.5 %	**0.249 %**	137 %
10.0 %	**0.256 %**	141 %

Table A.3 – Example Effects of Interfaces on Total Batch Uncertainty

Therefore, we accept that when the Interface represents 4 % or more of the total volume transferred, its measurement uncertainty will be considered to "justify" possible deviations in the tolerances per batch, since from said value, its contribution begins to be significant (the system uncertainty varies by approximately 5 %). The same does not happen in the monthly tolerance where it is negligible regardless of its contribution.

A.1.2 Tolerances

A.1.2.7 Batch Tolerance

Batch tolerance is the tolerance calculated from the different uncertainties present in the product quantification within the different measurement elements composing the entire system.

Depending on the number of measurement systems that can intervene in the transfer, we obtain the uncertainty and therefore the tolerance per batch for each section and for the entire system.

It should be considered that these values correspond to the worst-case condition (considering for a batch, that all inputs and outputs contribute to the uncertainty of the system) which can be optimized (considering for a batch only the inputs and outputs that intervened in it, with which it would be variable and its monitoring therefore much more complex). See Equation A.12.

$$Tolerance_{Batch} = U_{System} = \pm\sqrt{\sum_{i=1}^{n} U_i^2} \qquad \text{(A.12)}$$

Where,

i corresponds to each measurement system that affects the entire pipeline (whether it delivers or receives product).

Considering the measurement of interfaces in the pipelines, when these represent a percentage equal or greater than 4 % of the total volume transferred, the tolerance limits can be extended according with Table A.1.

A tolerance per batch is appropriate because:

- Only with punctual control of each batch it will be possible to continuously improve the quality of the measurements. A monthly limit would only allow us to take corrective action after one month of the occurrence. On the other hand, it may happen that in a month the balance has been closed correctly and yet it has operated inefficiently.
- A process is under statistical control if its statistical control limits at 95 % confidence (2σ) are within the tolerances established for the process (in this case for each batch).

A.1.2.8 Monthly Tolerance

It is calculated from the tolerance per batch and the number of monthly transfers of a product (number of batches for that product), among the Operational Units considered, with a confidence level of 95 % for the interval.

As in our case we work with a Monthly Accumulated Balance, the differences that are recorded in the measurement of a batch should be canceled (that is, a positive or negative trend would highlight the presence of a systematic error in the system), we adopt Equation A.13:

$$Tolerance_{Monthly} = \frac{Tolerance_{Batch}}{\sqrt{n}} \qquad \text{(A.13)}$$

Where,

n is the number of batches transferred during the month.

A.1.3 Example

Given the pipeline system as pictured in Figure A.2 and its corresponding balance for the last 16 batches, provided in Table A.4, the tolerance can be determined. The uncertainty of the measurement system for unit 1, unit 2 and unit 3 are all as describe in examples above. For this example, the uncertainty of one metering unit is considered to be ±0.182 %.

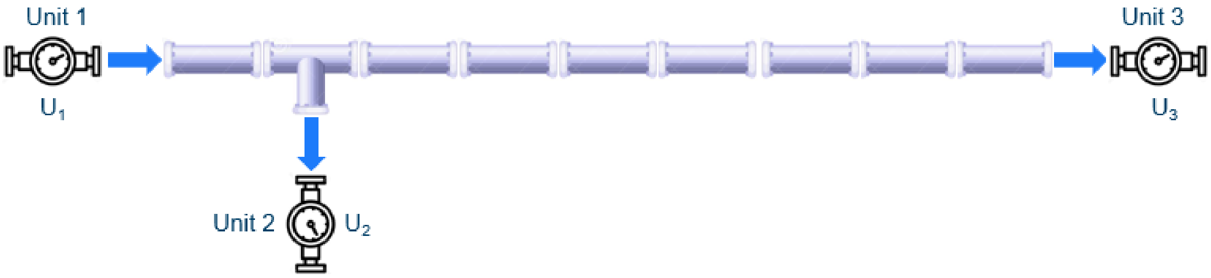


Figure A.2—Example of a pipeline with two delivery points

BATCH	UNIT 1	UNIT 2	UNIT 3	Difference	Diff %	Accumulated Volume
1	3,997,580	0	3,999,437	1,857	0.046 %	1,857
2	6,000,650	0	6,003,757	3,107	0.052 %	4,964
3	3,998,920	3,992,279	0	-6,641	-0.166 %	-1,677
4	4,000,300	0	4,005,035	4,735	0.118 %	3,058
5	3,997,060	0	3,970,952	-26,108	-0.653 %	-23,050
6	6,005,170	0	6,026,551	21,381	0.356 %	-1,669
7	12,000,380	1,988,940	10,006,462	-4,978	-0.041 %	-6,647
8	2,000,530	0	2,007,682	7,152	0.358 %	505
9	10,007,770	0	10,001,597	-6,173	-0.062 %	-5,668
10	6,505,820	0	6,531,327	25,507	0.392 %	19,839
11	8,500,160	0	8,469,007	-31,153	-0.366 %	-11,314
12	5,199,810	0	5,201,293	1,483	0.029 %	-9,831
13	3,999,590	0	4,010,229	10,639	0.266 %	808
14	10,000,030	0	9,993,969	-6,061	-0.061 %	-5,253
15	12,992,150	4,989,810	8,005,208	2,868	0.022 %	-2,385
16	4,999,780	0	5,003,664	3,884	0.078 %	1,499
TOTAL	**104,205,700**	**10,971,029**	**93,236,170**	**1,499**	**0.001 %**	

Table A.4 – Example of Balance in a Pipeline System

1. Determine the Tolerance for one batch using Equation A.14:

$$Tolerance_{Batch} = U_{System} = \pm\sqrt{\sum_{i-1}^{n} U_i^2} = \pm\sqrt{U_1^2 + U_2^2 + U_3^2} \qquad \text{(A.14)}$$

Since the three systems are considered to be similarly designed:

$$U_1 = U_2 = U_3 = \pm 0.181\%$$

$$Tolerance_{Batch} = U_{System} = \pm\sqrt{0.181\%^2 + 0.181\%^2 + 0.181\%^2}$$

$$Tolerance_{Batch} = U_{System} = \pm 0.314\%$$

2. Determine the Tolerance for the period analyzed using Equation A.15:

$$Tolerance_{Period} = \frac{Tolerance_{Batch}}{\sqrt{n}} \qquad \text{(A.15)}$$

$$Tolerance_{Period} = \pm\frac{0.314\%}{\sqrt{16}} = \pm\frac{0.314\%}{4} = \pm 0.078\%$$

3. The next step is to detect the outliers, by applying the tolerances determined in previous step. This is done by applying the batch tolerance to each batch, and the system tolerance to the final volume accumulated.

BATCH	UNIT 1	UNIT 2	UNIT 3	Difference	Diff %	Tolerance	Accumulated Volume
1	3,997,580	0	3,999,437	1,857	0.046%	Inside	1,857
2	6,000,650	0	6,003,757	3,107	0.052%	Inside	4,964
3	3,998,920	3,992,279	0	-6,641	-0.166%	Inside	-1,677
4	4,000,300	0	4,005,035	4,735	0.118%	Inside	3,058
5	3,997,060	0	3,970,952	-26,108	-0.653%	Outside	-23,050
6	6,005,170	0	6,026,551	21,381	0.356%	Outside	-1,669
7	12,000,380	1,988,940	10,006,462	-4,978	-0.041%	Inside	-6,647
8	2,000,530	0	2,007,682	7,152	0.358%	Outside	505
9	10,007,770	0	10,001,597	-6,173	-0.062%	Inside	-5,668
10	6,505,820	0	6,531,327	25,507	0.392%	Outside	19,839
11	8,500,160	0	8,469,007	-31,153	-0.366%	Outside	-11,314
12	5,199,810	0	5,201,293	1,483	0.029%	Inside	-9,831
13	3,999,590	0	4,010,229	10,639	0.266%	Inside	808
14	10,000,030	0	9,993,969	-6,061	-0.061%	Inside	-5,253
15	12,992,150	4,989,810	8,005,208	2,868	0.022%	Inside	-2,385
16	4,999,780	0	5,003,664	3,884	0.078%	Inside	1,499
TOTAL	**104,205,700**	**10,971,029**	**93,236,170**	**1,499**	**0.001%**	**Inside**	

Table A.5 – Example of Determination of Outliers in a Pipeline System

In this example, the totals at the bottom of the Table A.5 show that the system is within the tolerance determined (0.001 % vs ±0.078 %).

In case, as the system is out of tolerance, an investigation with the out of tolerance batches should be initiated.

In the other scenario, when the system is within tolerance, there may be several batches out of the control limits, which may be investigated. It is possible to assume that those batches that are out of the limits, it is because of poor density cut process.

A.1.4 Frequency of revision of the study

It is advisable to conduct a review of the study in any of the following conditions:

- Changes in Measurement Instruments (other characteristics or technologies).
- Changes in the densities of the products that may affect the interfaces.

A.2 Statistical Calculations of a System

A.2.1 Calculating Standard Deviation

The normality assumption means that the collected data follows a normal distribution. Before applying these calculations, the population of data should agree with the normal distribution. But the periodic calculations of system L/G are more likely the result of biases of the measurements than normal random error. Despite this issue, considering system L/G as normal distributed is the best approach available.

To determine Standard Deviation, refer to API *MPMS* Chapter 13.3 Annex E. The general standard deviation equation is defined in Equation A.16:

$$s^2 = \sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1} \tag{A.16}$$

For example:

Month	**L/G, %**	$\boldsymbol{x_i}$	$(\boldsymbol{x_i} - \bar{\boldsymbol{x}})$	$(\boldsymbol{x_i} - \bar{\boldsymbol{x}})^2$
1	0.12	0.12	0.002	0.000004
2	0.15	0.15	0.032	0.001024
3	0.11	0.11	–0.008	0.000064
4	0.08	0.08	–0.038	0.001444
5	0.13	0.13	0.012	0.000144
Sum		0.59		0.002680

$$\bar{x} = \frac{0.59}{5} = 0.118$$

$$s = \pm\sqrt{\left(\frac{0.00268}{4}\right)} = \pm 0.026$$

Table A.6 – Sample Calculation of Mean and Standard Deviation

A.2.2 Standard Deviation Method to set Upper and Lower Control Limits

A.2.2.1 General

Refer to the section above to calculate the standard deviation.

The next calculations are an example of how to determine an upper/lower control limit for a L/G data series. For the next example, it was decided to use the year 1 information to determine the control limits, and then, apply these new limits to year 2 information.

Month	L/G (Year 1)	L/G (Year 2)
January	-0.006 %	0.017 %
February	-0.019 %	-0.010 %
March	0.017 %	0.007 %
April	-0.013 %	0.001 %
May	0.011 %	0.000 %
June	-0.008 %	0.005 %
July	0.015 %	0.037 %
August	0.022 %	-0.011 %
September	-0.019 %	0.004 %
October	-0.011 %	0.003 %
November	-0.015 %	-0.006 %
December	-0.012 %	0.003 %
$s = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \overline{x})^2}{n-1}} = \pm 0.015\%$		

Table A.7 – Sample Calculation of Estimated Standard Deviation

Once the standard deviation has been determined, the action and warning limits can be set based on multiples of this deviation.

$$UCL = 3 \times s = +0.045\%$$

$$LCL = -3 \times s = -0.045\%$$

$$UCW = 2 \times s = +0.030\%$$

$$LCW = -2 \times s = -0.030\%$$

In the Figure A.3 below, action limits (red lines) and warning limits (yellow lines) are shown:

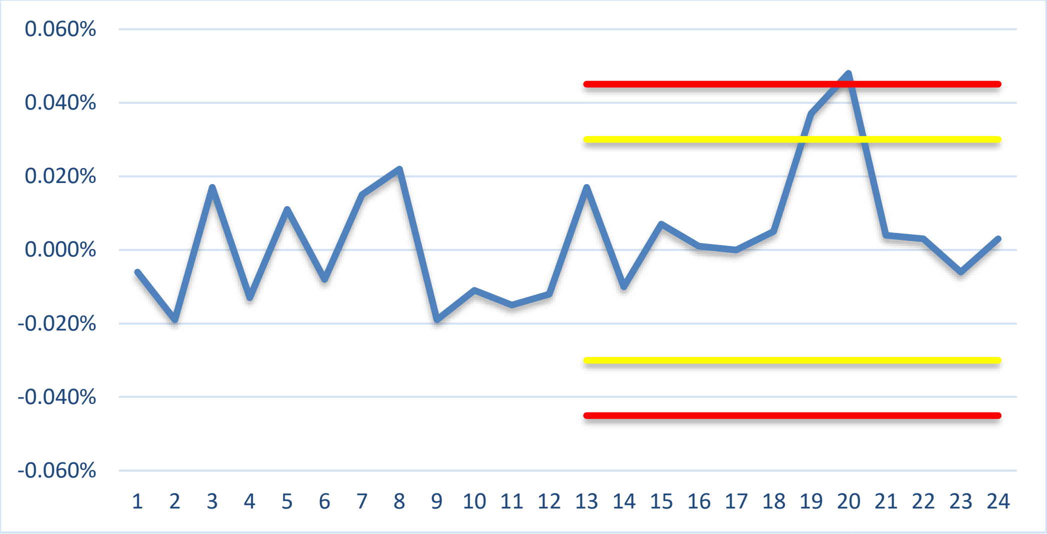


Figure A.3

Year 1 information is considered to be representative of the L/G process.

Based on the year 1 information, limits are determined to control future differences. From year 2 and forward, the months that are out of the control limits should be investigated.

A.2.2.2 Correlation Coefficient

The strength of the correlation between two variables can be measured statistically with the correlation coefficient calculated per the Equation A.17:

$$Correl(X,Y)=\frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \tag{A.17}$$

Where,

$\bar{x}$ and $\bar{y}$ are the sample means AVERAGE (array 1) and AVERAGE (array 2).

Correlations range from −1 to +1. Numeric values close to the end points indicate strong negative or positive correlation and values close to 0 indicate weak or no correlation.

A correlation can sometimes be found between the volume throughput in a tank farm vs L/G for the tank farm or between gains or losses and the monthly throughput on a pipeline segment (see Table A.8 and Figure A.3).

Month	Pipeline Throughput X	Monthly L/G Y
1	25,300	−755
2	45,300	−445
3	25,200	−141
4	117,050	−142

5	95,000	−24
6	104,600	−166
7	323,200	250
Correl(X,Y) = (X1:X7,Y1:Y7) = 0.77		

Table A.8 – Example of Calculation of a Correlation Coefficient

This example would be considered a moderate positive correlation.

NOTE When reporting correlation, it is important to indicate positive or negative, whichever is the case.

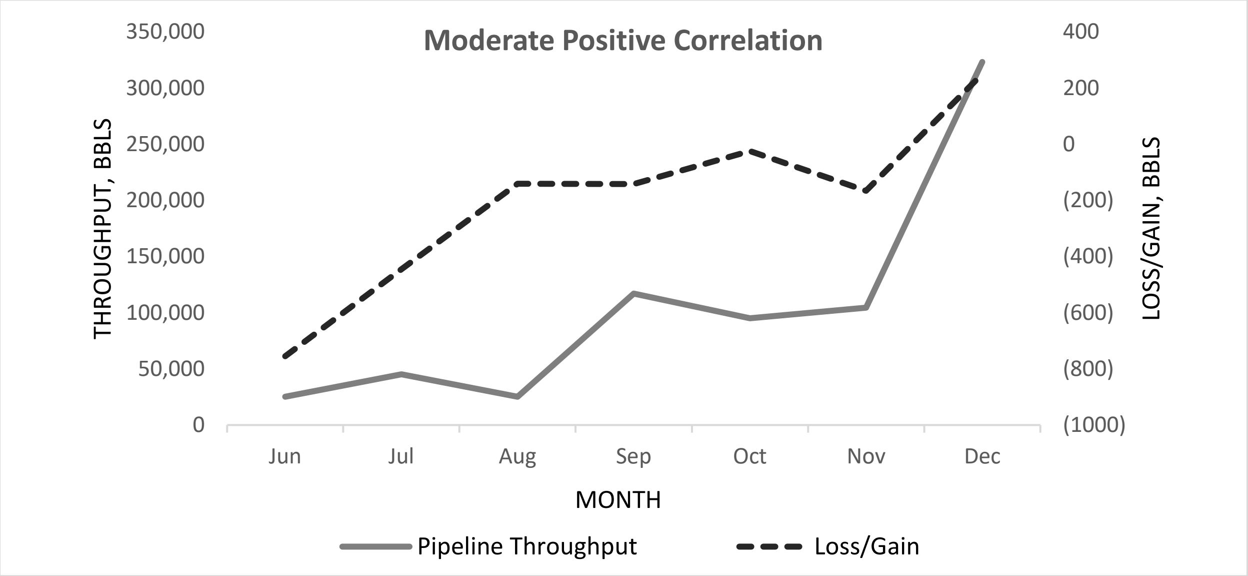


Figure A.4 – Example of Correlation Between Two Data Sets

A.3 Least Squares Method for Calculating Linear Regression Lines

A linear regression line is a straight line that represents the “best fit” of a straight line to the data and takes the form of Equation A.18:

$$Y = a + bX \tag{A.18}$$

Where,

Y is the dependent variable, e.g., L/G;

X is the independent variable, e.g., time period (month, etc.);

a and *b* are constants derived from the data by the Least Squares Method and apply only to that data set.

The Least Squares Method is a statistically derived pair of equations for determining the values of the constants *a* and *b*. The equations are as follows in Equations A.19 and A.20:

$$b = [\Sigma xy - n(X_b)(Y_b)]/[\Sigma X^2 - n(X_b)^2] \tag{A.19}$$

$$a = (Y_b) - b(X_b) \tag{A.20}$$

Where,

X_b and Y_b	are the means (i.e. arithmetic averages) of all the X values and all the Y values in the data set;
X_b and Y_b	are read as “X bar” and “Y bar” and are commonly written with a small horizontal bar over the “X” and the “Y” instead of the subscript “b.” The subscript form is used when the bars could be lost in typing and/or editing.

Use of the Least Squares Method is most easily illustrated with an example of a system with a leak shown in Figure A.5.

The data before the loss, which in this example occurred about the seventh month, are used to develop a regression line which represents the typical behavior of the curve before the leak. The regression line is used to project what the system L/G would have been if the leak had not happened. In this example the leak was found and repaired in the eleventh month, and the accumulated loss by that time is 790 barrels. If no liquid had been physically lost, the projected cumulative L/G would have been 640 barrels as estimated from the projected regression line. The difference of 150 barrels is the estimated loss due to the leak.

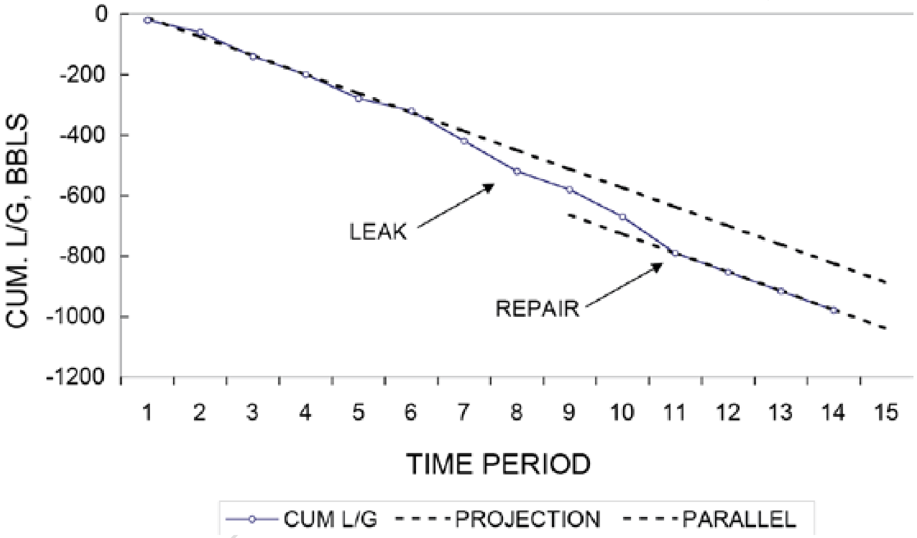


Figure A.5 – System with a leak

Using the data from the first six data points of Figure A.5, the calculations are as shown in the following Table A.9.

X (Month)	**Y** (Cum. L/G)	**X^2**	**XY**
1	–20	1	–20
2	–60	4	–120
3	–140	9	–420
4	–200	16	–800
5	–280	25	–1400
6	–320	36	–1920
$\sum X = 21$	$\sum Y = –1020$	$\sum X^2 = 91$	$\sum XY = –4680$

$n = 6$

$(X_b) = \sum X/n = 21/6 = 3.5$

$(Y_b) = -1020/6 = -170$

$b = [\sum XY - n(X_b)(Y_b)]/[\sum X^2 - n(X_b)^2]$

$= [-4680 - (6)(3.5)(-170)]/[91 - (6)(3.5)^2]$

$= -63.4$

$a = (Y_b) - b(X_b) = -170 - (-63.4)(3.5) = 51.9$

Thus, Cum. L/G = 51.9 – (63.4×Month). This equation was used to calculate the values for the projection line plotted in Figure A.4.

Table A.9

All values shall be numerical. For example, months shall be 1, 2, 3, etc., not January, February, March, etc.

Annex B

(informative)

Interpreting Control Charts

B.1 Various States of Process

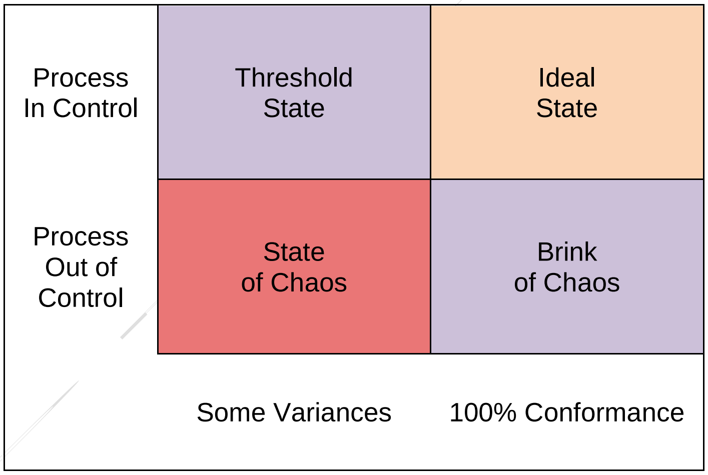
B.1.1 Processes fall into one of four states: 1) the ideal, 2) the threshold, 3) the brink of chaos and 4) the state of chaos (Table B.1).

When a process is at its "Ideal State," it is statistically controlled and produces 100 percent conformance. Over time, the process has demonstrated stability and target performance. This process is predictable, and the results are as expected.

The "Threshold State" is defined as a process that is statistically controlled but nevertheless produces occasional changes. This procedure produces a consistent degree of variations and has limited capabilities. This process, while predictable, does not always satisfy expectations.

The state of "Brink of Chaos" denotes a process that is out of statistical control but not beyond tolerance. To put it another way, the process is unexpected, yet the results nevertheless fulfill expectations. The absence of variations gives the illusion of security, but such a process can develop variances at any time. It's only a matter of time before it happens.

The "State of Chaos" is the fourth process state. The process is not statistically controlled in this case, resulting in unpredictably high amounts of volatility.



	Some Variances	100% Conformance
Process In Control	Threshold State	Ideal State
Process Out of Control	State of Chaos	Brink of Chaos

Table B.1—Four Process States

Every process will at some point fall into one of these stages, but it will not stay there. All procedures will eventually devolve into chaos. When a process reaches a level of chaos, companies usually start working on improving it (although they would be better served to initiate improvement plans at the brink of chaos or threshold state). Control charts are a reliable and useful tool to utilize as part of a strategy to detect the degradation of a natural process.

B.1.1 Control charts are the way an L/G system communicates, so it is important to know how to interpret control charts. Control charts are a statistical process control tool used to determine if a process is in a state of control. If an L/G system is in statistical control, most of the data points will be near the centerline, some may be close to the control limits and no points will be beyond the control limits. It is acknowledged that pipeline systems would be expected to follow a log-normal distribution rather than a normal distribution, however the 8 control chart rules listed in Table B.2 and further in section

B.2 of this Annex B may provide indications that there are special-cause variations present. These rules can distinguish between a shift and a pattern. Within the rules, where σ = standard deviation,

- Zone A is between 2σ and 3σ (normally occurs 4.3 % of the time)
- Zone B is between 1σ and 2σ (normally occurs 27.2 % of the time)
- Zone C is between the centerline and 1σ (normally occurs 68.3 % of the time)

Rule	Rule Name	Shift/Pattern
1	Beyond Limits	One or more points beyond the control limits
2	Zone A	2 out of 3 consecutive points in Zone A or beyond
3	Zone B	4 out of 5 consecutive points in Zone B or beyond
4	Zone C	7 or more consecutive points on one side of the centerline (in Zone C or beyond)
5	Trend	7 consecutive points trending up or trending down
6	Mixture	8 consecutive points with no points in Zone C
7	Stratification	15 consecutive points in Zone C
8	Over-control	14 consecutive points alternating up and down

Table B.2—Control Chart Rules

B.1.2 These control chart rules represent different situations resulting in different types of patterns. Table B.3 summarizes the rules by the type of pattern.

Pattern Description	Rules
Large shifts from the average	1, 2
Small shifts from the average	3, 4
Trends	5
Mixtures	6
Stratification	7
Over-control	8

Table B.3—Control Chart Rules by Pattern Type

The value of a control chart is in its capacity to distinguish between common-cause variations and special-cause variations.

<u>Common-cause variations</u> are characterized by:

- Consistent over time
- Phenomena constantly active within the system
- Variation expected probabilistically

- Irregular variation within a historical experience base; and
- Lack of importance in individual high or low values

Common-cause variations are the noise within the system.

Special-cause variations are characterized by:

- Not Consistent over time
- New, unanticipated, developing or previously neglected phenomena within the system
- Variation inherently unpredictable, even by chance
- Variation outside the historical experience base; and
- Evidence of some inherent change in the system or our knowledge of it

Special-cause variations almost always arrive as a surprise. It is a signal that there is an issue.

A special-cause variation is a variation that may be corrected by changing a component or process, whereas a common-cause variation is equivalent to noise in the system and specific actions cannot be made to prevent the variation.

B.2 Control Chart Rules

B.2.1 Rule 1 (One or more data points beyond the control limits) states that any data point that falls outside the control limits may be the result of a special cause (e.g., equipment failure, procedural error, etc.) and should be investigated immediately to determine the cause. Signals from rule 1 takes top priority and the other rules will provide little additional information. Special causes often lead to correction tickets and should be investigated as soon as possible before memories fade, the data becomes dated, and the investigation becomes more difficult. Figure B.1 depicts two points that meet rule 1.

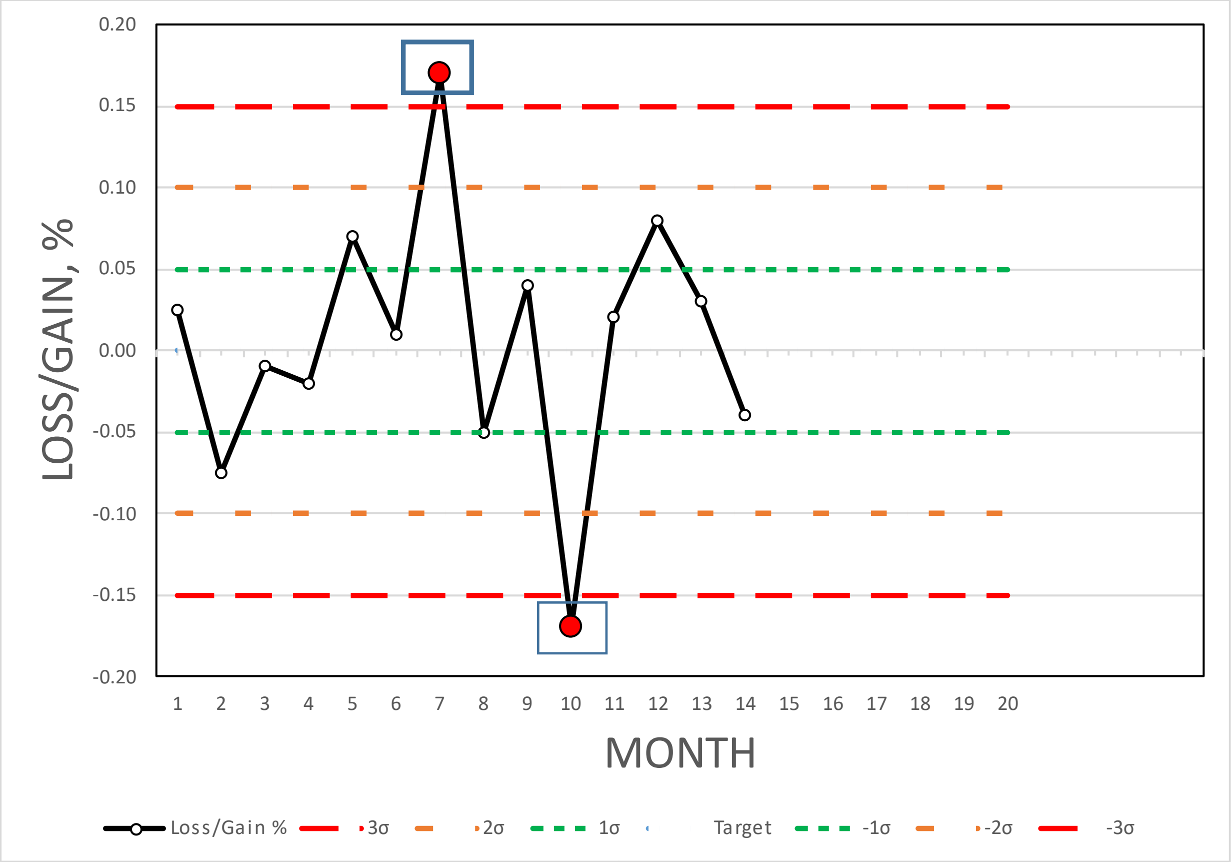


Figure B.1 – Rule 1 – One or more data points beyond the control limits

B.2.2 Rule 2 (Zone A test - 2 out of 3 consecutive points in Zone A or beyond) represents sudden, large shifts from the average as shown in Figure B.2. This rule is applied on the same side of the centerline. The mismeasurement of inventory could cause the shifts. Like rule 1, these shifts are often one-time occurrences of a special cause – like travel time increase due to having a flat tire when driving to work.

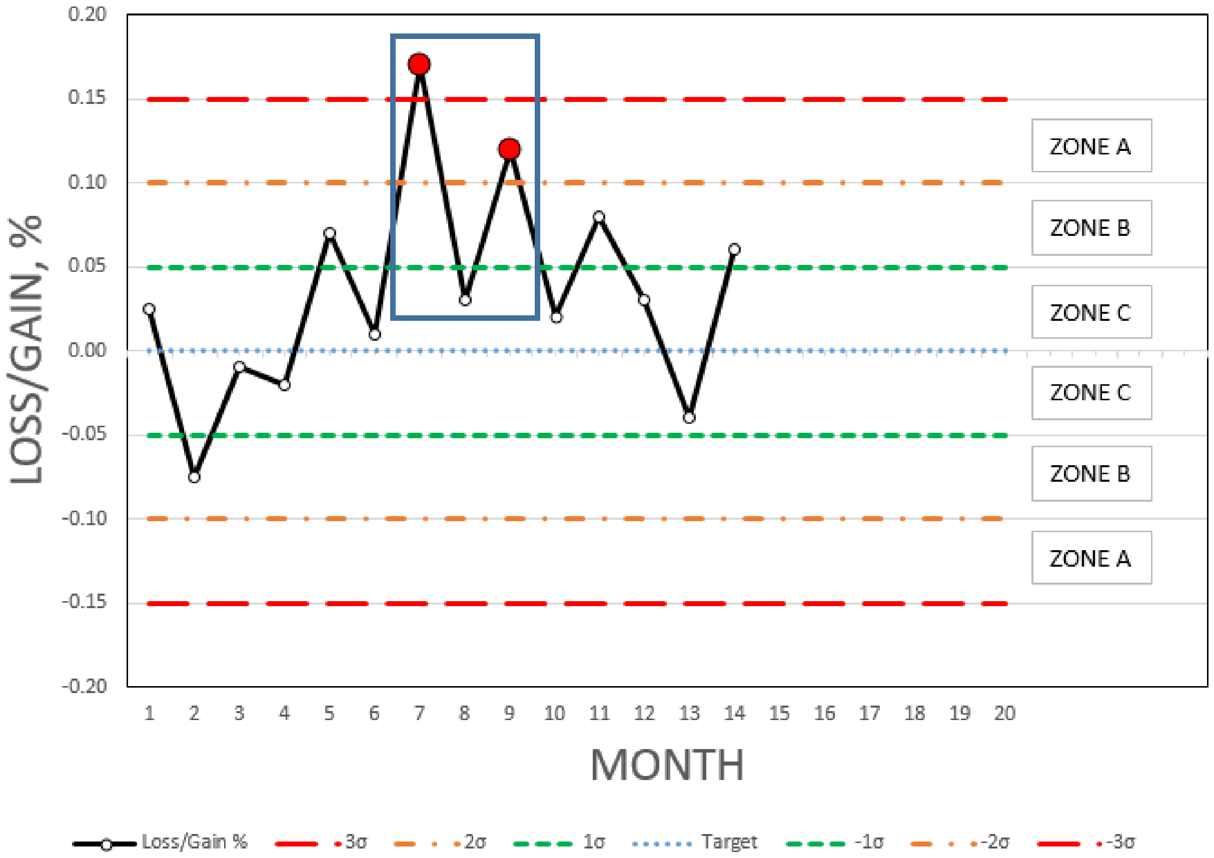


Figure B.2 – Rule 2 – Zone A test – 2 out of 3 consecutive points in Zone A or beyond

B.2.3 Rule 3 (Zone B test - 4 out of 5 consecutive points in Zone B or beyond) represents smaller shifts that are sustained over time which is depicted in Figure 6. Like rule 2, this rule is applied on the same side of the centerline. The key is that the shifts are sustained over times longer than the time frames of Rules 1 and 2.

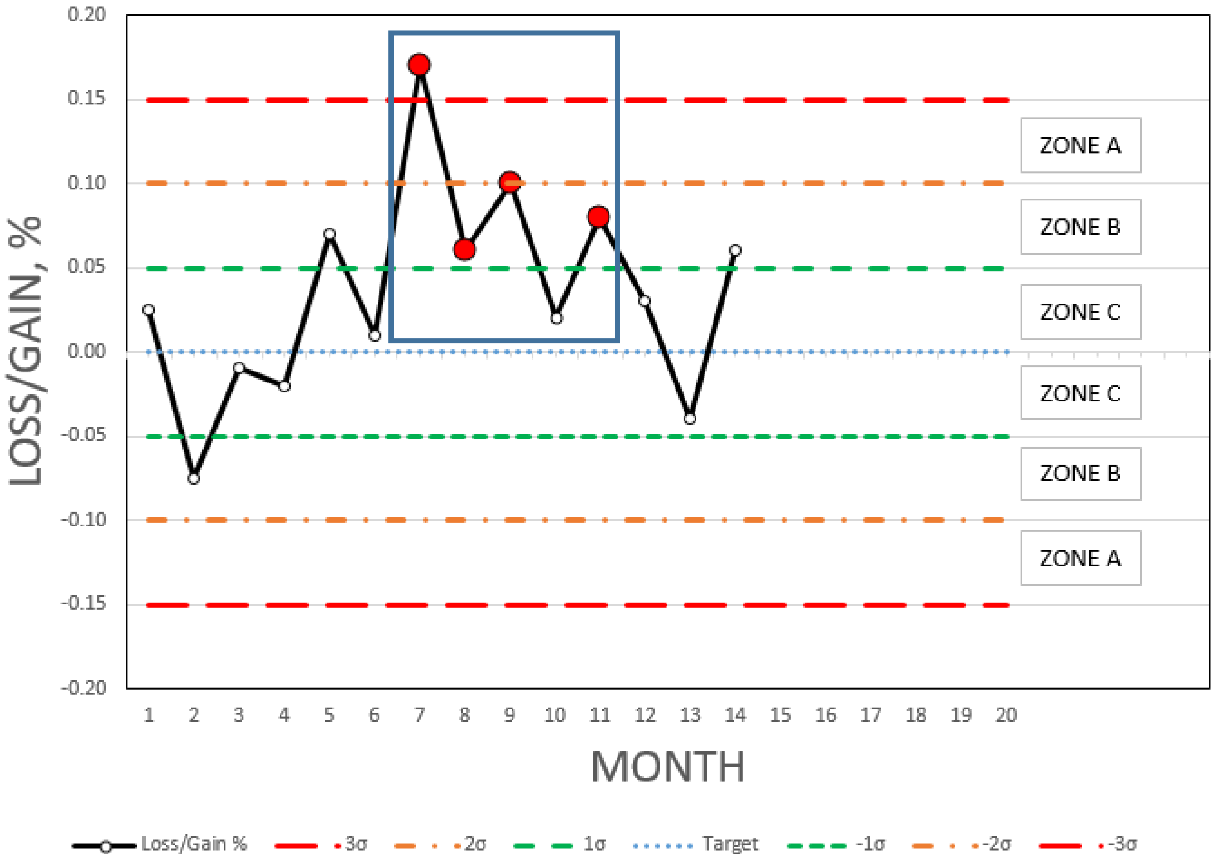


Figure B.3 – Rule 3 – Zone B test – 4 out of 5 consecutive points in Zone B or beyond

B.2.4 Rule 4 (Zone C test - 7 or more consecutive points on one side of the centerline (in Zone C or beyond)) indicates that some prolonged bias exists as seen in Figure B.4. A change in base prover volume could cause this shift in performance. The key is that the shifts are sustained over times longer than the time frames of Rules 1 and 2.

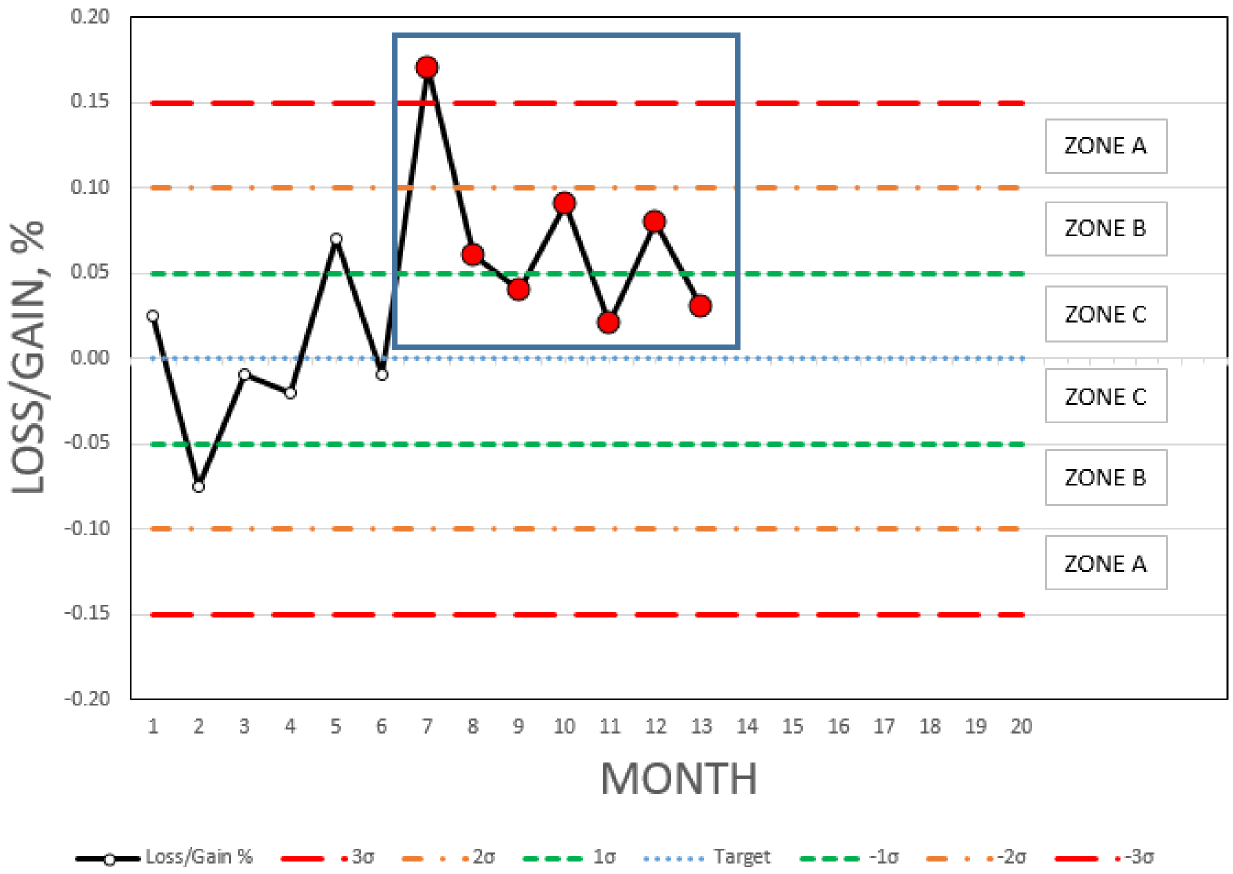


Figure B.4 – Rule 4 – Zone C test – 7 or more consecutive points on one side of the centerline (in Zone C or beyond)

B.2.5 Rule 5 (Trend - 7 consecutive points trending up or trending down) represents a process that is trending in one direction. Neither the zones nor the centerline comes into play for this test. For example, meter wear could cause this type of trend. Seven consecutive points trending in one direction (up or down) indicate a loss of control. For some systems, even fewer points in a row may be significant warning. Examples might be leaking tanks (in which case the losses are real) or meters that are wearing badly and are not being proved often enough (which are book losses or gains). An upward trend is no better than a downward trend. Either condition is out of control. A system gain can be just as bad as a system loss. Losses and gains occur because of some deficiency in measurement. Figure B.5 illustrates two cases of rule 5.

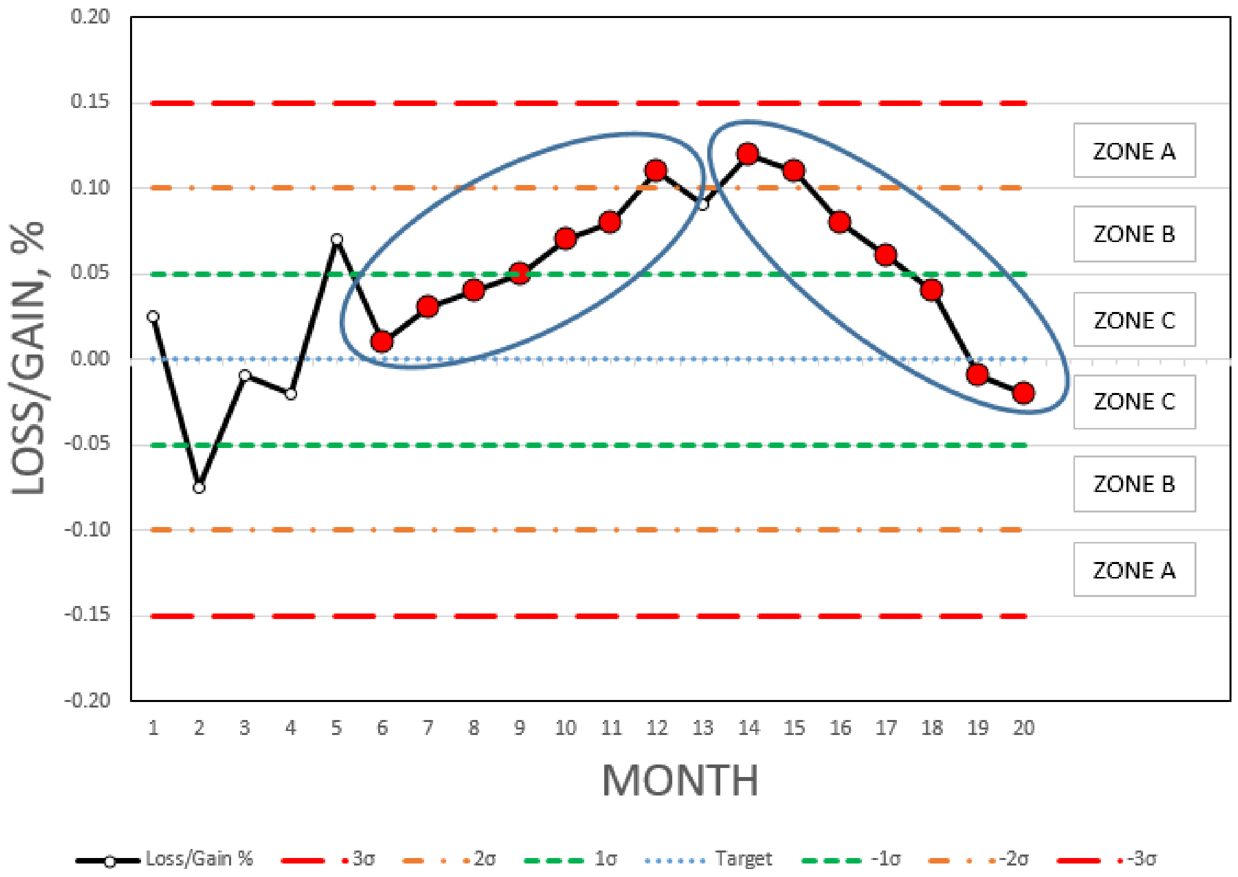


Figure B.5 – Rule 5 –Trend – 7 consecutive points trending up or trending down

B.2.6 Rule 6 (Mixture - 8 consecutive points with no points in Zone C) is the tendency to avoid the centerline. A mixture may exist when the data is from two different special causes and are plotted on a single control chart. As shown in Figure B.6, the absence of points near the centerline is identified as a mixture pattern. Jumping from above to below while missing the first standard deviation band (Zone C) is rarely random. A large change in throughput volume can cause a mixture pattern. Another example is taking data from different crews. Crew 1 operates at a different average than crew 2. The control chart could have crew 1 in zone B or beyond above the average and crew 2 in zone B below the average – with nothing in zone C. Changing average flow rate without proving may also cause a mixture pattern.

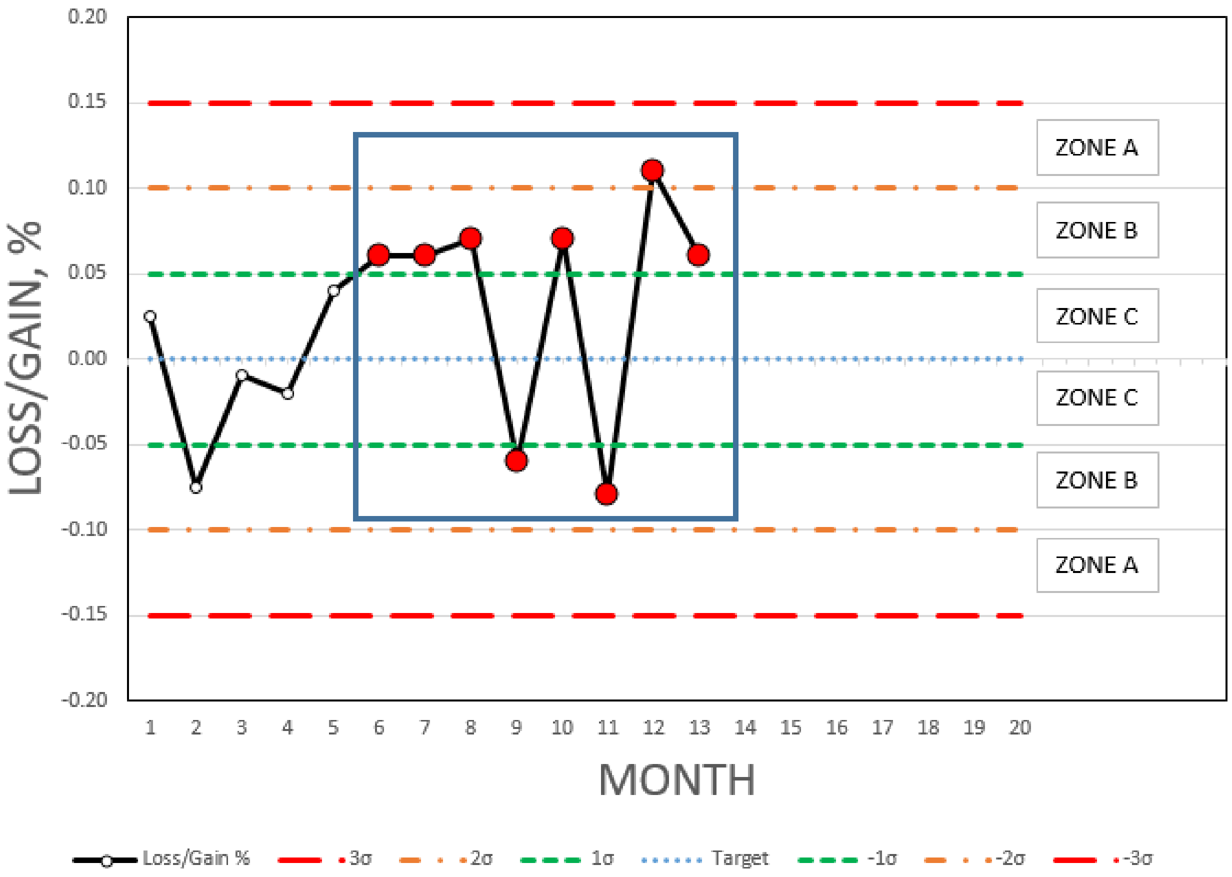


Figure B.6 – Rule 6 – Mixture – 8 consecutive points with no points in Zone C

B.2.7 Rule 7 (Stratification - 15 consecutive points in Zone C) also occurs when you have multiple processes, but you are including all the processes in a subgroup. This can lead to the data “hugging” the average – all the points in zone C with no points beyond zone C as represented in Figure 10. If possible, break the system down into smaller segments or by components (i.e., Regular and Premium versus combining them into Mogas). This stratification may also be an indication that the control limits are too wide.

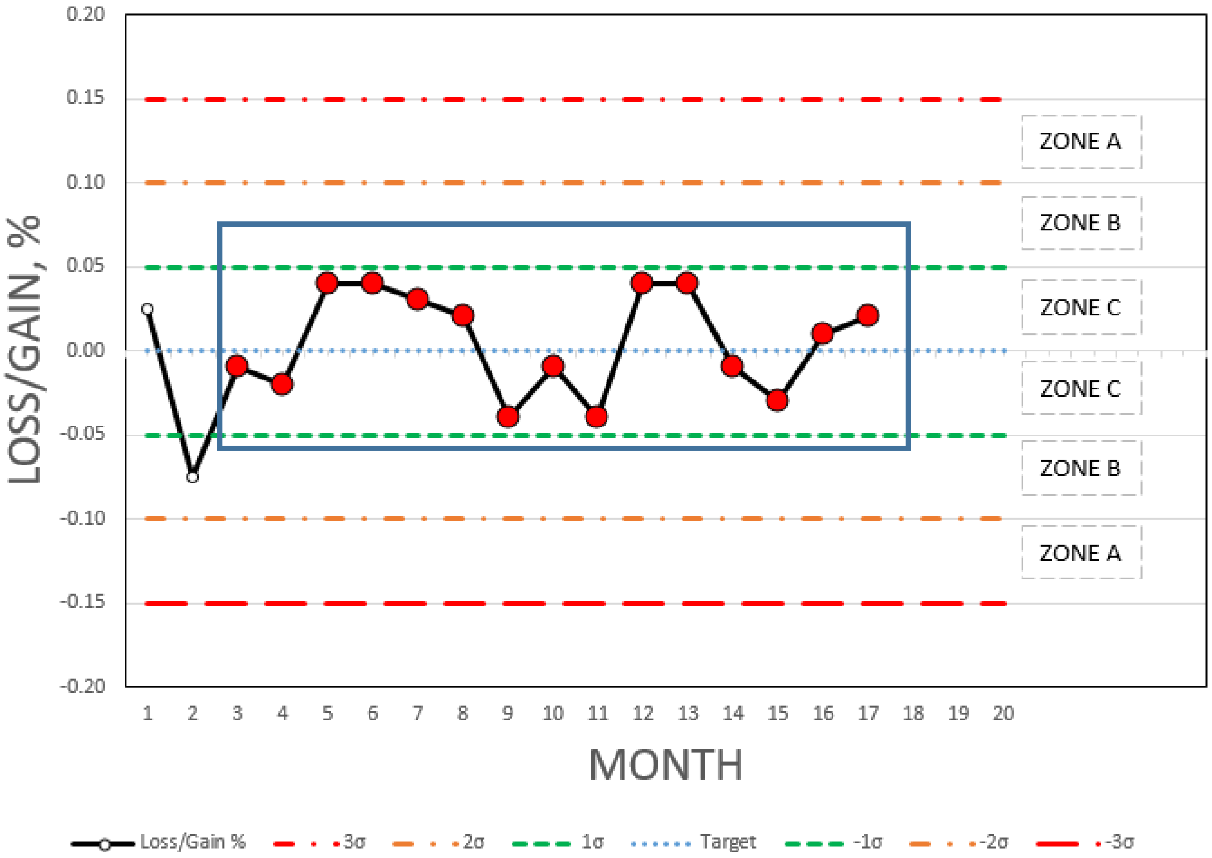


Figure B.7 – Rule 7 – Stratification – 15 consecutive points in Zone C

B.2.8 Rule 8 (Over-control - 14 consecutive points alternating up and down) is often due to over adjustment. Neither the zones nor the centerline comes into play for this test. This is often called “tampering” with the process. Adjusting a process that is in statistical control actually increases the process variation. This much oscillation is beyond noise. The rule is concerned with directionality only. The position of the centerline and the size of the standard deviation have no bearing. For example, an operator is trying to hit a certain value. If the result is above that value, the operator makes an adjustment to lower the value. If the result is below that value, the operator makes an adjustment to raise the value. Figure B.8 displays rule 8.

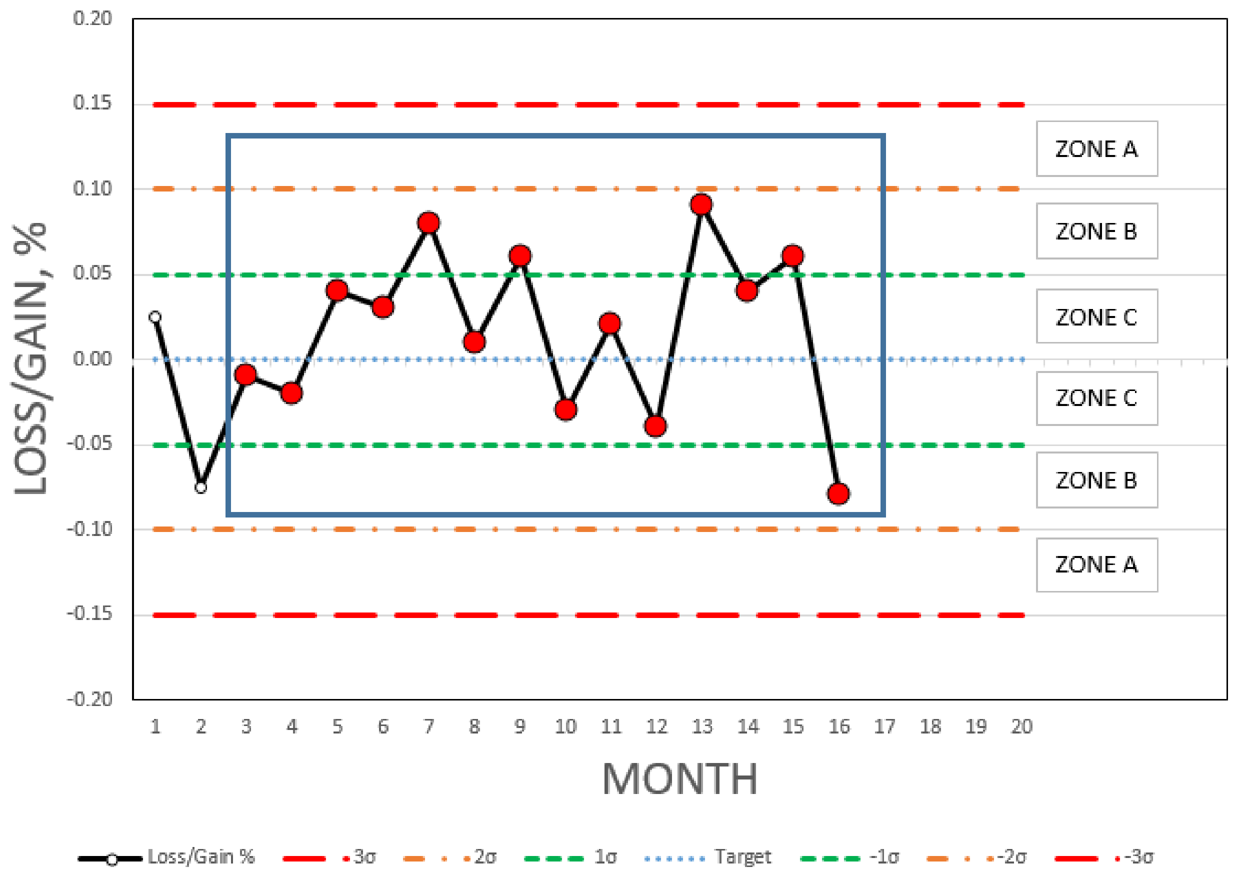


Figure B.8 – Rule 8 – Over-control – 14 consecutive points alternating up and down

If the data tends to swing back and forth as shown in Figure B.9, the system is cyclic. This may result in a saw-tooth pattern. If the cause of the cycles could be eliminated, the system should be able to achieve a state of better control with narrower control limits.

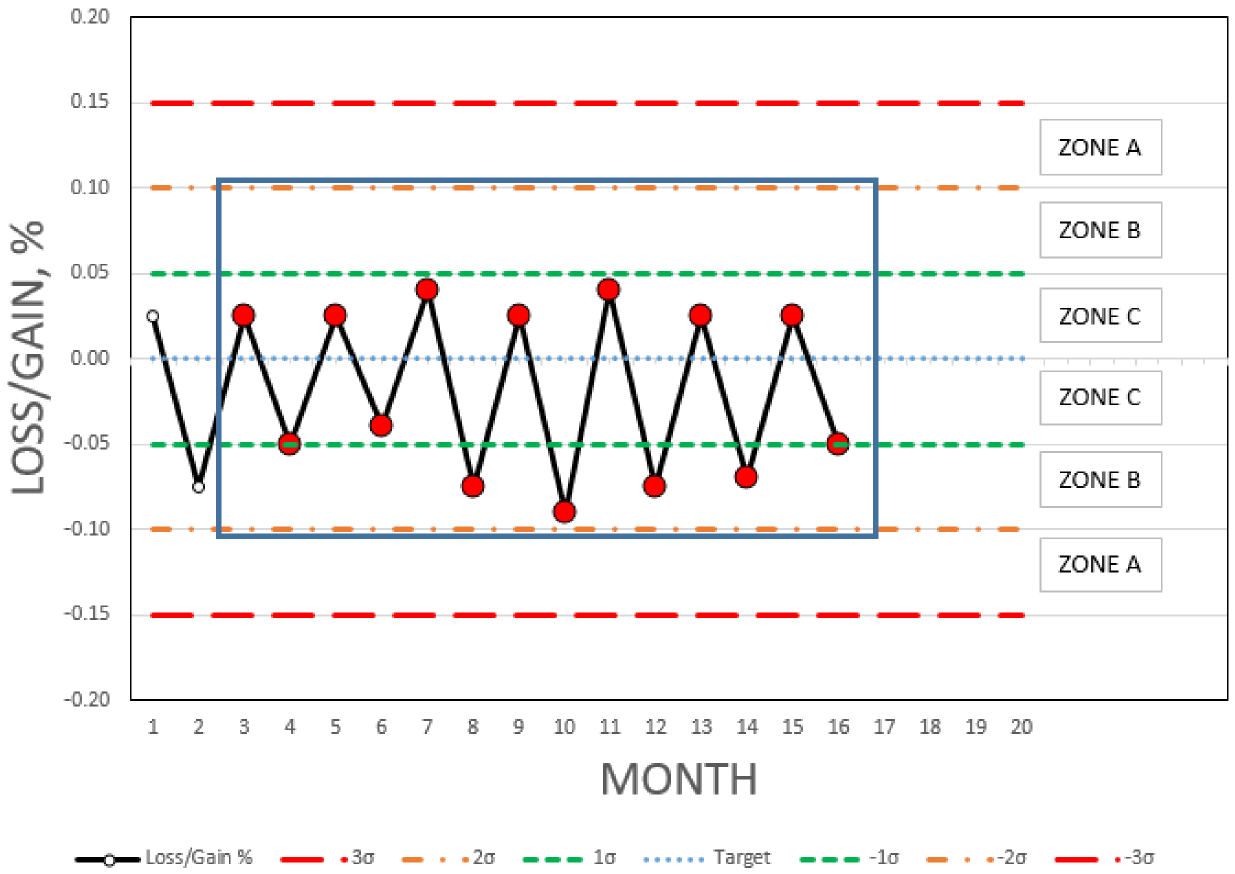


Figure B.9 – Rule 8 – Cyclic Pattern

B.2.9 It is difficult to list all possible causes for each pattern type because special causes (just like common causes) are very dependent on the type of process. Maintenance processes have different issues than procedural processes. Different types of control charts look at different sources of variation. Still, it is helpful to show some possible causes by pattern description. Table B.4 attempts to do this based on the type of pattern.

Pattern Description	Rules	Possible Causes
Large shifts from the average	1, 2	New person doing the job (training issue) Wrong setup (flow computer) Measurement error (i.e., tank gauging, blocked strainer, leaking valve, etc.) Process step skipped or not completed Power failure Equipment breakdown Line fill changes
Small shifts from the average	3, 4	Change in product properties Change in work procedure or frequency Different measurement device/calibration (new prover volume) Different crews Change in maintenance procedure Change in setup procedure Sampling and testing issues
Trends	5	Equipment wearing Temperature effects (cooling, heating)
Mixtures	6	More than one process present (e.g., shifts, crews, equipment, and measured products.) Changing average flow rate without proving Large change in throughput volume
Stratifications	7	More than one process present (e.g., shifts, crews, equipment, and measured products.) Control limits too wide
Over-control	8	Tampering by operator Alternating measured products

Table B.4 — Possible Causes by Pattern Type

Analyzing a control chart for special cause variation can be facilitated by using categories. Table B.5 lists the potential special causes to consider. When stratification is identified (Rule 7), it is generally due to one of two issues. The operators are truncating the measurements, or the process has improved significantly, which will require the recalculation of the statistical control limits.

Category	RULE 1	RULE 2	RULE 3	RULE 4	RULE 5	RULE 6	RULE 7	RULE 8
Measurement Equipment								
damaged equipment	X	X	X	X				
equipment failure/breakage	X			X				
gradual equipment failure					X	X		
sudden equipment failure	X							

improper equipment maintenance	X	X	X			X		X
improper setup	X	X	X	X		X		X
improper start-up	X							
intermittent equipment failure		X				X		X
equipment wear			X	X	X	X		
power interruption	X							
Operating Environment								
temperature gradually drifting too low/high					X	X		
pressure gradually drifting too low/high					X	X		
temperature shifted too low/high	X	X	X	X		X		
pressure shifted too low/high	X	X	X	X		X		
temperature intermittently too low/high						X		X
pressure intermittently too low/high						X		X
Measurement Process								
equipment has not stabilized	X					X		
inadequate work procedures	X					X		X
incorrect process parameters		X	X	X		X		X
missed process step	X					X		X
new process	X					X		X
new process parameters		X	X	X		X		X
process has degraded			X	X				
process has improved			X	X				
process is slowly degrading					X			
process is slowly improving					X			
two or more processes						X		
Inspection								
damaged inspection, measuring, and testing equipment	X	X	X	X	X	X		X

inspection, measuring, and testing equipment not adequate for the intended use		X	X		X	X		X
inspection, measuring, and testing equipment not properly calibrated	X	X	X	X		X		

Table B.5 – Potential Causes by Rule

Category	RULE 1	RULE 2	RULE 3	RULE 4	RULE 5	RULE 6	RULE 7	RULE 8
Measured Products								
change in product properties	X			X		X		
change in components	X			X		X		
mixed product (shrinkage)		X	X			X		X
mixed components		X	X			X		X
variation in the product					X	X		
variation in the components					X	X		
Operator								
inadequate training	X	X	X	X	X	X		X
multiple shifts						X		
new operators	X	X	X	X		X	X	X
operator interrupted or distracted	X	X	X	X	X	X	X	
operator not waiting for the process to stabilize before making process adjustments							X	X
operator overcompensating when making process adjustments	X						X	X
Shift/crew change		X	X	X				

Table B.5 (continued) – Potential Causes by Rule

B.2.10 It is good practice to determine whether a system is stable and in control. A system is generally considered to be in control if the data are all within control limits that have been established from the data. Data points outside the control range indicate poor control. A system is said to be stable if the data exhibit only random fluctuations around the centerline without trends. Adding trend lines to the control charts may give an indication of how the L/G system is performing over time and provide additional information. Figures B.10 and B.11 are the Rule 1 and Rule 5 figures with a linear trend line.

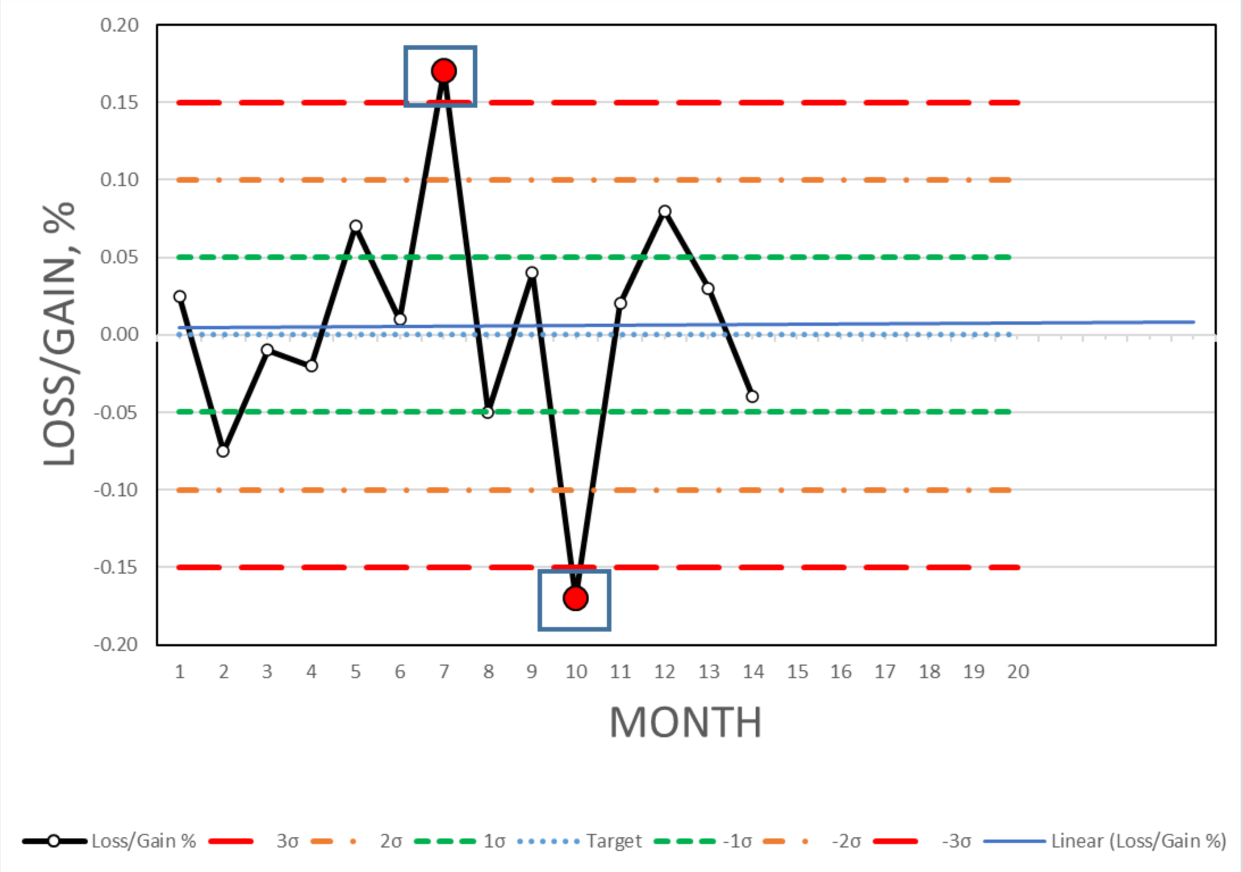


Figure B.10 – Rule 1 with Trend Line

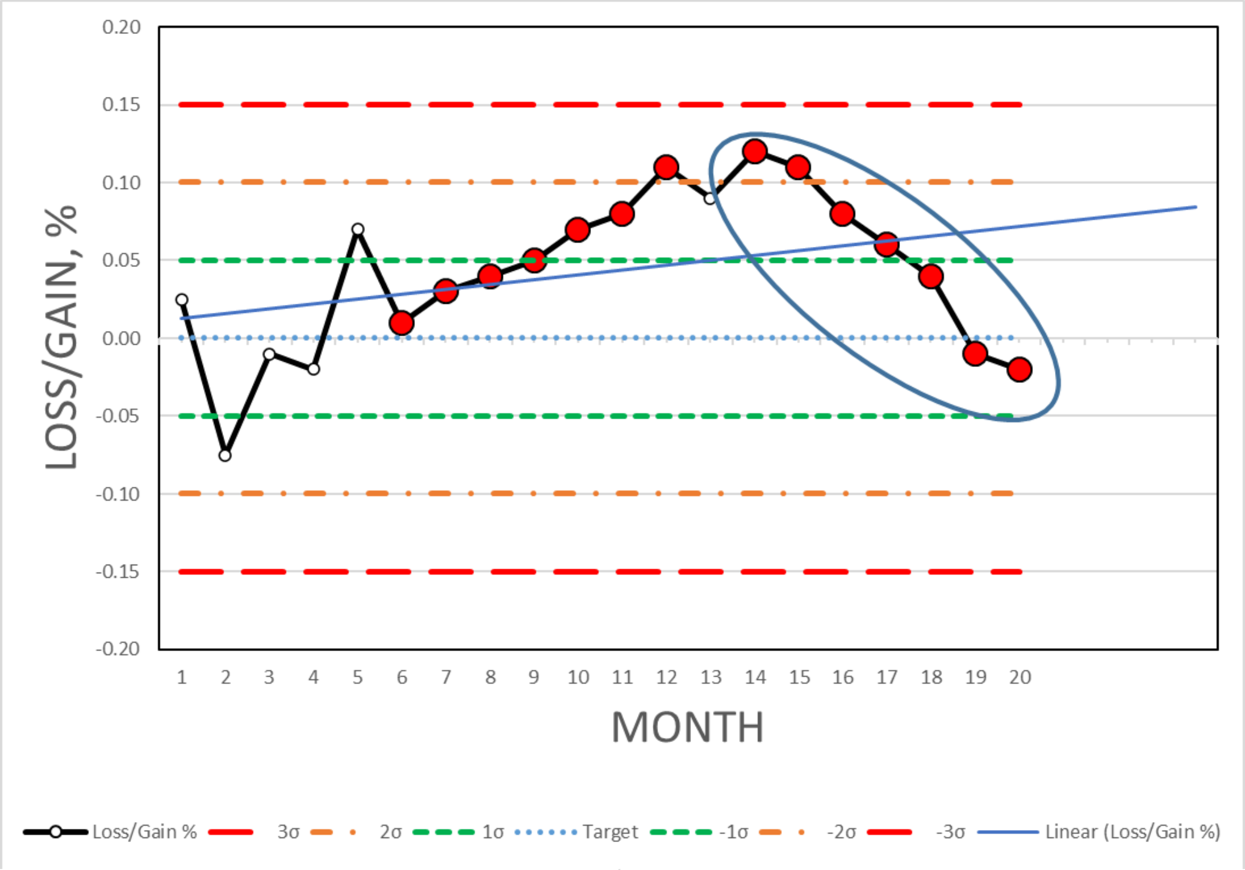


Figure B.11 – Rule 5 with Trend Line

B.2.11 A histogram can be created to depict the distribution of the zones over a time period. A histogram works best when there are at least 20 data points. If the sample size is too small, each bar on the histogram may not contain enough data points to accurately show the distribution of the data. Things to look for in histograms are:

- Skews – the majority of the data are located on one side of the histogram
- Multiple modes – more than one peak
- Outliers – data far away from the other data values
- Fit – ideally, a histogram should follow a normal distribution and look like a bell curve

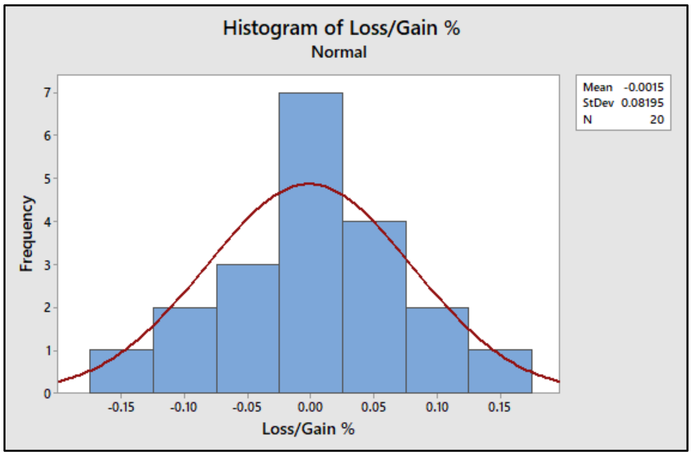


Figure B.12 - Histogram for data in Table B.6

Month	Loss/Gain %	3σ	2σ	1σ	CL	-1σ	-2σ	-3σ
1	0.03	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
2	-0.12	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
3	-0.01	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
4	-0.02	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
5	0.07	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
6	0.01	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
7	0.17	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
8	-0.05	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
9	-0.12	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
10	-0.17	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
11	0.02	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
12	0.08	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
13	0.03	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
14	-0.04	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
15	-0.08	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
16	0.01	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
17	-0.02	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
18	0.05	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
19	0.01	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
20	0.12	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15

Table B.6 – Example data

B.2.12 An Individual and Moving Range (I-MR) chart can also be created to monitor the mean and variation of the process. The I chart is simply the control chart discussed above and the MR chart data is the absolute value of the change from one data point to the next. Control chart rules 1, 4, 5 and 8 can be applied to the MR chart. I-MR charts are useful when there are homogeneous batches and repeat measurements vary because of measurement errors.

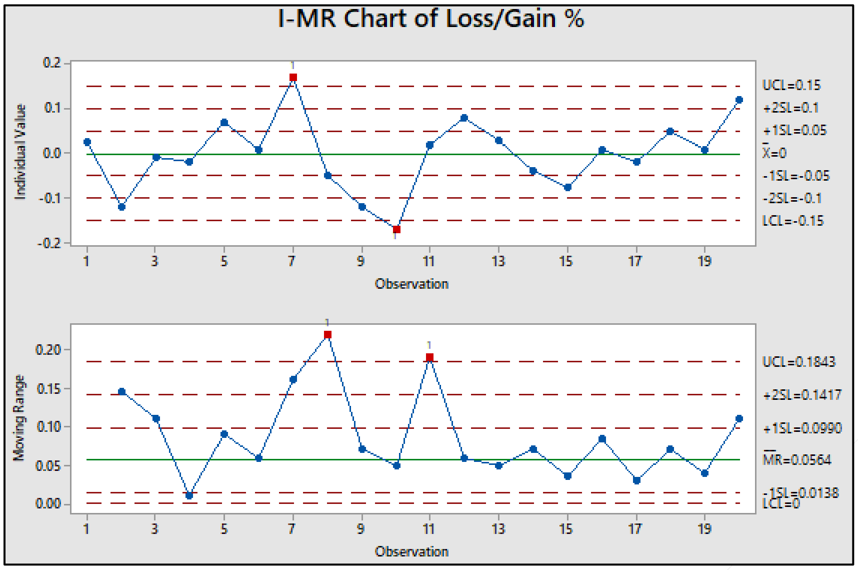


Figure B.13 – I-MR Chart Using Histogram Data

B.2.13 The performance of a system may change, positively or negatively, due to deliberate process changes, such as new equipment, improved procedures, increased/decreased maintenance frequencies or tolerances, etc. A system can change without any apparent reason. Any process change, be it deliberate or unplanned, may show up as a change in performance.

Whenever the data clearly shows a sustained change, the centerline and control limits should be changed accordingly as presented in Figure B.14. The process should be stable before it can be centered at a target value, or its overall variation (control limits) can be reduced.

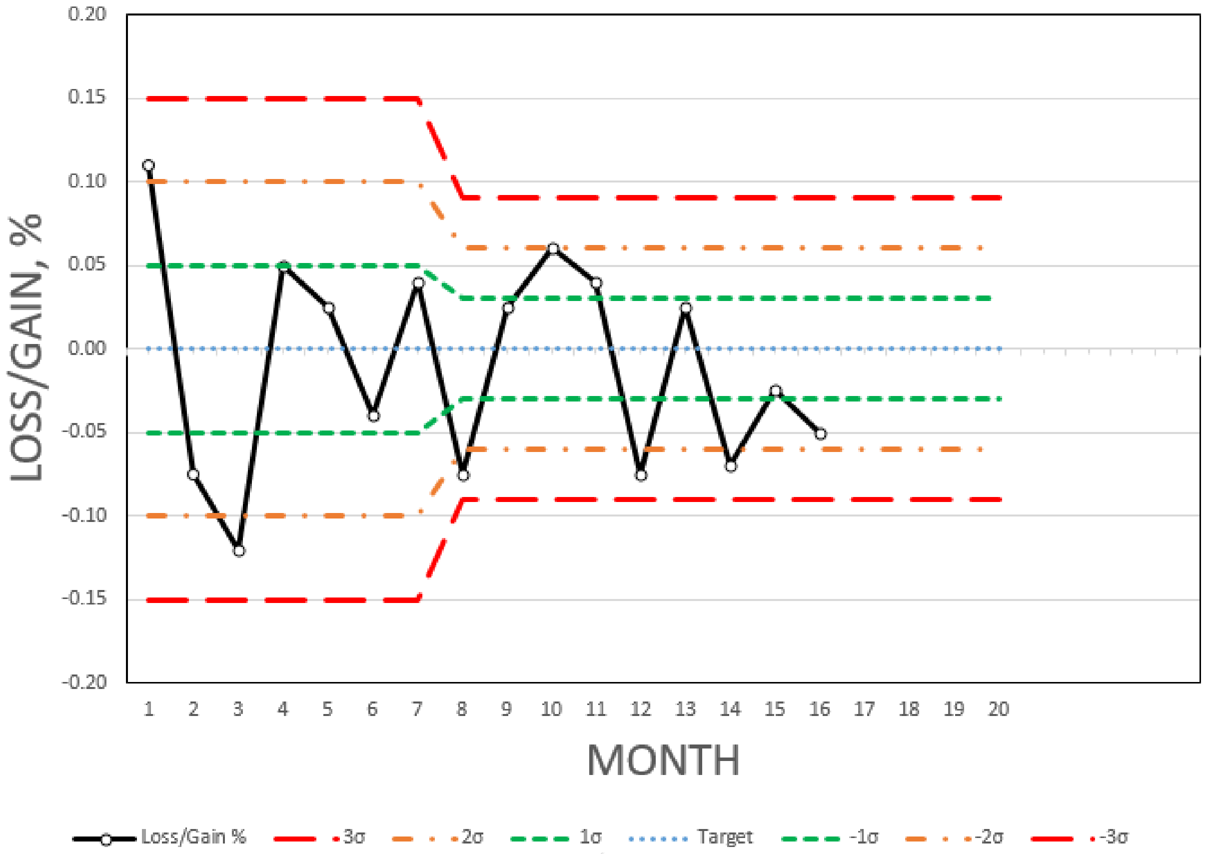


Figure B.14 – Control Chart with a Change in the Process

Caution should be taken if data suggests increasing limits or shifting the centerline as to not build in a bias, as shown in Figure B.15. Instead, the L/G system should be investigated for special causes.

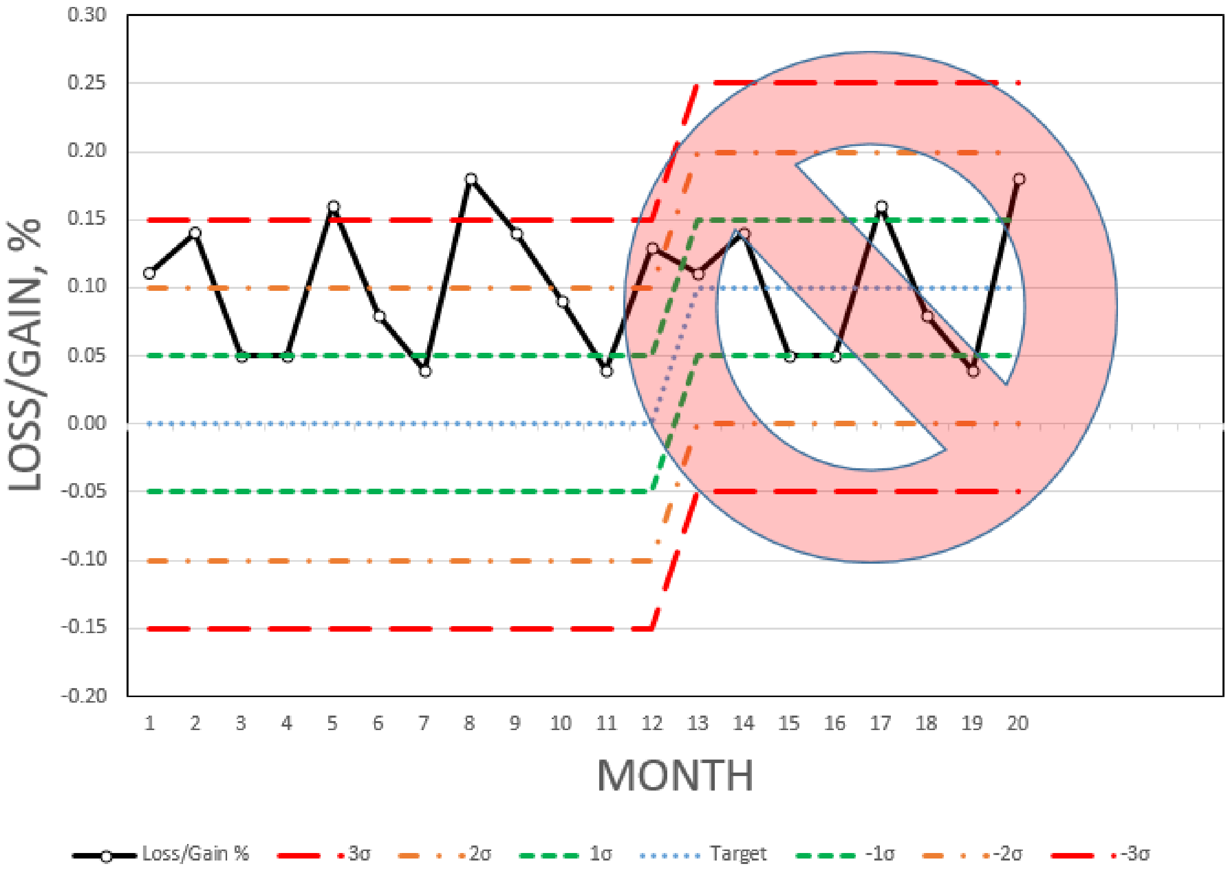


Figure B.15 – Control Limits Change with Unexplained Bias

Annex C
(informative)

Special Considerations for NGL System Balancing

While many of the procedures of determining and tracking gains and losses are the same, some of the operational practices and equipment used for NGL measurement and storage differ from standard crude oil, refined product, or petrochemical measurement.

C.1 Characteristics of NGLs

Natural Gas Liquids (NGLs) are hydrocarbons that are separated from natural gas in the form of liquids. These include ethane, propane, butanes, and natural gasoline. The proper reconciliation of pipeline quantities for NGLs is critical for accurate accounting and operational efficiency.

NGLs have unique properties that influence their measurement and reconciliation:

1. **Variable Composition**: NGLs are often a mixture of different hydrocarbons, each with its own density and vapor pressure.
2. **Temperature and Pressure Sensitivity**: NGLs can exist in both liquid and vapor phases, depending on the temperature and pressure, making accurate measurement challenging.
3. **High Volatility**: Due to their volatility, NGLs can experience significant volume changes with small variations in temperature and pressure.

NGLs present unique challenges for pipeline quantity reconciliation due to their variable composition and phase behavior. One critical aspect of accurate measurement and reconciliation is the choice between mass meters and volumetric meters.

Special care shall be taken when measuring mixed NGL streams due to a phenomenon called ‘solution-mixing error’. When metering NGL mixes in volume, especially mixes that are high in ethane content (more than 2 % to 5 % ethane), losses will occur when the smaller molecules fill the voids between larger molecules, resulting in lower volumes. When metering in mass, these properties are identified as units of mass. When the stream composition is identified, these units of mass can be converted to volume without this loss.

The amount of potential loss depends upon the stream composition. With Y-Grades that are high in ethane content, the potential for apparent loss can be substantial. With heavier component or high purity streams, when the effect of shrink is relatively insignificant the volumetric measurement is considered acceptable. With heavier component mixtures (C6+), compressibility and thermal expansion and contraction are not as significant as with lighter component mixtures. With high purity streams, predictions from EOS models have lower uncertainty than with diverse mixtures.

Another issue with using conventional volumetric methods involves the ability to correct the stream for the effects of temperature and pressure. Mixed NGL streams, especially of very light composition, do not readily fall into a particular category that is suited for a certain set of correction tables. Inherent errors can be introduced due to the varying expansion rates of the different products within the stream.

To help to eliminate these issues, measurement by mass is often the preferred method.

NOTE Refer to API MPMS Chapters 14.4 and 14.7

C.2 Mass Measurement of NGLs

C.2.1 Direct Mass by Coriolis Meter

Direct mass mainly involves the use of a Coriolis meter, since it is the only meter capable of a mass pulse output. With this method, the entire data stream, from the meter to the end device, should be programmed to accept and calculate mass quantities. The mass to volume calculations are most often not done in the flow computer, but in the accounting system.

The prover volume will be converted to mass when proving a direct mass meter. This involves the accurate determination of the flowing density at the prover to calculate the prover's displaced mass instead of volume.

Direct mass eliminates some of the potentials for error that exist with the inferred mass. Since the Coriolis meter's pulse output is in mass rather than volume, the need to convert meter volume to mass is eliminated, as well as the need for density to convert volume to mass. See Equation C.1:

$$Q_m = IM_m \times MF_m \tag{C.1}$$

Where,

Q_m is total mass

IM_m is indicated mass from Coriolis meter when configured in mass, and

MF_m is the meter factor when Coriolis meter is configured in mass

C.2.2 Direct Mass by Truck Scales

Another method of direct mass measurement involves hauling NGL product by truck and using drive-on scales to determine mass.

High quality multi-celled truck scales can be certified down to a very precise level. It is common to see a scale rated for 120,000 lbs. certify to within 40 lbs. or 0.03 %. Like other equipment used for custody transfer, the scales shall be periodically certified.

C.2.3 Inferred Mass

Inferred mass measurement utilizes a conventional volumetric meter but does not apply temperature and pressure corrections as in traditional volumetric methods. To accurately calculate mass, the system must also determine the density in real-time. Using the volumetric meter's indicated volume, the flowing density, the meter factor, and the density correction factor (DMF), the mass of the fluid can be precisely calculated. This approach ensures accurate mass measurement by integrating these critical factors into the calculation process. See Equation C.2:

$$Q_m = IV \times MF_v \times P_f \times DMF \tag{C.2}$$

Where,

Q_m *– Total mass*

IV *– Meter indicated volume (pulses/K factor)*

MF_v *– Meter factor when meter is configured in volume*

P_f *– Flowing density, uncorrected*

DMF *– Density meter factor.*

C.3 Composition Determination Scenarios for NGL Pipelines

Accurate reconciliation of NGL pipeline quantities involves various scenarios for determining product composition, each requiring specific approaches and technologies:

C.3.4 Inlet and Outlet Composition Measurement

Install gas chromatographs or online analyzers at both the inlet and outlet points of the pipeline to continuously monitor the composition of NGLs entering and exiting the system. This setup provides real-time data on composition changes, essential for accurate reconciliation. Usually, gas chromatographs in liquid service involve a means to vaporize the sample immediately before it is injected into the unit for analysis.

C.3.5 Intermediate Points Measurement

For long pipelines, installing additional measurement points along the pipeline helps in monitoring composition changes due to potential phase transitions or mixing from different sources. Intermediate measurements provide a more detailed understanding of composition variations along the pipeline.

C.3.6 Batch Analysis

In situations where continuous measurement is not feasible, periodic batch sampling and analysis can be performed. Samples are taken at regular intervals and analyzed using laboratory gas chromatography to determine the composition. While less real-time, this method still provides valuable data for reconciliation purposes.

C.3.7 Density and Pressure Correlation

Continuous density and pressure measurements can be used to infer composition changes. By correlating density and pressure data with known composition profiles, operators can estimate the composition of NGLs in real-time, supplementing direct composition measurements.

C.3.8 Composition-Based Volume Correction

Use composition data to apply specific volume correction factors that account for the unique properties of the NGL mixture. This approach ensures that volume measurements are adjusted accurately for temperature and pressure variations based on the current composition.

C.4 Composite Sampling

Proper pressure maintenance during NGL sampling is crucial to avoid the loss of lighter components, so that that the sample remains representative of the actual pipeline contents.

NOTE Refer to API Chapter 8.2 / ASTM D4177 “Standard Practice for Automatic Sampling of Petroleum and Petroleum Products” for standard practices and installation recommendations.

C.5 Converting Mass to Volume

API MPMS Chapter 14.4 / GPA 8173, *Converting Mass of Natural Gas Liquids and Vapors to Equivalent Liquid Volumes,* outlines the procedures to calculate mass of each component in NGL mixture, and then convert mass to volume. The following components in Table C.1 are shown in pounds/gallon, and can be found in the GPA-2145 table and are at 60 ºF and equilibrium vapor pressure.

Component	lb / gal
CO2	6.8129
Methane (C1)	2.5000
Ethane (C2)	2.9704
Propane (C3)	4.2285
iso-Butane (iC4)	4.6925
n-Butane (nC4)	4.8706
iso-Pentane (iC5)	5.2120
n-Pentane (nC5)	5.2584

Hexanes and heavier (C6+) *	Shall be determined from extended analysis.

Table C.1 – Liquid Densities of NGL Components

NOTE Refer to GPA-2186 ”Method for the Extended Analysis of Hydrocarbon Liquid Mixtures Containing Nitrogen and Carbon Dioxide by Temperature Programmed Gas Chromatography”

C.6 Densitometers

Refer to API 9.4, *Continuous Density Measurement under Flowing Conditions*, for installation and maintenance recommendations for densitometers.

C.7 Line Fill and Line Pack Volumes

By accurate accounting for Line Fill and Line Pack in the reconciliation process, operators can achieve more precise control over their pipeline operations, ensuring accurate measurement and management of NGL quantities. While Line fill refers to the volume of NGLs required to fill the entire length of the pipeline, Line pack reflects the compressible nature of NGLs under varying pressure conditions. When pressure and temperature changes occur, it can significantly affect the volume of the product within the NGL pipeline.

NOTE For further information, refer to GPA Midstream Guideline PFPDM-23 “Guidelines for Pipeline Fill, Pack, and Determination Methodology”

C.8 Pressurized Tanks

Pressurized tanks used for delivering and receiving Natural Gas Liquids (NGLs) are designed to handle the specific properties and requirements of these hydrocarbon mixtures. These tanks shall maintain appropriate pressure levels to keep NGLs in the liquid phase, preventing vaporization and ensuring safe and efficient transfer to and from pipelines. The tanks are constructed to withstand high pressures typically required to keep NGLs in a liquid state. They shall be built according to relevant industry standards and regulations to ensure safety and durability.

Accurate level measurement systems are integrated to monitor the volume of NGLs in the tank continuously. Maintaining a consistent temperature is crucial as NGLs can be sensitive to temperature changes. The tanks may include insulation and temperature control systems to prevent excessive heating or cooling. To manage unexpected pressure surges and prevent over-pressurization, the tanks are equipped with pressure relief valves and safety mechanisms.

C.9 Refrigerated Tanks

Refrigerated NGL tanks are specialized storage units designed to keep NGLs at low temperatures to maintain them in a liquid state, which reduces the pressure requirements compared to pressurized tanks. Accurate measurement and monitoring of refrigerated NGL tanks are crucial for safe and efficient operations, as well as for precise reconciliation of quantities.

These are some key characteristics of Refrigerated NGL Storage Tanks:

C.9.1 Level Measurement

Non-contact radar level gauges are commonly used for measuring the liquid level in refrigerated NGL tanks. They provide accurate and reliable measurements even under cryogenic conditions.

Float and Tape Systems are also used to measure the liquid level in tanks. These systems are also used in some installations, providing a mechanical means of level measurement that is reliable under low-temperature conditions.

C.9.2 Temperature Measurement

Accurate temperature sensors are installed at various levels within the tank to monitor the temperature of the NGLs. Maintaining a consistent low temperature is crucial to prevent vaporization.

Thermocouples and RTDs (Resistance Temperature Detectors) are commonly used types of temperature sensors that offer precise measurements in cryogenic environments.

C.9.3 Pressure Measurement

Installed at different points in the tank, pressure transmitters monitor the internal pressure to ensure it remains within safe limits. The pressure shall be controlled to prevent boiling and maintain the liquid state of NGLs.

C.9.4 Density Measurement

Densitometers measure the density of the NGLs, which can vary with temperature and composition. Accurate density measurements are essential for converting volume measurements to mass.

C.9.5 Volume Calculation

Using the level, temperature, and density data, the volume of NGLs in the tank is calculated. This involves applying correction factors for temperature and density to ensure accurate volume determination.

C.9.6 Composition Analysis

Regular sampling of NGLs is necessary to analyze their composition. This helps in determining the exact proportions of different hydrocarbons, which is critical for density calculations and reconciliation.

Continuous composition online analyzers can provide real-time data on the NGL mixture, improving the accuracy of volume and mass calculations.

C.10 NGL Reconciliation priorities

During the NGL reconciliation process, priority should be given to mass balance first (if feasible), followed by volume balance.

Hydrocarbon vapors in large empty vessels can complicate accurate quantity determination.

Balancing issues can include:

- If the mass does not balance, it likely indicates a meter error or another product loss issue.
- If the volume does not balance, it usually points to a physical property discrepancy.

NOTE Refer to the relevant API and GPA standards (such as API MPMS Chapter 11.2.5 / GPA 8117, API MPMS Chapter 14.4 / GPA 8195, API MPMS Chapter 11.2.4 / GPA 8217, etc.) for guidance.

Annex D

(informative)

Troubleshooting Guide for Liquid Pipeline Measurement Operations

See the Troubleshooting Guide in Excel attachment to this document.

Bibliography

[1] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 3.1A, *Standard Practice for the Manual Gauging of Petroleum and Petroleum Products*

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[3] API *Manual of Petroleum Measurement Standards (MPMS) Chapter 5, Metering*

[4] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 7, *Temperature Determination*

[5] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 8, *Sampling*

[6] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 11.1, *Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils*

[7] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 11.2.4, Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E, and 60E (GPA Midstream Standard 8217)

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[12] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 13.2, *Statistical Methods of Evaluating Meter Proving Data*

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[14] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 14.4, *Converting Mass of Natural Gas Liquids and Vapors to Equivalent Liquid Volumes* (GPA Midstream Standard 8173)

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[16] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 17.6, *Guidelines for Determining the Fullness of Pipelines between Marine Vessels and Shore Facilities*

[17] API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 20, *Allocation Measurement*

[18] GPA Midstream Guideline PFPDM-23, *Guidelines for Pipeline Fill, Pack, and Determination Methodology*

[19] GPA Midstream Standard 2145, *Table of Physical Properties for Hydrocarbons and Other Compounds of Interest to the Natural Gas and Natural Gas Liquids Industries*

[20] GPA Midstream Standard 2186, *Method for the Extended Analysis of Hydrocarbon Liquid Mixtures Containing Nitrogen and Carbon Dioxide by Temperature Programmed Gas Chromatography*

Manual of Petroleum Measurement Standards
Chapter 23.1

Reconciliation of Liquid Pipeline Quantities

SECOND EDITION, 202X

Introduction

In the ideal world, every drop of liquid received into a pipeline system and every drop delivered out of the system, as well as all liquid inventory within the system, would be measured and accounted for precisely, and a comparison of all receipts and all deliveries—adjusted for inventory changes—would be exactly the same. The system would never experience a loss or a gain. Unfortunately, this ideal pipeline balance seldom exists in the real world.

Most pipeline systems typically experience some degree of loss or gain over time. This represents the normal loss/gain performance for a system. From time to time, losses or gains greater than normal may occur for a variety of reasons. Excessive or unexplained loss/gain often leads to contention between participating parties, sometimes requiring monetary settlements to adjust for abnormal loss/gain. In such cases, it is necessary to be able to (1) identify abnormal loss/gain as quickly as possible, (2) determine the magnitude of abnormal loss/gain, and (3) institute corrective actions.

Sometimes losses or gains are real, and adjustments shall be made to correct shipper batches and/or inventories. Most of the time, though, there are no ~~real physical~~physical losses or gains. The loss/gain that occurs in day-to-day operation is usually small (a fraction of a percent) and is caused by small imperfections in a number of measurements in a system.

In a sense, loss/gain is an indicator of the ability to measure within a system. Loss/gain should be monitored for any given system at regular intervals to establish what is normal for that system and to identify any abnormal loss/gain so that corrective action can be taken.

Reconciliation of Liquid Pipeline Quantities

1 Scope

1.1 General

~~This publication~~Chapter 23.1 provides methodologies for monitoring liquid hydrocarbon pipeline loss/gain and for determining the ~~normal~~ loss/gain performance level range for any ~~given~~ such pipeline system. ~~Troubleshooting suggestions are also presented.~~

This document does not establish industry standards for loss/gain performance level range because each system has its own characteristics~~is individual~~ and exhibits its own loss/gain level range and/or patterns ~~under normal operating conditions~~.

~~The document~~P~~ p~~rovides operational and statistically based tools for identifying when a system has deviated from normal, the magnitude of the deviation, and guidelines for identifying the causes of ~~deviation from normal~~ those variations. Troubleshooting ~~suggestions~~suggestions are also presented.

~~1.2~~

~~1.3~~1.2 Field of Application

The primary application of this publication is in custody transfer liquid pipeline systems in which there is provision for measuring all liquids that enter the system and exit the system, as well as liquid inventory within the system. The application is not intended for nonliquid or mixed-phase systems.

The applications and examples in this document are intended primarily for custody transfer pipeline systems, but the principles may be applied to any system that involves the measurement of liquids into and out of the system and possibly, inventory of liquids within the system. Such systems may include pipelines, marine terminals, marine voyages, bulk loading or storage terminals, tank farms, and rail and trucking systems.

2 Normative References

~~The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.~~There are no normative references in this document.

3 Terms and Definitions

For the purposes of this document, these specific definitions apply.

3.1 ~~Terms and~~ Definitions

3.1.1
action limits
Lines on a control chart that represent a boundary between taking or not taking action to modify a process.~~Control limits applied to a control chart or log to indicate when action is necessary to inspect or calibrate equipment and possibly, issue a correction ticket. Action limits are normally based on 95 % to 99 % confidence levels for statistical uncertainty analyses of the group of measurements.~~

3.1.2

control chart
A graphical method for evaluating whether a process is in or out of a state of statistical control by using warning and action limits determined by statistical analysis of the process data.

3.1.3
control chart loss/gain
A graphical method for evaluating whether L/G and/or meter proving operations are in or out of a "state of statistical control."

~~**3.5**~~
~~**control chart or log of fixed limit**~~
~~A control chart or log whose control limits are based on adopted fixed values applicable to the statistical measurements displayed on the log or chart. Historically, fixed limits have been used to control the limits on meter factor changes.~~

3.1.4 ~~**6**~~
control limits
Lines on a control chart used to evaluate whether or not a process is in statistical control.~~Lines on a control chart used to evaluate whether or not a process is in statistical control.~~

3.1.5 ~~**7**~~
loss/gain system
L/G
L/G is the difference between deliveries and receipts, adjusted for changes in inventory, experienced by a system over a given time period (e.g., day, week, month) or over a single (or multiple) product movement(s).

NOTE Often referred to as gain / loss, or G/L.

~~**3.1.5**~~**3.1.6**
natural gas liquids
~~**(**~~**NGL**
Those hydrocarbons liquefied at the surface in field facilities or in gas processing plants. Natural gas liquids include ethane, propane, butanes and natural gasoline.

~~**3.1.6**~~**3.1.7** ~~**8**~~
repeatability
Measurement precision under a set of repeatable conditions of measurement.

~~**3.1.7**~~**3.1.8** **9**~~**8**~~
standard deviation
Positive square root of the variance.

~~**3.1.8**~~**3.1.9** ~~**9**~~
statistical control
The data on a control chart are in a state of statistical control if the data hover in a random fashion around a central mean value, and at least 99 % of the data are within the three standard deviation control limits, and the data do not exhibit any trends with time.

~~**3.1.9**~~**3.1.10** ~~**0**~~
~~**systems**~~ **tolerance limits**
Control limits that define the action and conformance boundaries for variations to indicate when an audit or technical review of the facility may need to be conducted to determine sources of errors and changes that may be required to reduce variations.

3.1.11

standard deviation limits

Control limits equal to one, two and/or three standard deviations from the arithmetic mean of the set.

~~3.1.10~~3.1.12 ~~2~~

warning limits

~~Lines on a control chart that represent a boundary between a predictable and unpredictable process.~~

~~Note: This is typically equal to the 2 standard deviation limit.~~

Control limits applied to a control chart to indicate when equipment, operating conditions or computations should be checked because one or more data points were outside pre-established limits. Warning limits are normally based on 90-95 percent confidence levels.

~~3.1.11~~3.1.13

line fill

The quantity of liquid contained in a segment of pipeline.

4 Measurement Data Analysis

4.1 General

Data may be presented in the form of control charts, trending charts, or cumulative charts. Guidelines on such charts may include control limits and trending lines. Charts used for monitoring measurement systems should be living documents and should be updated whenever new data is available.

Accumulating data for some period of time and periodically updating charts (e.g., semi-annually) serves no useful purpose. Charts and monitoring procedures can be effective only if charts are current and used as constructive tools.

4.2 Loss/Gain (L/G) Analysis

4.2.1 Loss/Gain Equations

Losses and gains may be physical issues (e.g., leaks, evaporation, theft, shrinkage, unmeasured or unaccounted liquid is added to the system etc.) or apparent issues (e.g., errors in measurement, tickets, procedures, etc.). More often, there is no actual physical loss or gain, just simply small measurement inaccuracies or accounting discrepancies. The combination of these may result in a system being outside of normal or acceptable limits.

L/G analysis typically involves collecting data, calculating L/G, and plotting L/G on any of several different types of control charts. These control charts may include control limits or other analytical guides that are derived from some simple statistical tools as per the equations described in the following sections. The tools described in this document may be used by anyone and may not require an understanding of statistics.

The two basic L/G equations (not all inclusive) are shown below. One expresses a loss as a negative value and the other expresses the loss as a positive value.

It is important to keep in mind which convention is being used to correctly decide whether the L/G values represent losses or gains.

Loss expressed as a negative number can be calculated with Equation 1:

$$\frac{L}{G} = (CI + D) - (OI + R) \qquad (1)$$

Loss expressed as a positive number can be calculated with Equation 2:

$$\frac{L}{G} = (OI + R) - (CI + D) \qquad (2)$$

Loss or gain of the system to be reconciled may also be provided as an absolute value to express relative distance of the variance from zero as shown in Equation 3:

$$\frac{L}{G} = \left|(CI + D) - (OI + R)\right| \qquad (3)$$

System Gain: If (*CI* + *D*) > (*OI* + *R*)
System Loss: If (*OI* + *R*) > (*CI* + *D*)

In such case, loss or gain is always an absolute value, where

CI is the closing inventory in the system at the end of the time period,

D is the sum of deliveries out of the system during the time period,

OI is the opening inventory in the system at the start of the period,

R is the sum of receipts into the system during the time period, and

$\frac{L}{G}$ may be reported in units of volume (e.g., barrels, gallons or kiloliters) or mass (e.g., pounds or metric tons)

When expressed in percent, the actual L/G quantity is divided by the quantity of total receipts for a receipt-based system or by the quantity of total deliveries for a delivery-based system and multiplied by 100. Receipt based systems typically have consistent receipt volumes and delivery-based systems typically have consistent delivery volumes.

For Receipt-based systems, see Equation 4:

$$\frac{L}{G}\% = \left(\frac{L}{G} \div R\right) \times 100 \qquad (4)$$

For Delivery-based systems, see Equation 5:

$$\frac{L}{G}\% = \left(\frac{L}{G} \div D\right) \times 100 \qquad (5)$$

For A~~a~~verage-~~-~~based systems, see Equation 6:

$$\frac{L}{G}\% = \left(\frac{L}{G} \div \left(\frac{(R + D)}{2}\right)\right) \times 100 \qquad (6)$$

NOTE In the equations above, variables shall be expressed in like units of measure. Variables calculated under the same conditions (mass, or gross standard volume [GSV] and net standard volume [NSV]), will yield the most meaningful information. (Reference API MPMS Ch. 12.1.1, *Calculation of Static Petroleum Quantities, Part 1—Upright Cylindrical Tanks and Marine Vessels*, Ch. 12.1.2, *Calculation of Static Petroleum Quantities, Part 2—Calculation Procedures for Tank Cars*, and Ch. 12.2, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors*)

4.2.2 Factors to account for in the L/G equations

~~3.1.11.1~~ Change in line fill: Opening Inventory (OI) and Closing Inventory (CI)

~~3.1.11.2 Effect of the~~

4.2.2.1

~~line fill~~

Change in line fill volume may contribute significantly to system inventory. If possible, line fill should be corrected for temperature, pressure and density. Pipelines should be completely empty or completely full at the beginning and end of the time period. ~~See section XXX for more details on line fill calculations.~~

Line fill may be considered static, but depending on the line fill volume and throughput it may impact L/G.

The potential impact of line fill change can be estimated by performing the following calculation provided in Table 1. When the throughput of the system is considered, it clearly shows the impact reduction with increased throughput.

	Calculation	Opening	Closing	Opening	Closing	Opening	Closing
	Formulas / Units	NO CTS & CPS	NO CTS & CPS	With CTS & CPS	With CTS & CPS	Differ-ence	Differ-ence
Average Temp	Temp., °F	70.0	75.0	70.0	75.0	-	-
Average Pressure~~SI~~	Pressure, psi	100.0	150.0	100.0	150.0	-	-
Weighted Avg. API	°API Gravity	35.0	35.0	35.0	35.0	-	-
Weighted Avg. S&W %	S&W Vol%	0.500 %	0.500 %	0.500 %	0.500 %	-	-
GOV	Gross line fill, Barrels	100,000	100,000	100,000	100,000	-	-
Pipe ID	Inches	-	-	16	16	-	-
Wall Thickness	Inches	-	-	0.50	0.50	-	-
CTL	CTL @ Temp. & °API	0.99526	0.99289	0.99526	0.99289	-	-
CPL	CPL @ Temp & °API	1.00052	1.00079	1.00052	1.00079	-	-
CTPL	CTL * CPL	0.99578	0.99367	0.99578	0.99367	-	-
CPS	1 + (PD/Et)	1.00000	1.00000	1.00011	1.00016	-	-
CTS	1 + (T – 60) g	1.00000	1.00000	1.00019	1.00028	-	-
CCF	CTPL * CPS * CPS	0.99578	0.99367	0.99607	0.99411	-	-
GSV Volume	GOV * CCF	99,578	99,367	99,607	99,411	29	44
Net Volume	GSV – (GSV * S&W %)	99,080	98,870	99,109	98,914	29	44
Throughput	Volume, Barrels	500,000		500,000		-	-

Line fill change % of Through-put	%	-0.042 %	-0.039 %	-	-
Throughput	Volume, Barrels	5,000,000	5,000,000	-	-
Line fill change % of Through-put	%	-0.004 %	-0.004 %	-	-

Table 1—~~.~~ Line Fill volume change with and without Temperature and Pressure effects on steel pipe.

For a better estimation, the following pipeline corrections may be applied.~~:~~

To correct for the effect of pressure on steel of pipe (CPS), use Equation 7:~~Correction for the effect of pressure on steel of pipe~~

$$\text{12-month average \%} = \left(\frac{\sum \text{last 12-months } \frac{L}{G} \text{ volume}}{\sum \text{last 12-months } (\text{receipts, deliveries, or average})} \right) \times 100 \qquad (7)$$

~~CPS = 1 + (PD/Et),~~

Where,

P is ~~P =~~ internal pressure, psig

D ~~D =~~ is internal diameter, inches

t ~~t =~~ is wall thickness of pipe, inches, and

E ~~E =~~ is modulus of elasticity for pipe (E = 3.00E+07 for mild steel)

To correct for the effect of temperature on steel of pipe (CPS), use Equation 8:~~Correction for the effect of temperature on steel of pipe~~

$$CTS = 1 + (T - 60)g \qquad (8)$$

~~CTS = 1 + (T - 60)g~~

Where,

T is ~~T =~~ temperature in ~~degrees~~ °F (fluid temperature), and

g ~~g =~~ is coefficient of cubical expansion per ~~degree~~ °F of pipe material (1.86E-05 for mild steel)

4.2.2.1.1 Factors to account for in the L/G equations

Several additional factors may impact loss / gain equations, including:

- Cavern inventory (generally salt caverns are not included in L/G systems)
- Line fill volume may change due to a project or maintenance work ~~during the time period~~

~~See API MPMS Chapter 17.6 for determination of pipeline fullness~~

- ~~Tank Inventory (generally salt caverns are not included in L/G systems)~~Slack line

NOTE See API MPMS Chapter 17.6, *Guidelines for Determining the Fullness of Pipelines Between Marine Vessels and Shore Facilities*, for determination of pipeline fullness

~~The physical closing tank gauge reading from the previous period should match the physical opening tank gauge reading for the current period.~~

~~Tanks that are gauged for inventory and that are active at the time of gauging should be allowed to rest long enough to be gauged without liquid moving in or out.~~

~~Accurate month-end inventory gauges are especially important because they are used to balance and close out pipeline and/or terminal inventories and to issue customer and billing reports. Multiple customers may share the same storage in a fungible tank, and L/G offsets from month to month can be difficult to allocate.~~

~~NOTE See API MPMS Chapter 3 for further details.~~

~~3.1.11.3~~4.2.2.2 Deliveries (D) and Receipts (R)

The following are factors which can influence loss / gain on deliveries or receipts:

~~3.1.11.3.1~~

4.2.2.2.1 Meters or Custody tank transfer

Perhaps the most common errors occurring on manually calculated measurement tickets are arithmetic errors and wrong correction factors applied.

Tickets that do not get into the accounting process on time will cause an apparent loss or gain in the current accounting period and an offsetting gain or loss in the following period.

4.2.2.2.2 Sump tank

Sumps collect drips and drains from several sources and may add a bias to a system loss or gain if the sumps are emptied by pumping into a pipeline system without being measured. Usually, sump volumes are small enough to not impact the overall L/G for the system. However, the volumes may be significant if sumps accumulate large volumes, such as frequent drain downs from provers or pig traps.

~~3.1.11.3.2~~4.2.2.2.3 Unmetered Volumes

Factors to consider when unmetered volumes are present in the system or are estimated:

- Pipeline relief events and/or unmetered product flaring
- Pigging
- Line emptying
- Project work
- Chemical Additive injection
- Theft
- Tank evaporation

—

— Product growth or shrinkage

NOTE See~~.~~ API MPMS Ch. 12.3,~~-~~ *Volumetric Shrinkage Resulting from Blending Light ~~–~~Hy~~y~~dro~~o~~car~~r~~bons With Crude Oils*

4.2.2.3 Once the reconciliation of the system (or a part of the system) is complete, its results shall be compared to the criteria and limits established by the operator. If the system's Loss or Gain meets the established criteria (see ~~s~~Section 4.3~~4.3~~), and there are no known issues associated with the system's performance during the timeframe being evaluated, then no further action may be required. It is a good practice to always develop control charts to conduct further data analysis ~~in order to~~to ensure that all components of the system were in control, and no special cause variations were present, which could mask a potential issue with either equipment or processes. Detailed analysis (segmenting system into smaller segments) may be desirable on the complex systems with multiple inlets and outlets and with multiple parties in the system. The overall Loss or Gain may stay well within the acceptable limits, but some segments can show larger variances which can seriously affect the involved parties.

If the system's Loss or Gain is found outside of the established criteria, then further data analysis and investigation of the excessive variances should be conducted. Various control charts and other troubleshooting tools and techniques included in this document can help operator to identify the cause of the problem and work on necessary corrections.

NOTE 1 ~~:~~ See ~~s~~Section ~~[~~5~~]~~ and Annex D for troubleshooting suggestions and techniques.

NOTE 2 For additional information on ~~linefill~~line fill refer to GPA Midstream'~~s~~ Guideline PFPDM-23, ~~–~~"*Guidelines for Pipeline Fill, Pack, and Determination Methodology*"~~"Guidelines for Pipeline Fill, Pack, and Determination Methodology"~~.

~~4.2. calculation – ISHM Troubleshooting document as reference. Add reference to GPA PFPDM-23~~

~~Line fill volume as percentage of thruput (effects)~~

4.3 Control Charts

4.3.1 General

To ensure accurate measurement, it's essential to continuously monitor measurement results to determine if systems, or equipment and procedures, perform as expected and operate within acceptable limits. Utilizing control charts can facilitate this process.

Control limits are often determined by historical performance of the system. In other cases, the control limits are set on an established value (e.g., contractual limits). Due to inherent issues (built in biases, etc.) with both of those models, consideration should be given to establishing control limits based on the capabilities of the equipment in the L/G system. Statistical analysis of the uncertainties of the measurement equipment (i.e., meters, prover, etc.) and procedures (verification/calibration frequencies, tolerances, etc.) can also be utilized to establish control limits. See Annex B for one such method for establishing control limits. Control charts are the most common method of ascertaining system L/G performance. Control charts display a collection of data over some period of time and include the control limits. Control charts help to define normal trends of a system and may indicate when something has changed. Typical L/G charts, as shown in Figure 1, indicate a system's performance based on a percentage of throughputs over time. Typically, because accounting systems encompass a 30-day period, monthly evaluations of a system are commonly used to evaluate performance. Control charts may be prepared for any time span (e.g., weekly or daily) if adequate data are available.

Control charts may be maintained for entire systems or for individual segments of a system if measurement and records are available at the junctures of segments. The limits of the control charts will depend on the accuracy of the available measurement systems.

The data on control charts should remain near or around a target value and can be represented by a horizontal line on the chart. This target value is generally based on the anticipated or expected L/G of the system (typically at or near 0 %). The control chart also includes UCLs and LCLs that may be:

1) Defined statistically as two and three standard deviations above and below the target value or

2) Defined as engineering, historical or contractual limits, which are values based on experience or performance objectives

Standard deviation is a statistical measure of the spread of a data set with respect to the mean value of the set the specific number of deviations as determined by the user(s). Procedures for calculating statistical quantities are shown in Annex A.

Figure 1 shows the example of a typical control chart.

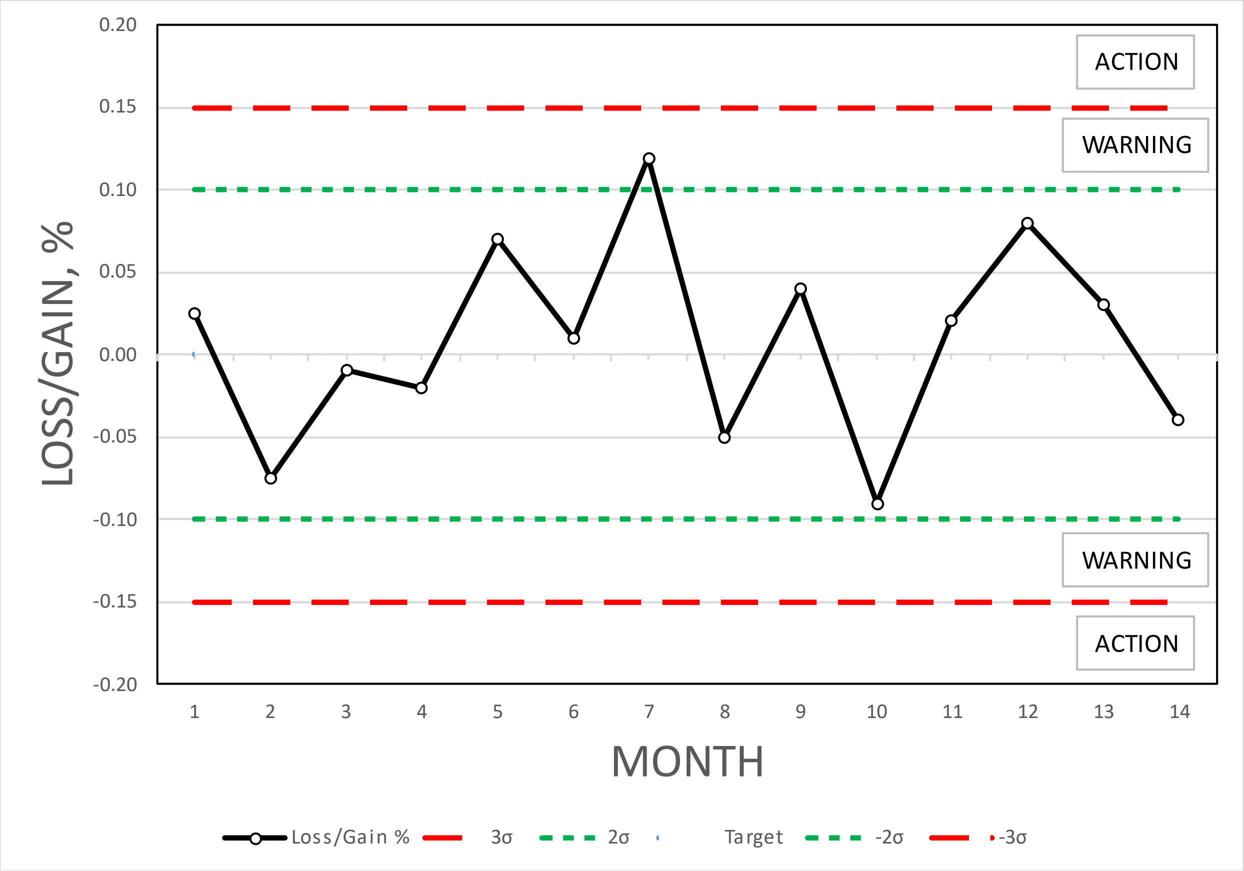


Figure 1 – Sample Control Chart

The data shall be representative of the expected performance of the system, as the control limits will be used to predict near-future performance. Any data point that is known to be the result of a special cause should be shown on the control chart but should not be included in the calculation of target, standard deviation, or control limits, and the number of data points shall be adjusted accordingly. A special cause is an event (e.g., meter failure, late run ticket, line displacement with water for hydrostatic pressure test, etc.) that results in mismeasurement for a given period of time but is not a part of the normal operation of the system.

Charts can be used to determine system stability, cyclical trends, or step changes in performance. One of the most important benefits of using charts to assess performance is the instant visual representation it provides.

The adage “a picture paints a thousand words” best summarizes the effectiveness of control charting.

NOTE For further information on control charts and their interpretation, refer to Annex B “Interpreting Control Charts”.

4.4 Pipeline System Control Charts

4.4.1 A useful tool for monitoring pipeline systems is the control chart that shows L/G as percent of throughput over time. Total receipts are used for throughput in receipt-based systems, and total deliveries are used for delivery-based systems.

For historical performance-based control limits to be statistically significant, a minimum of 30 data points is required. For practical purposes, control limits for a pipeline system that is monitored monthly will often be based on monthly L/G data. For our purposes, the 24 data points are acceptable. It is common practice to set limits at the beginning of each calendar year based on the prior history. These limits are carried forward for the calendar year unless there is a change in the process that would require new limits. Until enough data is collected to establish historically performance-based control limits, reasonable control limits should be established and applied by the system operator.—

NOTE ~~ote:~~ When calculating limits based on historical data, pay careful consideration to outliers. Outliers are data points that are notably different from other data points, and they can cause problems in statistical procedures. There are several statistical outlier tests that can be used to remove biases caused by outliers.

4.4.2 Setting fixed limits for L/G, without regard to actual data, may be required for contractual reasons. Whenever possible, it is more practical to set limits based on historical data. Care should be taken to avoid bias conditions or outliers affecting the control limit calculations. A pipeline system tends to operate at a level of performance that is dictated by, but not limited to, physical configuration, equipment, procedures, maintenance practices, environmental conditions, and employee training. ~~All of~~All these factors combine to produce a natural randomness and, sometimes, a natural bias in a system. For systems that have other constraints, it may be desirable to include a second set of limits. –See Annex A for tolerance calculations.

Figure 2 shows the L/G data for two years. This data may be used to set control limits for the following year.

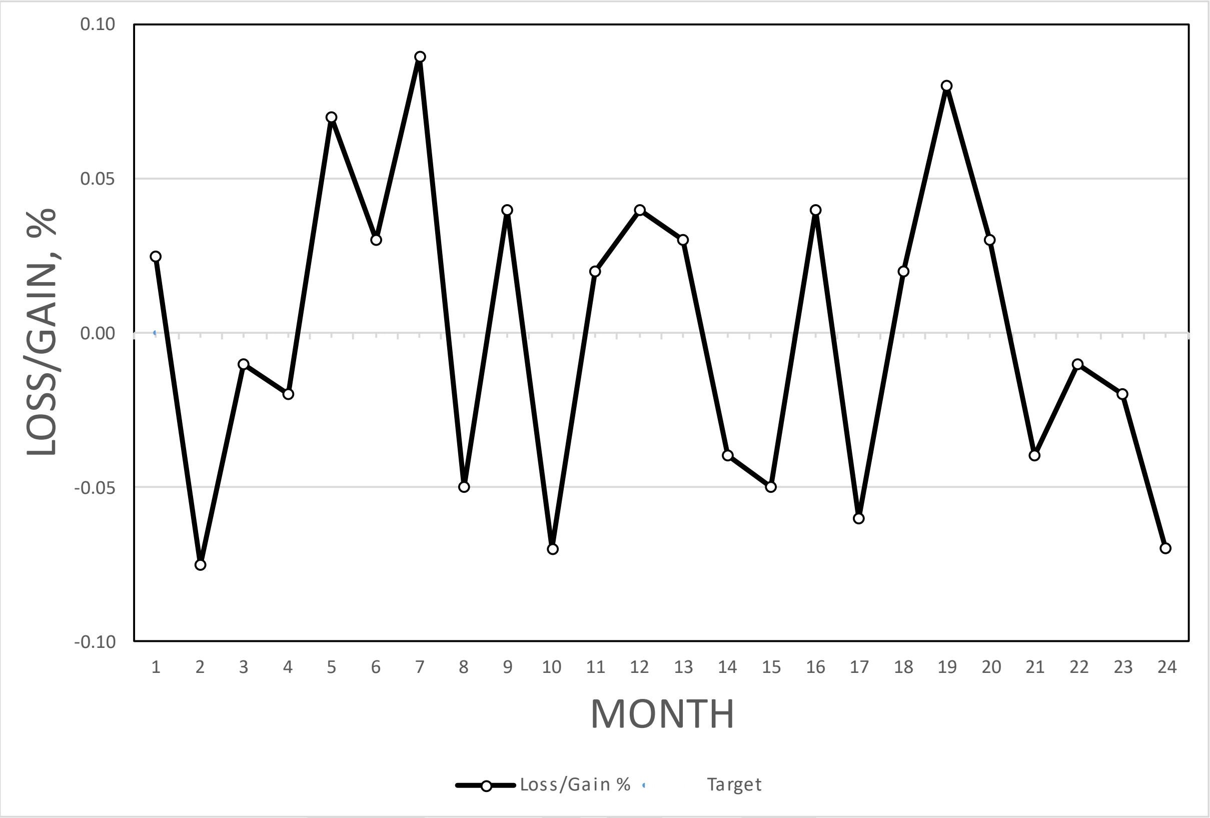


Figure 2 – Two Years of Data for Control Limits

~~Insert Calculations of the Upper and lower control limits. (Outlier tests?) Add note about not averaging the averages. Add all L/G and divide by either receipts or deliveires.~~

~~$\mathit{Standard\ Deviation}\ (\sigma) = \sqrt{\frac{\Sigma|x-\mu^2|}{N}}$~~

~~x = Data Points~~

~~µ = Mean (the sum of the L/G volume divided by the Receipt or Delivery volume. This is not the average of the L/G %.)~~

~~N = Number of data points~~

~~LCL (2σ) = ± 2 x σ from Mean (centerline)~~

~~UCL (3σ) = ± 3 x σ from Mean (centerline)~~

Figure 3 shows the first three-month data compared with the two-year historical control limits.

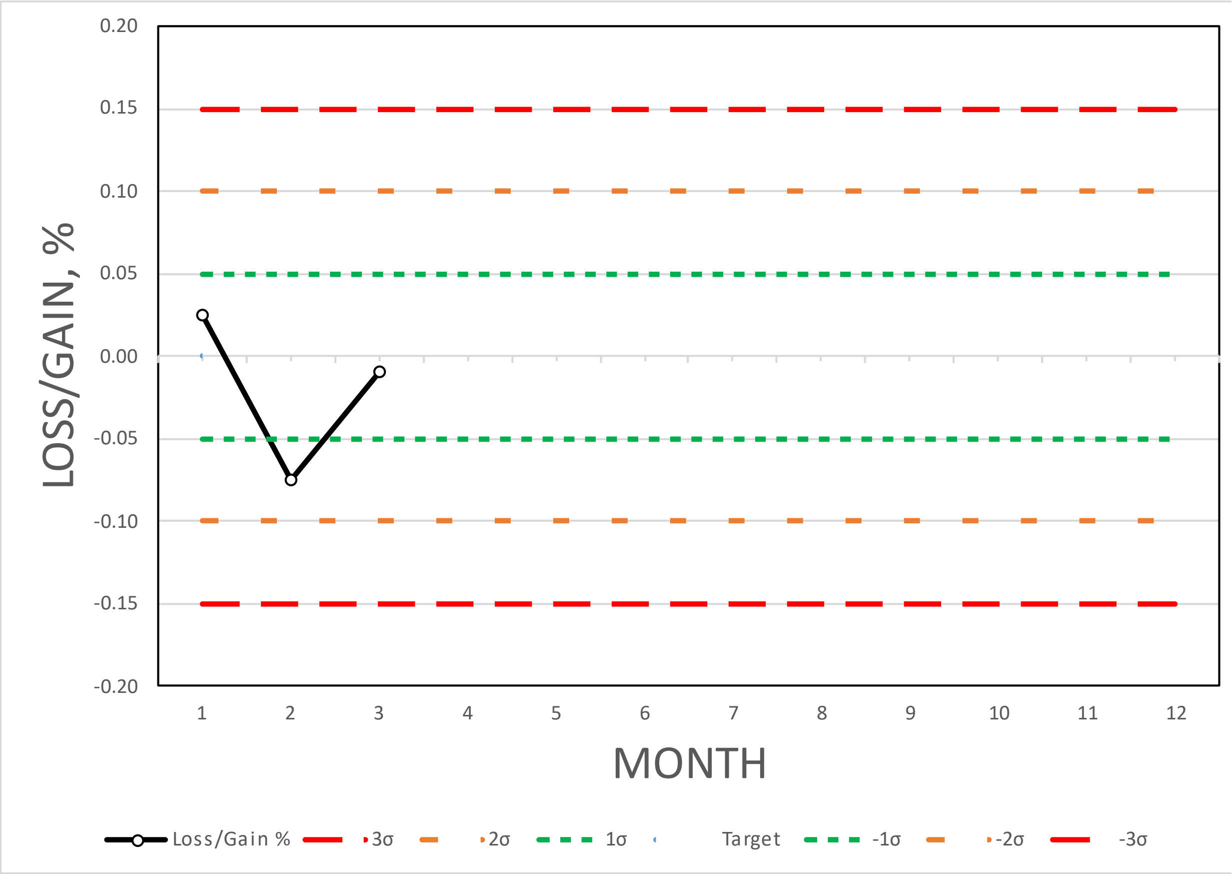


Figure 3 – Control Chart for the Following Year

4.4.3 Users should determine ~~whether or not~~whether a system is stable and in control. A system is said to be stable if the data exhibit only random fluctuations around the mean without trends. A system is generally considered to be in control if the data are all within control limits that have been established from the data. Data points outside the control range indicate poor control. ~~A system is said to be stable if the data exhibit only random fluctuations around the mean without trends.~~

4.4.4 When physical or operational changes are made to a system, the L/G pattern for the system will often change. When this happens, the prior two-year history may not be suitable for setting the control limits. In such cases, a moving range chart may be used until sufficient history is developed to define the system's new pattern. In a moving range chart, the mean and standard deviation are recalculated each time new data are available using all data since the change. The resulting mean and control limit lines on the control chart may exhibit an immediate step change to a new level of control or may change gradually for some period of time until the system stabilizes at a new level of control.~~It is acknowledged that pipeline systems would be expected to follow a log-normal distribution rather than a normal distributions, however themay saresaresares~~

4.5 Meter Factor Control Charts

4.5.1 Control charts can be used for tracking various things. Meter factors are an example.

4.5.2 Control charts may also be used to monitor meter performance, in which case meter factor is plotted as a function of either time or volume throughput.

NOTE For additional guidance on uncertainties in meter data, see API MPMS Ch.~~apter~~ 13.2, ~~—~~*Methods of Evaluating Meter Proving Data.*

4.6 Trending Charts

4.6.1 Trending charts may be used when data exhibit a definite upward or downward trend and may not hover around a simple horizontal mean value. Such charts may be shown as a trending run chart merely to show a trend in the data or may resemble a control chart with lines representing average performance (similar to “mean”) and control limits that follow the upward or downward trend of the data.

4.6.2 12~~-~~-month rolling average charts are often trending charts that can assist in identifying process issues as shown in Figure 4. 12~~-~~-month rolling average control chart tolerance should be tighter than monthly control charts because normal monthly fluctuations should smooth out over a ~~12 month~~12-month period. As shown in Figure 4, the ~~12 month~~12-month tolerances are 50 % of the monthly tolerances.

The calculation of the ~~12 month~~12-month rolling average is not the average of the L/G % averaged over the previous 12 months. Depending on whether the system is receipt-based, delivery-based or average-based, it is calculated as follows in Equation 9:

$$\text{12-month average }\% = \left(\frac{\sum \text{last 12-months } \frac{L}{G} \text{ volume}}{\sum \text{last 12-months } \left(\text{receipts, deliveries, or average}\right)} \right) \times 100 \qquad (9)$$

~~$12\ Month\ Average\ \% = \frac{\sum Last\ 12\ months\ G/L\ volume}{\sum Last\ 12\ months\ \ (receipts, deliveries\ or\ average)}\ x\ 100$~~

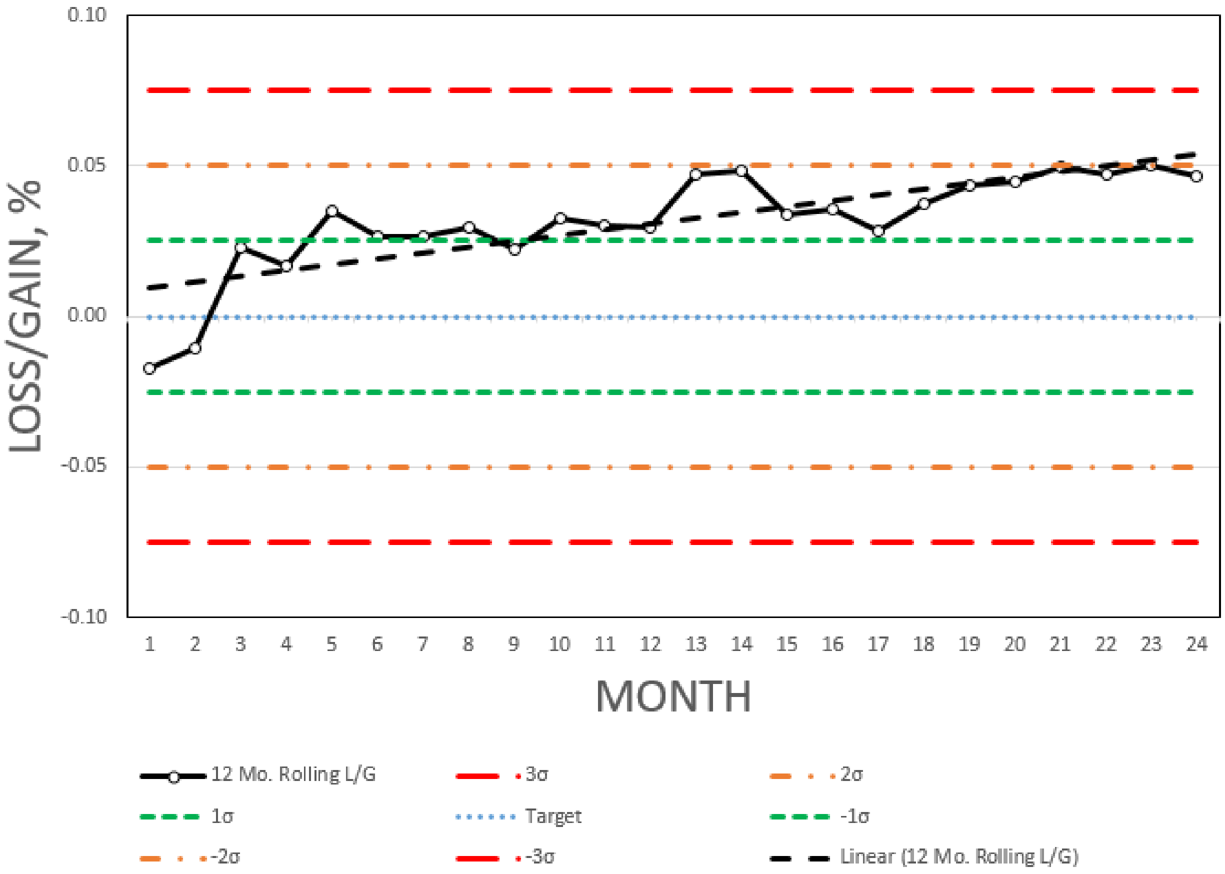


Figure 4 – 12 month Rolling Average

4.7 Cumulative Charts

4.7.1 Cumulative charts are similar to trending charts but plot the cumulative values of some variable such as L/G vs time. The cumulative value is obtained by arithmetically (i.e., keeping the plus and minus signs) adding the value of each data point to the sum of all the data points preceding it in a sequence of data.

4.7.2 The data in cumulative charts do not hover around a central mean value. They exhibit an upward or downward trend. The shape of the curve is the main characteristic of cumulative charts, and changes in shape or general trend are very important.

4.7.3 L/G data may be plotted on cumulative charts. In Figure 5, the L/G quantities are measured in barrels, but other volume or mass quantities may be used as appropriate.

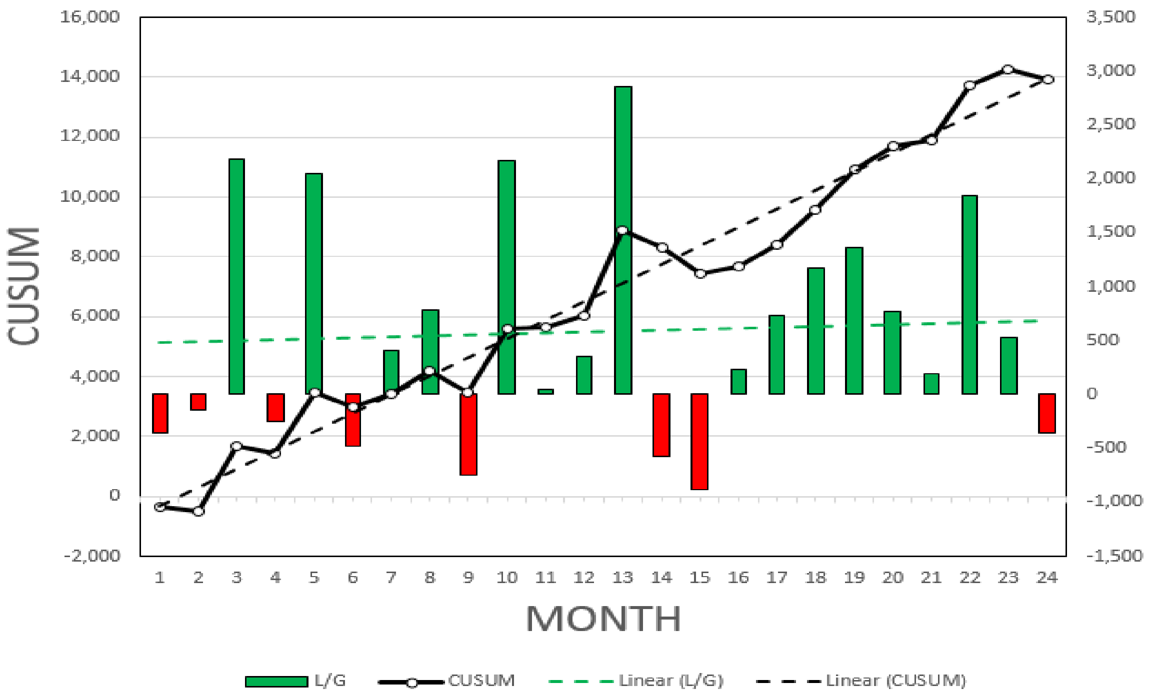


Figure 5 – Cumulative Chart – CUSUM vs L/G

4.7.4 Cumulative L/G charts can be informative to the practiced eye. They often indicate the onset of a trend before it is evident on a conventional control chart. A system that is performing normally will generally exhibit a steady trend. A sudden shift in the pattern or a definite change in the rate of trend (change in general slope of the data) usually indicates that something abnormal happened.

4.7.5 The cumulative chart can also be useful for visually demonstrating the quality of sediment and water (S&W) measurement in a crude liquid system by plotting GSV and NSV on the same chart as shown in Figure 6. In this chart, the first eight months are typical of a system with consistent S&W measurement. The NSV line may be a bit below the GSV. However, if the two lines are close together and essentially parallel, S&W measurement is consistent and uniform. If, on the other hand, the two lines diverge, as shown during the last eight months in Figure 6, S&W measurement is not consistent and/or is not uniform. This could signal an opportunity to improve S&W measurement in the system. Figure 6 depicts a potential issue with the delivery S&W measurement and Ffigure 7 depicts a potential issue with the receipt S&W measurement.

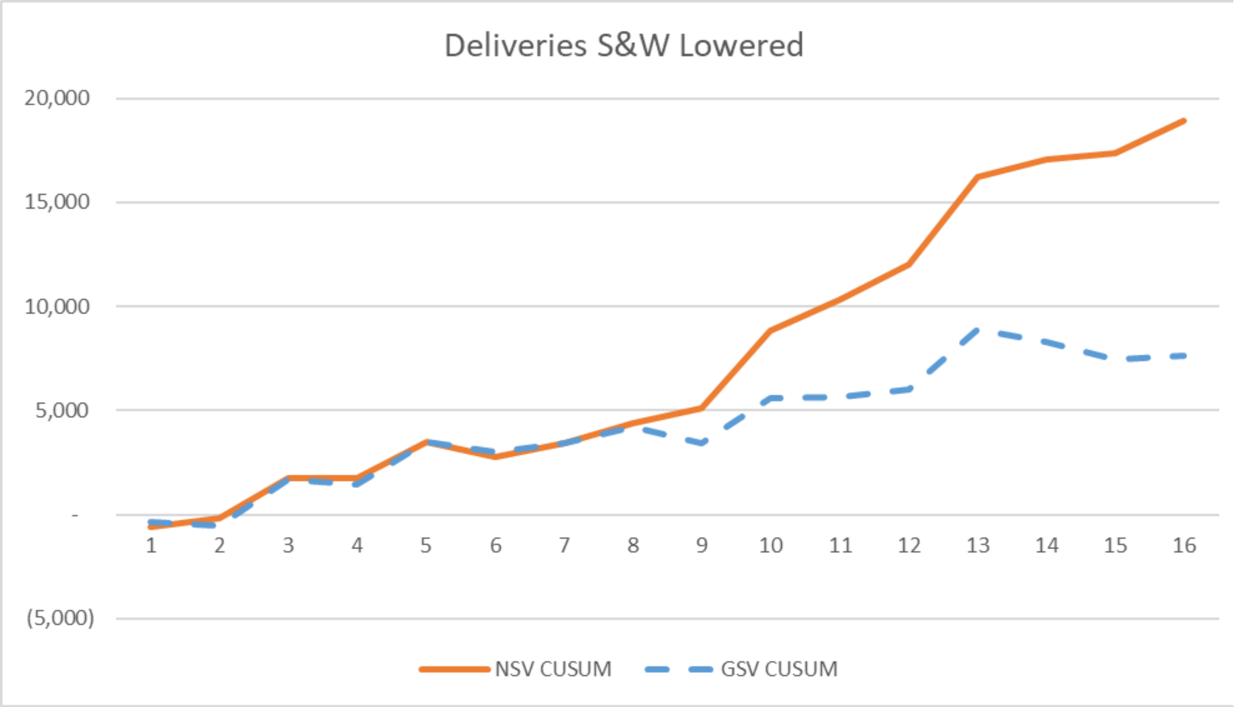


Figure 6 – Cumulative NSV versus GSV

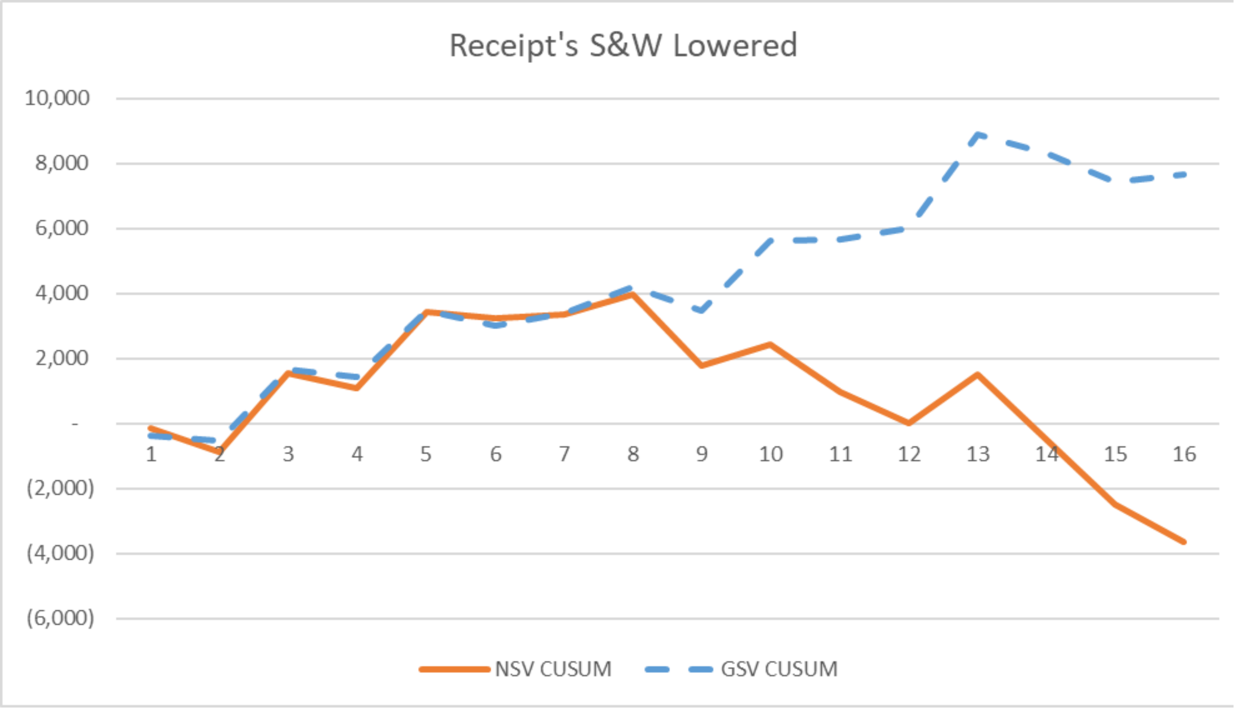


Figure 7 – Cumulative NSV versus GSV

4.7.6 S&W content is the composite of sampling equipment type and installation, frequency of sampling, stream mixing ahead of the sampler, withdrawing the laboratory portion of sample from the field sample container, maintaining the integrity of the sample between the field and the laboratory, handling and remixing in the laboratory, and the S&W measurement process. Inexactitude in any part of the chain of events will lead to an erroneous answer. Individual companies may set acceptable tolerances based on experience for use in their operations.

NOTE For further information on control charts and their interpretation, refer to Annex B “Interpreting Control Charts”.

~~1 Loss/Gain Measurement Data Analysis~~

~~1.1 General~~

~~Data may be presented in the form of control charts, trending charts, or cumulative charts. Guidelines on such charts may include control limits and trending lines. Charts used for monitoring measurement systems should be living documents and should be updated whenever new data isare available. Accumulating data for some period of time and periodically updating charts (e.g. semiannually) serves no useful purpose. Charts and monitoring procedures can be effective only if charts are current and used as constructive tools.~~

~~Loss/gain (L/G) is the difference between deliveries and receipts, adjusted for changes in inventory, experienced by a system over a given time period (e.g. day, week, month). Losses may be real (e.g. leaks, evaporation, theft, etc.). Gains may occur if unmeasured liquid is added to the system—higher than actual receipts or lower than actual deliveries. More often, there is no actual physical loss or gain, just simply small measurement inaccuracies or accounting discrepancies. The combination of these small measurement inaccuracies may result in a system being outside of normal or acceptable limits.~~

~~L/G analysis typically involves collecting data, calculating L/G, and plotting L/G on any of several different types of charts. These charts may include control limits or other analytical guides that are derived from some simple statistical tools. The tools described in this document may be used by anyone and do not require an understanding of statistics.~~

~~The terms “over/short” and “imbalance” are sometimes used interchangeably with “loss/gain.”~~

~~Loss/Gain Equations(L/G) Analysis~~

~~L/G is the difference between deliveries and receipts, adjusted for changes in inventory, experienced by a system over a given time period (e.g. day, week, month) or over a single (or multiple) product movements. Losses and gains may be physical issues (e.g. leaks, evaporation, theft, unmeasured or unaccounted liquid is added to the system etc.) or apparent issues (e.g. errors in measurement, tickets, procedures, etc.). Gains may occur if unmeasured liquid is added to the system – higher than actual receipts. More often, there is no actual physical loss or gain, just simply small measurement inaccuracies or accounting discrepancies. The combination of these small measurement inaccuracies may result in a system being outside of normal or acceptable limits.~~

~~L/G analysis typically involves collecting data, calculating L/G, and plotting L/G on any of several different types of control charts. These control charts may include control limits or other analytical guides that are derived from some simple statistical tools as per the equations described in the following sections. The tools described in this document may be used by anyone and maydo not require an understanding of statistics.~~

~~**1.1.1** The two basic L/G equations are shown below. One expresses a loss as a negative value and the other expresses the loss as a positive value.~~

~~**1.1.2** It is important to keep in mind which convention is being used in order to correctly decide whether the L/G values represent losses or gains.~~

~~The two basic L/G equations (not all inclusive) are shown below. One expresses a loss as a negative value and the other expresses the loss as a positive value.~~
~~It is important to keep in mind which convention is being used in order to correctly decide whether the L/G values represent losses or gains.~~

~~Loss expressed as a negative number:~~

~~$L/G = (CI + D) - (OI + R)$~~ ~~$L/G = (CI + D) - (BI + R)$~~
~~(1)~~

~~Loss expressed as a positive number:~~

~~$L/G = (BI + R) - (CI + D)$~~ ~~$L/G = (OI + R) - (CI + D)$~~
~~(2)~~

~~Loss or gain of the system to be reconciled may also be provided as an absolute value to express relative distance of the variance from zero:~~

~~$L/G = |(CI + D) - (OBI + R)|$~~

~~(3)~~

~~System Gain: If $(CI + D) > (OBI + R)$~~
~~System Loss: If $(OBI + R) > (CI + D)$~~

~~In such case, gain or loss or gain is always an absolute value,~~

~~where~~

~~CI is the closing inventory in the system at the end of the time period;~~

~~D is deliveries out of the system during the time period;~~

~~OBI is the beginningopening inventory in the system at the start of the period;~~

~~R is receipts into the system during the time period.~~

~~L/G may be reported in units of volume (e.g. bbl, gallons or bblkiloliters) or mass (e.g. lb or metric tons).~~

~~When expressed in percent, the actual L/G quantity is divided by the quantity of total receipts for a receipt-based system or by the quantity of total deliveries for a delivery-based system and multiplied by 100. Receipt based systems typically have consistent receipt volumes and delivery based systems typically have consistent delivery volumes.~~

~~For Receipt-based system: L /G% = (L/G / R)*100 (43)~~

~~For Delivery-based system: L/G% = (L/G / D)*100 (54)~~

~~NOTE In the equations above, variables shall be expressed in like units of measure. Variables calculated under the same conditions (e.g. gross standard volume [GSV] and/net standard volume [NSV], standard temperature and pressure) will yield the most meaningful information. (Reference API *MPMS* Chapter 12.)Things to account for in the L/G equations.~~

~~*OI* and *CI*:~~

- ~~Line fill~~
  - ~~Change in line fill volume may contribute significantly to system inventory. If possible, line fill should be corrected for temperature and pressure. Pipelines should be completely empty or completely full at the beginning and end of the time period. See section X.X.X for more details on line fill calculations.~~
  - ~~Line fill volume may change due to project or maintenance work during the time period.~~
- ~~Tank Inventory (generally salt caverns are not included in L/G systems)~~
  - ~~The physical closing tank gauge reading from the previous period should match the physical opening tank gauge reading for the current period.~~
  - ~~Tanks that are gauged for inventory and that are active at the time of gauging should be stilled long enough to be gauged without liquid moving in or out.~~
  - ~~Accurate month-end inventory gauges are very important because they are used to balance and close out pipeline and/or terminal inventories and to issue customer reports and billing. Multiple customers may share the same storage in a commingled tank, and L/G offsets from month to month can be difficult to allocate.~~

~~*D* and *R*:~~

- ~~Meters or Custody tank transfer~~
  - ~~Perhaps the most common errors occurring on manually calculated measurement tickets are arithmetic errors and wrong correction factors applied.~~
  - ~~Tickets that do not get into the accounting process on time will cause an apparent loss or gain in the current accounting period and an offsetting gain or loss in the following period.~~
- ~~Sump tank~~
  - ~~Sumps collect drips and drains from several sources and may add a bias to a system loss or gain if the sumps are emptied by pumping into a pipeline system without being measured. Usually, sump volumes are small enough to not impact the overall L/G for the system. However, the volumes may be significant if sumps accumulate large volumes, such as frequent drain downs from provers or pig traps.~~
- ~~Unmetered volume~~
  - ~~Pipeline relief events~~
  - ~~Pigging~~
  - ~~Line emptying~~
  - ~~Project work~~
  - ~~Chemical Additive injection~~
  - ~~Theft~~
  - ~~Tank evaporation~~
- ~~Product growth or shrinkage~~

~~Once the reconciliation of the system (or a part of the system) is complete, its results shall be compared to the criteria and limits established by the operator. If the system's Loss or Gain meets the established criteria (see section 4.3), and there are no known issues associated with the system's performance during the timeframe being evaluated, then no further action may be required. It is a good practice to always develop control charts to conduct further data analysis in order to ensure that all components of the system were in control, and no special cause variations were present, which could mask a potential issue with either equipment or processes. Such dDetailed analysis (segmenting system into smaller segments) may be is especially desirable on the complex systems with multiple inlets and outlets and with multiple parties inusing the system. The overall Loss or Gain may stay well within the acceptable limits, but some segments can show larger variances which can seriously affect the involved parties.~~

~~If the system's Loss or Gain is found outside of the established criteria, then further data analysis and investigation of the excessive variances shouldwill be conductedrequired. Various control charts and other troubleshooting tools and techniques included in this document can help operator to identify the cause of the problem and work on necessary corrections.~~

~~1.2 Presentation of Data~~

~~**1.2.1** Data may be presented in the form of control charts, trending charts, or cumulative charts. Guidelines on such charts may include control limits and trending lines.~~

~~**1.2.2** Charts used for monitoring pipeline systems should be living documents and should be updated whenever new data are available. Accumulating data for some period of time and periodically updating charts (e.g. semiannually) serves no useful purpose. Charts and monitoring procedures can be effective only if charts are current and used as constructive tools.~~

~~1.3 Control Charts~~

~~General~~

~~Good measurement can be ensured by continuously monitoring measurement results to determine if systems, or equipment and procedures, are performing in predictable ways and are operating within acceptable limits. This may be done by the use of control charts.~~

~~**1.3.1** Control charts display a collection of data over some period of time and include control limits shown as horizontal lines on the charts. Control limits help to define normal and abnormal system performance and may indicate when something in the system has changed and/or corrective action(s) may be required.~~

~~Control limits are often determined by historical performance of the system. In other cases, the control limits are set on an established arbitrary value, (e.g. contractual limits). Due to inherent issues (built in biases, etc.) with both of those models, consideration should be given to establishing control limits based on the capabilities of the equipment in the L/G system. Statistical analysis of the uncertainties of the measurement equipment (i.e. meters, prover, etc.) and procedures (verification/calibration frequencies, tolerances, etc.) can also be utilized to establish control limits. See Annex X for one such method for establishing control limits. Control charts are the most common method of ascertaining system L/G performance. Control charts display a collection of data over some period of time and include the control limits. Control charts help to define normal trends of a system and may indicate when something has changed. Typical L/G charts, as shown in Figure 1, indicate a system's performance based on a percentage of throughputs over time. Typically, because accounting systems encompass a 30-day period, monthly evaluations of a system are commonly used to evaluate performance. Control charts may be prepared for any time span (e.g. weekly or daily) if adequate data are available.~~

~~Control charts may be maintained for entire systems or for individual segments of a system if adequate measurement and records are available at the junctures of segments. The limits of the control charts will depend on the accuracy of the available measurement systems.~~

~~The data on control charts tend toshould hoverremain near or around a targetcentral mean value, which is the arithmetic average of the data and can be represented by a horizontal line on the chart. This targetcentral value is generally based on the anticipated or expected L/G of the system (typically at or near 0%). The control chart also includes UCLs and LCLs that may be:~~

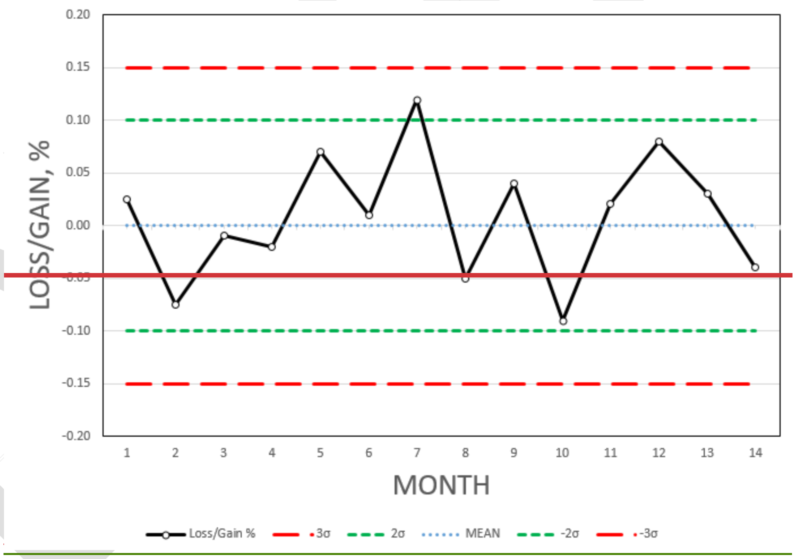
~~defined statistically as two and/or three standard deviations above and below the target value or~~

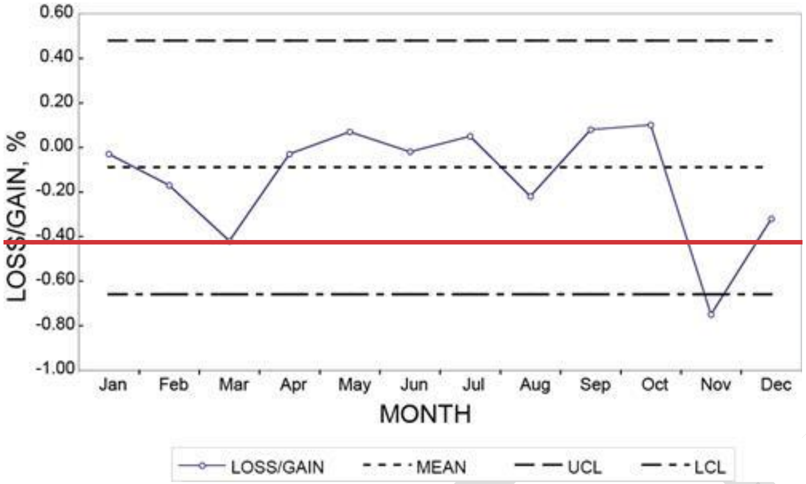
~~defined as engineering, historical or contractual limits, which are values based on experience or performance objectives, or~~

~~defined statistically as two and / or three standard deviations above and below the mean.~~

~~Standard deviation is a statistical measure of the spread of a data set with respect to the mean value of the set the specific number of deviations as determined by the user(s). Procedures for calculating statistical quantities are shown in Annex A.The data on control charts tend to hover around a central (mean) value, which is the arithmetic average of the data and can be represented by a horizontal line on the chart. The control chart also includes upper and lower control limits (UCL and LCL, respectively) that may be (1) defined as engineering limits, which are values based on experience or performance objectives, or (2) defined statistically as three standard deviations above and below the mean. Standard deviation is a statistical measure of the spread of a data set with respect to the mean value of the set. Procedures for calculating statistical quantities are shown in Annex A.~~

~~Figure 1 shows a typical control chart.~~





~~**Figure 1—Sample Control Chart**~~

~~The data shall be representative of the normal expected performance of the system, as the control limits will be used to predict near-future performance. Any data point that is known to be the result of a special cause should be shown on the control chart but should not be included in the calculation of targetmean, standard deviation, or control limits, and the number of data points shall be adjusted accordingly. A special cause is an event (e.g. meter failure, late run ticket, line displacement with water for hydrostatic pressure test, etc.) that results in mismeasurement for a given period of time but is not a part of the normal operation of the system.~~

~~Charts can be used to determine system stability, cyclical trends, or step changes in performance. One of the most important benefits of using charts to assess performance is the instant visual representation it provides.~~

~~The adage “a picture paints a thousand words” best summarizes the effectiveness of control charting.~~

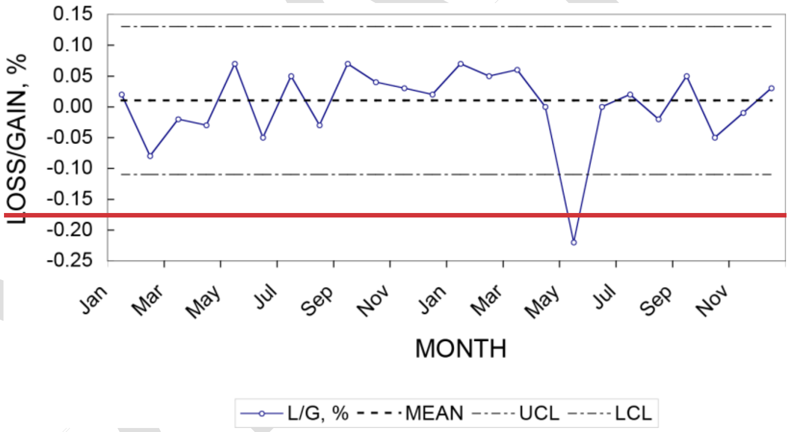
~~1.4 Pipeline System Control Charts~~

~~**1.4.1** A useful tool for monitoring pipeline systems is the control chart that shows L/G as percent of throughput over time. Total receipts are used for throughput in receipt-based systems, and total deliveries are used for delivery-based systems.~~

~~For historical performance based Strictly speaking, for control limits to be statistically significant, a minimum of 30 data points are required. For practical purposes, control limits for a pipeline system that is monitored monthly will often be based on monthly L/G data. For our purposes, the 24 data points are acceptable. It is common practice to set limits at the beginning of each calendar year based on the prior history. These limits are carried forward for the calendar year unless there is a change in the process that would require new limits.Until enough data is collected to establish historically performance based control limits, reasonable control limits should be established and applied by the system operator.~~

~~**1.4.2** Setting fixed limits for L/G, without regard to actual data, may be required for contractual reasons. Whenever possible, it is more practical to set limits based on historical data. Care should be taken to avoid bias conditions or outliers affecting the control limit calculations. A pipeline system tends to operate at a level of performance that is dictated by, but not limited to, physical configuration, equipment, procedures, maintenance practices, environmental conditions, and employee training. All of these factors combine to produce a natural randomness and, sometimes, a natural bias in a system. For systems that have other constraints, it may be desirable to include a second set of limits.~~

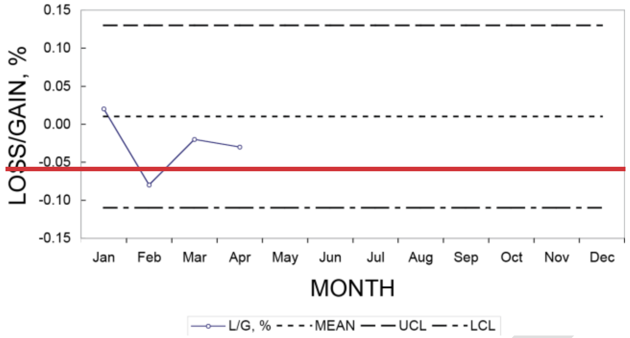
~~Figure 2 shows the L/G data for two years. Thisose data will be used to set control limits for the following year.~~



~~**Figure 2—Two Years of Data for Control Limits**~~

~~Insert Calculations of the Upper and lower control limits. (Outlier tests?) Add note about not averaging the averages. Add all L/G and divide by either receipts or deliveires.~~

~~Figure 3 shows the first three-month data compared with the two-year historical control limits.~~



~~**Figure 3—Control Chart for the Following Year**~~

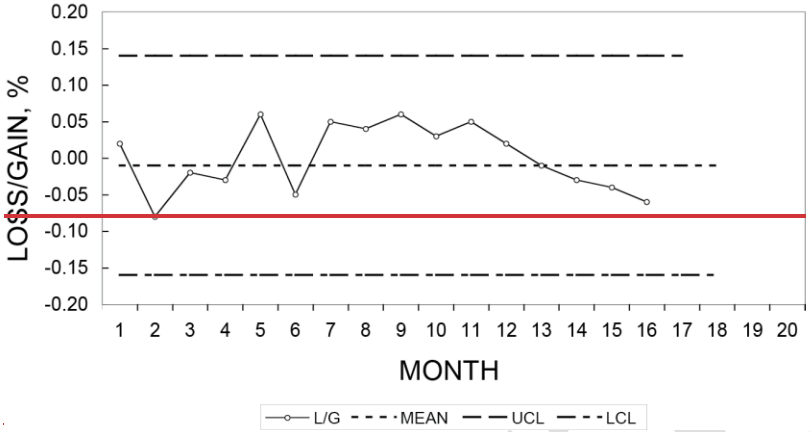
~~**1.4.3** Setting fixed limits for L/G, without regard to actual data, may provide performance guides that may be required for contractual reasons. Whenever possible, it is more practical to set limits based on historical data. A pipeline system tends to operate at a level of performance that is dictated by physical configuration, equipment, procedures, maintenance practices, environmental conditions, and employee training. All of these factors combine to produce a natural randomness and, sometimes, a natural bias in a system. For systems that have other constraints, such as loss allowance, it may be desirable to include a second set of limits set at the value of the loss allowance. This would indicate how the system is performing with respect to the loss allowance and if the assigned loss allowance is realistic.~~

~~**1.4.4** It is good practice to determine whether or not a system is stable and in control. A system is generally considered to be in control if the data are all within control limits that have been established from the data. Data points outside the control range indicate poor control. A system is said to be stable if the data exhibit only random fluctuations around the mean without trends.~~

~~When physical or operational changes are made to a system, the L/G pattern for the system will often change. When this happens, the prior two-year history may not be suitable for setting the control limits. In such cases, a moving range chart may be used until sufficient history is developed to define the system's new pattern. In a moving range chart, the mean and standard deviation are recalculated each time new data are available using all data since the change. The resulting mean and control limit lines on the control chart may exhibit an immediate step change to a new level of control or may change gradually for some period of time until the system stabilizes at a new level of control.~~

~~1.5 Interpreting Control Charts~~

~~**1.5.1** As an example, Figure 4 shows three distinct patterns that may be found on control charts. The points 1 through 7 exhibit random fluctuations around the mean and are well within the control limits. This portion of the data is stable and in control. The points 7 through 12 are within the control limits and appear to fluctuate randomly, but are all above the mean. This is a state of stability but not in control because the data do not hover around the mean. In fact, it would appear that the system has attained a new state of control that is centered around a higher mean value. The points 11 through 16 are neither stable nor in control because they are in a definite downward trend. The data do not center around a mean and appear to be headed off the chart.~~

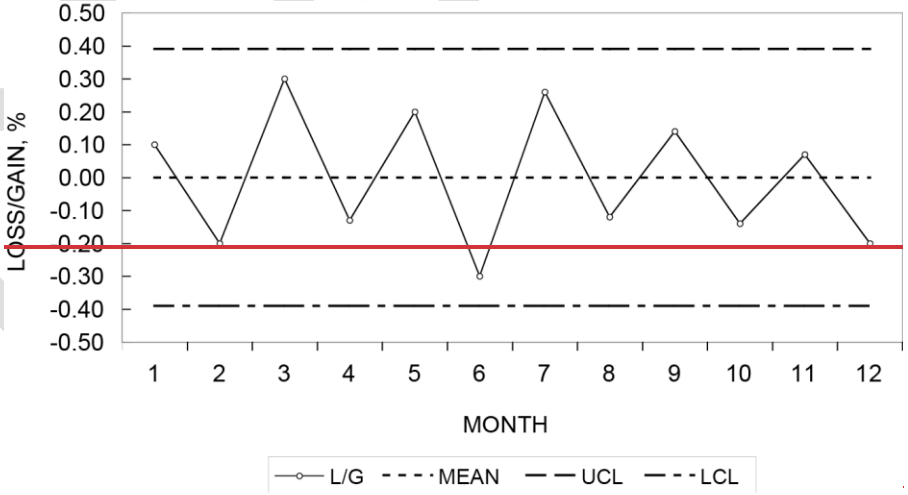


~~**Figure 4—Control Chart with Three Patterns**~~

~~**1.5.2** As a rule, five consecutive points above or below the mean indicate a loss of control or a change to a new level of performance. Five consecutive points trending in one direction (up or down) indicate a loss of control. For some systems, even fewer points in a row may be significant warning. Examples might be leaking tanks (in which case the losses are real) or meters that are wearing badly and are not being proved often enough (which are book losses).~~

~~**1.5.3** An upward trend is no better than a downward trend. Either condition is out of control. A system gain can be just as bad as a system loss. Losses and gains occur because of some deficiency in measurement.~~

~~**1.5.4** If the data tend to swing back and forth as shown in Figure 5, the system is cyclic. If the cause of the cycles could be eliminated, the system should be able to achieve a state of better control with narrower control limits.~~

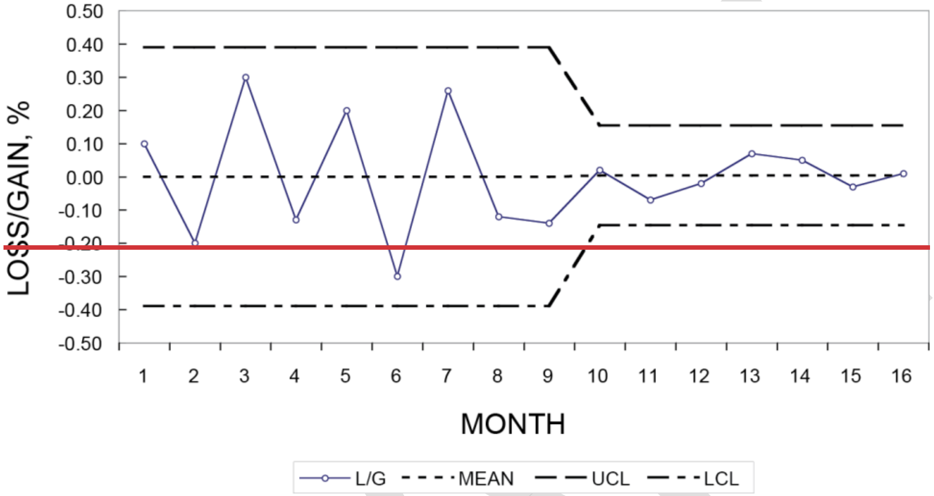


~~**Figure 5—Control Chart with Cyclic Patterns**~~

~~**1.5.5** A system may be stable and in control, but not acceptable if the mean differs significantly from~~ the target~~zero. For example, a system that has an average loss of −0.25 % loses 0.25 % consistently. Similarly, a wide span between UCL and LCL may indicate instability in the system and may not be acceptable performance.~~

~~**1.5.6** The performance of a system may change due to deliberate process changes, such as better new equipment, or improved procedures or changes to calibration/verification frequencies. These changes may have positive or negative effects on the system performance. Sometimes, though, a system will change without any apparent reason. Any process change, be it deliberate or unplanned, will usually show up as a change in performance.~~

~~**1.5.7** Whenever the data clearly show a change, the mean and control limits should be changed accordingly as shown in Figure 6.~~



~~**Figure 6—Control Chart with a Change in the Process**~~

~~Any data point that falls outside the control limits is the result of a special cause (e.g. equipment failure, procedural error, etc.) and should be investigated immediately to determine the cause. Special causes often lead to correction tickets and should be investigated as soon as possible before the data become dated and the investigation becomes difficult.~~

~~1.6 Meter Factor Control Charts~~

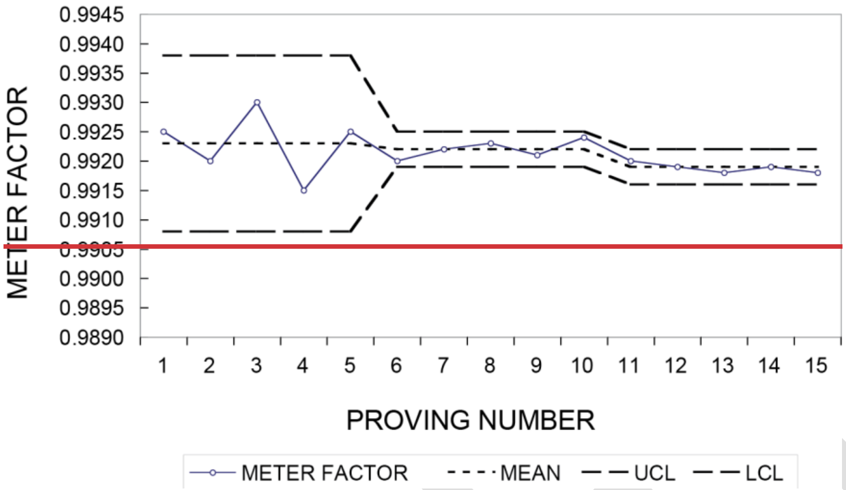
~~**1.6.1** Control charts can be used for tracking various things. Meter factors are an example.~~

~~**1.6.2** Control charts may also be used to monitor meter performance, in which case meter factor is plotted as a function of either time or volume throughput.~~

~~**1.6.3** It may not be practical to accumulate 24 meter factor data points for meters before setting control limits because changes in operating conditions (e.g. different grades of crude liquids or products, different flow rates, etc.) or normal meter wear may cause meter factor to change enough to invalidate control limits before achieving 24 provings.~~

~~**1.6.4** Thus, when plotting meter factor control charts, it may be more representative to use a moving range chart in which control limits are reset more often. Typical examples for meter factor control charts include resetting after every 5 or 10 provings. In these cases, the conventional standard deviation calculated by the equation in Annex A cannot be used. Instead, control limits and an estimated standard deviation are based on the ranges (differences) between contiguous meter factors.~~

~~**1.6.5** Figure 7 is an example of a moving range chart for which control limits are reset after every five meter provings.~~



~~**Figure 7—Moving Range Chart**~~

~~**1.6.6** Meter factors usually behave in a predictable way. If operating conditions are essentially constant and wear is not excessive, meter factors may be plotted on conventional control charts with warning, action, and tolerance limits. However, if meters are subject to variable operating conditions and/or liquids with different physical properties, their control charts will exhibit enough natural variation to dilute the value of warning and action limits.~~

~~**1.6.7** Meter factor patterns on control charts should be reviewed to determine if a meter (1) is about to go out of tolerance or (2) is developing an abnormal pattern or trend. If either of these occurs, the meter should be inspected for wear or damage. Some companies set a fixed meter factor tolerance for mandating meter repair.~~

~~**1.6.8** For multifunctional meters, interpretation of control charts is not straightforward. The patterns on the charts are composites of several subpatterns that are dictated by flow rate, temperature, pressure, and liquid properties. Insofar as possible, the data for such meters should be broken into separate plots of meter factor segregated by one variable, such as liquid type, with other conditions being as nearly constant as possible.~~

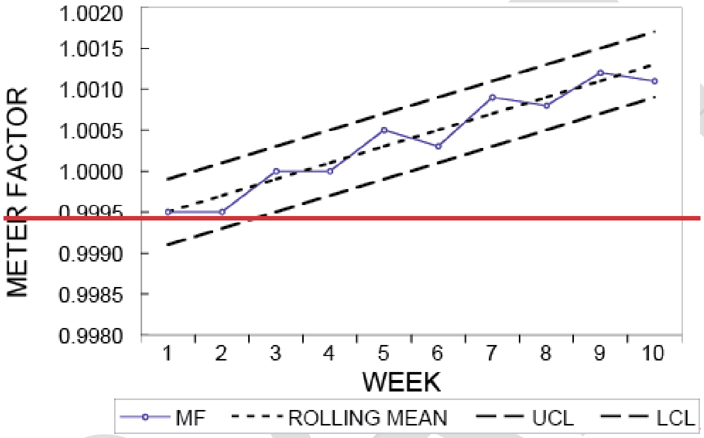
~~**1.6.9** Even when charts are broken out by crude type, conventional control charts may not be adequate, because in order to get enough data with one crude type, it may be necessary to accumulate single meter factors or small groups of meter factors for a given crude that are separated from each other by significant lengths of time. As a result, each subsequent factor or group of factors may be affected by meter use and wear between factors. This leads to a trending situation, and trending charts may be required to depict the data.~~

~~1.7 Trending Charts~~

~~**1.7.1** Trending charts may be used when data exhibit a definite upward or downward trend and do not hover around a simple horizontal mean value. Such charts may be shown as a trending run chart merely to show a trend in the data or may resemble a control chart with lines representing average performance (similar to “mean”) and control limits that follow the upward or downward trend of the data.~~

~~**1.7.2** Meter factor charts are often trending charts, as meter factors generally tend to increase in a regular fashion with time due to wear in a meter.~~

~~**1.7.3** An example of a trending control chart is shown in Figure 8.~~



~~**Figure 8—Trending Control Chart**~~

~~**1.7.4** Mean and control limit values cannot be represented by fixed-value horizontal lines on a trending control chart because the normal trend of data would soon move past the control limits. With a normal meter factor control chart, this would signal a need for some sort of action. However, with a trending chart, the system may be quite all right and the data are simply following a normal trend. Hence, mean and control limits shall be calculated in a different fashion. This can be done with a mathematical procedure called “linear regression.” Many computer spreadsheet programs and some types of handheld calculators (e.g. scientific, engineering, statistical, etc.) have linear regression programs and can be used simply by keying in the data. A method for hand-calculating a linear regression by the Least Squares Method is given in Annex A.~~

~~Linear regression yields an equation of the form:~~

~~$y = a + bx$~~ ~~(3)~~

~~where~~

~~y is the dependent variable (e.g. meter factor);~~

~~a is a constant (called the zero intercept);~~

~~b is a constant (called the X coefficient);~~

~~x is the independent variable (e.g. month, proving sequence, etc.).~~

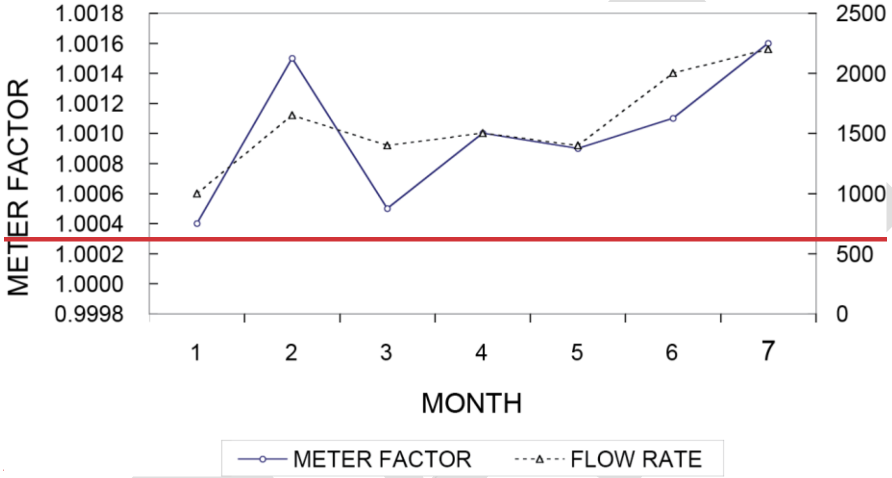
~~The values of a and b are derived from the data set and are unique to the particular data set.~~

~~The mean and control limits of trending data are represented by equations rather than fixed values.~~

~~NOTE For linear regression to work, values for *x* shall be numeric. That is, months shall be 1, 2, 3, etc., not January, February, March, etc.~~

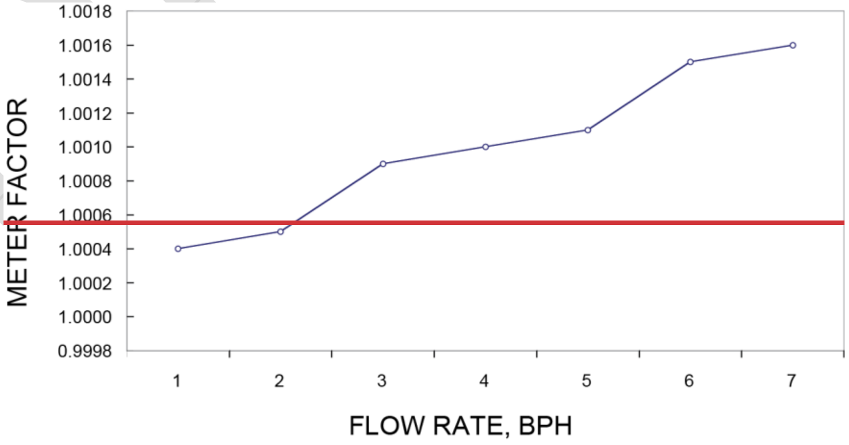
~~1.8 Cross Plots~~

~~**1.8.1** A cross plot is a way of illustrating how one variable changes as another variable changes. In particular, cross plots between meter factor and each operating variable can contribute to a better understanding of meters and their reactions to different variables. For example, Figure 9 shows a marked increase in meter factor during the last two months.~~



~~**Figure 9—Simultaneous Variations in Meter Factor and Flow Rate**~~

~~**1.8.2** Note that flow rates plotted on the same figure also increased markedly. A cross plot of meter factor vs flow rate in Figure 10 shows that the meter factor increases are due to flow rate increases. This chart may be inspected to determine if the new meter factor appears to be reasonable based on flow rate.~~



~~**Figure 10—Cross Plot of Meter Factor vs Flow Rate**~~

~~**1.8.3** A line representing the trending mean of the data can be constructed on a trending control chart by calculating the regression equation from the data, calculating the end points of the trending mean line from the regression equation, plotting those points on the chart, and connecting them with a straight line.~~

~~**1.8.4** Lines representing control limits may be constructed by calculating end points for UCL and LCL as $m \pm 3\sigma$, plotting those points on the chart and connecting the end points with straight lines. However, standard deviation (σ) cannot be calculated in the conventional way. The term "$(y - m)$" in the equation for standard deviation shall be calculated point by point using the value of m that corresponds to each X value.~~

~~**1.8.5** Sometimes it is helpful to know how much two variables interact with each other. One variable is the independent variable and the other is the dependent variable. The value of the dependent variable depends on the value of the independent variable. In other words, the dependent variable will change every time the independent variable changes. If the dependent variable is changed by some other influence, the independent variable will not change as a result. For example, a meter factor can be changed by changing flow rate, but flow rate cannot be changed by changing meter factor.~~

~~**1.8.6** The relationship between two variables is called the "correlation" and may be strong, in which case the dependent variable changes in a very predictable manner with changes in the independent variable, or may be weak, in which case the dependent variable tends to change with the independent variable, but the amount of change is not predictable.~~

~~**1.8.7** The strength of the correlation can be measured statistically with the correlation coefficient; the procedure for calculating the correlation coefficient is shown in Annex A.~~

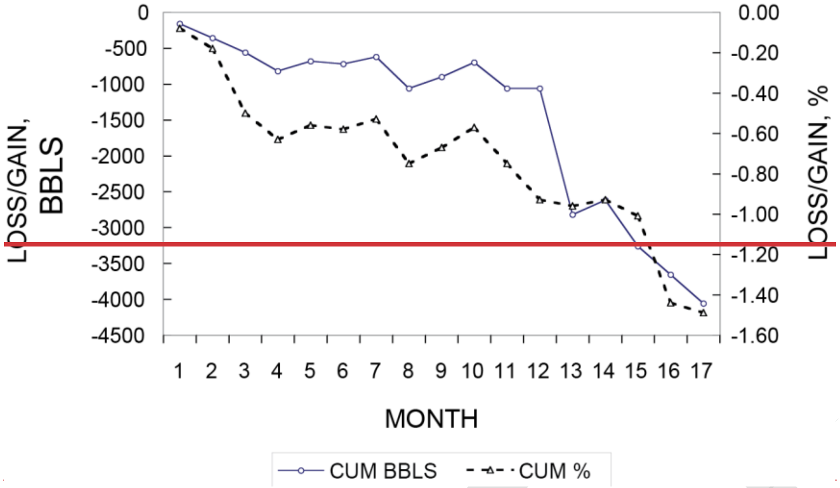
~~**1.8.8** It should be noted that even though a strong correlation exists, if the slope of the associated regression line is very flat, the correlation is relatively insignificant.~~

~~1.9 Cumulative Charts~~

~~**1.9.1** Cumulative charts are similar to trending charts but plot the cumulative values of some variable such as L/G vs time. The cumulative value is obtained by arithmetically (i.e. keeping the plus and minus signs) adding the value of each data point to the sum of all the data points preceding it in a sequence of data.~~

~~**1.9.2** The data in cumulative charts do not hover around a central mean value. They exhibit an upward or downward trend. The shape of the curve is the main characteristic of cumulative charts, and changes in shape or general trend are very important.~~

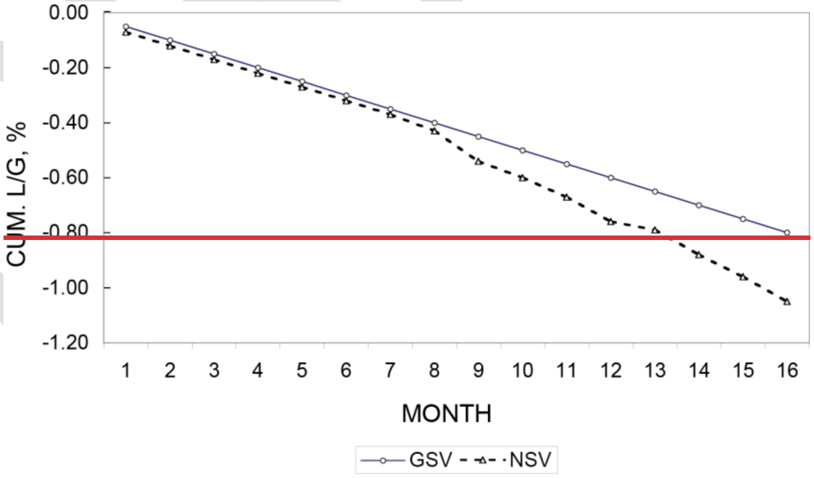
~~**1.9.3** L/G data may be plotted as cumulative barrels or cumulative percent. Examples are shown in Figure 11. In these examples, the quantities are measured in barrels, but other volume or mass quantities may be used as appropriate.~~



~~**Figure 11—Cumulative Plots**~~

~~**1.9.4** Cumulative L/G charts can be informative to the practiced eye. They often indicate the onset of a trend before it is evident on a conventional control chart. A system that is performing normally will generally exhibit a steady trend. A sudden shift in the pattern or a definite change in the rate of trend (change in general slope of the data) usually indicates that something abnormal happened.~~

~~**1.9.5** The cumulative chart can also be useful for visually demonstrating the quality of sediment and water (S&W) measurement in a crude liquid system by plotting GSV and NSV on the same chart as shown in Figure 12. In this chart, the first eight months are typical of a system with consistent S&W measurement. The NSV line may be a bit below the GSV. However, if the two lines are close together and essentially parallel, S&W measurement is consistent and uniform. If, on the other hand, the two lines diverge, as shown during the last eight months in Figure 12, S&W measurement is not consistent and/or is not uniform. This could signal an opportunity to improve S&W measurement in the system.~~

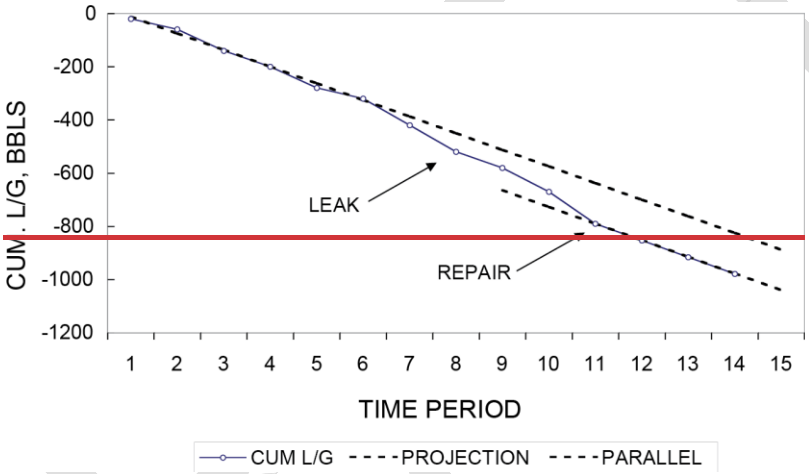


~~**Figure 12—Cumulative GSV and NSV**~~

~~**1.9.6** If the NSV and GSV lines on a cumulative chart are parallel and close together, the S&W measurement is probably about as good as can be achieved. If the two lines are parallel but the spread between them is large,~~

~~the S&W measurement is consistent but, probably, could be improved. S&W content is the composite of sampling equipment type and installation, frequency of sampling, stream mixing ahead of the sampler, withdrawing the laboratory portion of sample from the field sample container, maintaining the integrity of the sample between the field and the laboratory, handling and remixing in the laboratory, and the S&W measurement process. Inexactitude in any part of the chain of events will lead to an erroneous answer. Individual companies may set acceptable tolerances based on experience for use in their operations.~~

~~**1.9.7** The cumulative chart is an easy way to estimate the amount of liquid lost if there is an actual leak, lost to another system, or spill. For this purpose, the cumulative plot of volume is most convenient. An example is shown in Figure 13. The data before the loss, which in this example occurred about the seventh month, are used to develop a regression line that represents the typical behavior of the curve before the leak. The regression line is used to project what the system L/G would have been if the leak had not happened. In this example, the leak was found and repaired in the eleventh month, and the accumulated loss by that time is 790 barrels. If no liquid had been physically lost, the projected cumulative L/G would have been 640 barrels as estimated from the projected regression line. The difference of 150 barrels is the estimated loss due to the leak.~~



~~**Figure 13—System with a Leak**~~

~~1.10 Two Types of Cumulative Percent~~

~~**1.10.1** There are two ways to calculate cumulative percent. One is the cumulative sum. The other is the moving sum, which is often used to report year-to-date (YTD) data.~~

~~**1.10.2** In the cumulative sum method, each value of L/G percent is added to the sum of all the preceding values of L/G percent (see Table 1 for an example).~~

~~**Table 1—Example of Cumulative Sum**~~

~~**Month**~~	~~**Receipts M bbl**~~	~~**L/G**~~		
		~~**bbl**~~	~~**%**~~	~~**Cum. %**~~
~~1~~	~~100~~	~~100~~	~~0.100~~	~~0.100~~
~~2~~	~~120~~	~~150~~	~~0.125~~	~~0.225~~

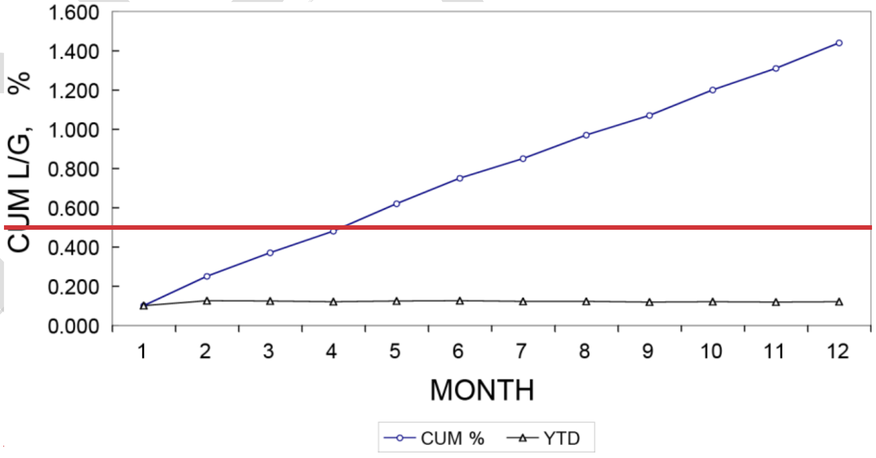
~~3~~	~~110~~	~~120~~	~~0.109~~	~~0.334~~
~~4~~	~~100~~	~~110~~	~~0.110~~	~~0.444~~

~~**1.10.3** In the moving sum method, for each time period (1) the value of throughput bbl is added to the sum of all the preceding values of throughput bbl, (2) each value of L/G bbl is added to the sum of all the preceding values of L/G bbl, and (3) each L/G bbl sum is divided by the corresponding throughput bbl sum and converted to percent (see Table 2 for an example).~~

~~Table 2—Example of Moving Sum~~

~~**Month**~~	~~**Receipts M bbl**~~	~~**Cum. Receipts M bbl**~~	~~**L/G bbl**~~	~~**Cum. L/G bbl**~~	~~**Moving Cum. %**~~
~~1~~	~~100~~	~~100~~	~~100~~	~~100~~	~~0.100~~
~~2~~	~~120~~	~~220~~	~~150~~	~~250~~	~~0.114~~
~~3~~	~~110~~	~~330~~	~~120~~	~~370~~	~~0.112~~
~~4~~	~~100~~	~~430~~	~~110~~	~~480~~	~~0.112~~

~~**1.10.4** Examples of cumulative sum and moving sum (YTD) are plotted in Figure 14. Note how the moving sum tends to flatten the curve. This is because the cumulative L/G bbl is divided by an ever-increasing cumulative throughput. The moving sum is a useful tool for some purposes (such as comparing YTD L/G with prior years L/G), but it is not particularly useful for evaluating system performance. Therefore, the cumulative sum is preferred when L/G data are plotted as percent.~~



~~**14—Types of Cumulative Percent**~~

~~4~~5 Troubleshooting

~~4.1~~5.1 General

One of the challenges of today's pipeline measurement personnel is troubleshooting pipeline losses and gains. Whenever losses or gains exceed established limits, an investigation should be initiated to determine the cause and whether ~~or not~~ adjustments are required to bring a system into balance.

Troubleshooting pipeline losses involves an understanding of the L/G process and may require collecting and analyzing data, interviewing personnel, and visiting facilities to assess equipment performance and witness measurement activities. Ultimately, loss investigations should include a conclusion of the findings along with recommendations for correction and improvements.

~~4.2~~5.2 The Troubleshooting Process

~~4.2.1~~5.2.1 General

Investigating pipeline losses can often be challenging if not frustrating. It is not uncommon for the process to take as long to resolve as it does for losses to appear. With a keen eye for detail, some losses can be ~~-~~ resolved in minutes, whereas some may take weeks, months, or even longer. (See Annex ~~B~~D for a Troubleshooting Guide for Pipeline Measurement Operations.)

~~4.2.2~~5.2.2 Analyzing Measurement Data

The first step in identifying losses involves a review of the measurement data. An L/G report is usually the red flag that signals that a system is out of control. Start by carefully reviewing the report and ensure that input data were accurate and timely. Computer generated reports are only as good as the data entered. It is important to first understand the data entry process and then the integrity of the data used to populate the report.

With the increasing number of automatic data acquisition and processing tools and options, the data validation is an extremely important step of each reconciliation process. The risks associated with data manipulation, built-in biases and errors shall be recognized. All tools and systems from the source through the final report should be validated and included into the troubleshooting process.

~~4.2.3~~5.2.3 Looking for the Obvious

Custody measurement records such as tickets, proving reports, and meter performance logs can be obtained and reviewed from the office environment. Reviewing measurement calculations is an easy way to check for measurement error. Often, human error, equipment failure, or software glitches can quickly be identified.

Reviewing records and historical data is of key importance. Look for patterns, often hidden among the noise caused by large month-to-month variations. Look for~~Are~~ step changes linked to operational changes at the facility.~~?~~ There are many possible operational changes that can affect reported losses. ~~Areas of change~~ Some items that should be ~~to~~ investigated are as follows:

- personnel,
- procedures,
- facility operating conditions~~ies~~,

~~equipment,~~

~~calibration of equipment,~~

- ~~piping,~~pigging operations,
- variables associated with DRA injection,
- product flaring, vaporization, or vapor recovery,
- ~~computers~~software/calculations,

~~security,~~

- missing data (e.g., run tickets),
- weather conditions,
- security, data security,
- physical theft or data theft~~.~~

For additional troubleshooting guidance refer to Annex D.

~~4.2.4~~5.2.4 Interviewing Personnel

The best method of identifying change is by interviewing the personnel responsible for the system(s). This includes the measurement technician, gauger, or operator, ~~as well as the electrical and mechanical~~other technicians and relevant personnel performing work at the sites. ~~Supervisors who may have information pertinent to the entire process should also be consulted.~~ The key to obtaining useful information from field personnel is to establish a dialogue that is nonconfrontational. Sharing ownership of the problem, as well as the credit for the resolution, is often the best approach.

~~4.2.5~~5.2.5 Reviewing the Facility

Another step in the process is to conduct a field assessment and investigate the causes of the excessive losses or gains. This may involve~~s~~ a visit to the facilities to review the equipment and the measurement procedures/documentation. Determine if the proper procedures are being followed in accordance with company and industry guidelines. Observe piping details, equipment placement, and other visual records that may be indicators to or influence the measurement performance.~~ Also, i~~It is ~~very~~ important to be able to discuss the facility and its operation with the measurement personnel who conduct day-to-day activities. They usually know the facility much better than the investigator and can often provide a detailed history of changes for a facility.

~~4.3~~5.3 Inaccuracies and Uncertainties

~~4.3.1~~5.3.1 General

Many everyday things can cause inaccuracy or uncertainty in measurement and, thereby, contribute to losses and gains in a system.

When ~~we make~~ a measurement of a quantity is conducted, the result ~~that we~~ obtained is not the actual true value of the quantity but only an estimate of the value. This is because no instrument is perfect; there will always be a margin of doubt about the result of any measurement. The uncertainty of a measurement is the size of this margin of doubt.

To fully express the result of a measurement three numbers are required:

1) The measured value. This is simply the figure indicated on the measuring instrument.
2) The uncertainty of the measurement. This is the margin or interval around the indicated value inside which you would expect the true value to lie with a given confidence level.
3) The level of confidence attached to the uncertainty. This is a measure of the likelihood that the true value of a measurement lies in the defined uncertainty interval. In industry, the confidence level is usually set at 95 %.

~~Very o~~Often the terms “inaccuracy” and “uncertainty” are confused and used interchangeably. As provided above, uncertainty is the margin of doubt associated with a measurement. Inaccuracy (or error) is the difference between the measured value and the true value.

NOTE For further details on uncertainty and the statistical calculations associated with uncertainly refer to Annex A.

~~4.3.2~~

~~4.3.3~~5.3.2 Meters and Meter Proving

~~NOTE 1~~ ~~Refer~~Users should refer to API MPMS Ch.~~apters~~ 4.1, *Section 1—Introduction*,~~.8~~ Ch. ~~and~~ 13.2, *Methods of Evaluating Meter Proving Data*, and Ch. 13.3– *Measurement Uncertainty*, for ~~.~~the uncertaint~~y~~ies of Flow Metering and Meter Proving as appropriate.

~~NOTE 2 See examples in Chapter 13.3 Annex B.~~

NOTE~~3~~ Additionally, ~~R~~refer Annex D of this chapter, *Troubleshooting Guide for Liquid Pipeline Measurement Operations*~~*to Dynamic Measurement Section of Troubleshooting Guide in Annex D*~~

~~4.3.4~~

5.3.3 Tanks

~~Add a sentence about the importance of looking for items which can affect the change in inventory rather than the absolute volume in the tank…~~

The physical closing tank gauge reading from the previous period should match the physical opening tank gauge reading for the current period.

Tanks that are gauged for inventory and that are active at the time of gauging should be allowed to rest long enough to be gauged without liquid moving in or out.

Accurate month-end inventory gauges are especially important because they are used to balance and close out pipeline and/or terminal inventories and to issue customer and billing reports. Multiple customers may share the same storage in a fungible tank, and L/G offsets from month to month can be difficult to allocate.

~~NOTE See API MPMS Chapter 3 for further details.~~

~~Tank gauging may be inaccurate if tanks are tilted, have flexing bottoms, or the insides of the walls are coated with sludge and encrustation.~~

~~Tank capacity tables that are not corrected for bulge due to hydrostatic head will be in error.~~

~~Temperature measurements in tanks may be wrong if thermometers are not suspended in the liquid long enough to reach thermal equilibrium. Even then, individual temperature measurements may not represent the entire product temperature.~~

~~An innage gauge may be in error if a free water layer in the bottom of a tank is frozen, thereby stopping the gauge tape bob above the true bottom.~~

~~Where tank gauging is used for receipts, free water in the receiving tank should not be drained before the tank is gauged to determine the quantity.~~

~~Measurements made in tanks with floating roofs in the critical zone are uncertain and may be subject to significant error.~~

~~Snow, water, ice, or other debris on a floating roof will change the buoyant weight of the roof and result in a quantity error.~~

~~An unslotted gauge well (pipe) can result in erroneous liquid depth and temperature measurement in the gauge well. The depth (height) of the hydrostatic column in the gauge well will be different from the depth of the hydrostatic column~~

~~in the tank when there is a difference in liquid densities in the gauge well and in the bulk of the tank. Any water in the tank that extends into the gauge pipe might also be impacted similarly.~~

~~Outage gauge errors may be caused by reference height markers that are loose or have moved.~~

~~Reference height markers on gauge hatches that are affixed to the top of cone roof tanks without gauging wells may be subject to vertical movement as a tank fills or empties due to flexing of the tank wall, as well as any flexibility of the roof itself (weight and position of gauger and others). This may introduce a measurable error in level gauging.~~

~~The accuracy of tank tables is obviously dependent on the accuracy with which the tanks were strapped. Some things that can affect the accuracy of strapping are as follows:~~

~~strapping tape temperature and tension,~~

~~temperature of tank shell,~~

~~tank filled or empty,~~

~~accuracy of strapping operation.~~

~~Other possible errors relating to tank calibration are discussed in API MPMS Chapter 2.~~

~~Tank volumes do tend to change with time. This may be due to stretching of the shell with continuous use over time, slippage between the plates of bolted or riveted tanks, disassembly and re-erection, being “moved bodily,” or sitting idle for a long time.~~

~~Experience in the industry has shown that tanks of up to 1000 bbl nominal capacity that have not been moved or disassembled do not show a significant change in volume over a period of 10 years. Larger tanks, though, may change volume enough over a 10-year span to warrant recalibration.~~

~~NOTE 1~~ Users should ~~R~~refer to API MPMS ~~Chapter~~ Ch. 3.1A, *Standard Practice for the Manual Gauging of Petroleum and Petroleum Products*, for information on uncertainties relating to tank measurement.~~.~~

NOTE Additionally, refer Annex D of this chapter, *Troubleshooting Guide for Liquid Pipeline Measurement Operations*~~NOTE 2 Refer to Static Measurement Section of Troubleshooting Guide in Annex D~~

~~4.3.5~~ Explainable L/G and

5.3.4 ~~System~~ Biases~~and General~~

Certain L/G inaccuracies can be explained and quantified, whereas others can be explained but not quantified. Likewise, minor meter imbalances or recurring hourly shortages/overages can be the result of many factors.

NOTE 1 Refer to Annex C for specifics associated with NGL quantity reconciliations.~~: Refer to Annex D for the examples of explainable Losses and Gains.~~

NOTE 2 Refer to Annex D for the examples of explainable Losses and Gains.~~ Refer to Annex C for specifics associated with NGL quantity reconciliations.~~

~~4.3.5.1~~5.3.4.1 The size of a tender (batch, parcel, movement, shipment) is a factor in the overall loss or gain in the tender. Fewer/larger tenders for the same period of time may help with better L/G performance.~~By way of illustration, a system loss of 0.1 % would be 1 bbl in a tender of 1000 bbl or 100 bbl in a 100,000 bbl tender. This is based on overall system L/G. Yet, the apparent per cent L/G in a 100,000 bbl tender may be less than that in a 1000 bbl tender. This may be due to a lesser effect of end effects (e.g. interface cut point) and more opportunity for operating conditions to stabilize during the longer run time of the larger tender. The measured loss on the 100,000 batch may be only 80 bbl, or 0.08 %, and the loss on the 1000 bbl batch may be 20 bbl, or 2 %. The overall system is still 0.1.~~

~~**4.3.5.2** A real source of loss is evaporation. The empty space in a tank above a volatile liquid, such as gasoline, is filled with varying concentrations of vapor from the liquid. When the contents of the vapor space are expelled from the tank during filling of the tank or diurnal breathing, the vapors in the expelled air are lost. Refer to API MPMS Chapter 19.~~

~~**4.3.5.3** Evaporation losses can be minimized by using floating roof tanks, which eliminate the air space above the liquid contents of a tank, or by connecting the roof vents of cone roof tanks to a vapor recovery system. Some states require evaporation loss prevention to reduce air pollution.~~

~~4.3.5.4~~5.3.4.2 Equipment that is not calibrated, certified, or verified~~—~~ such as thermometers, hydrometers, temperature gauges, gauge tapes, and centrifuge tubes~~—~~ may be inaccurate. If so, this will add a bias to the system L/G.

~~4.3.5.5~~5.3.4.3 Common errors occurring on manually calculated measurement tickets include arithmetic mistakes, data entry mistakes, and pulling wrong correction factors from tables.

~~4.3.5.6~~5.3.4.4 Tickets that do not get into the accounting process on time will cause an apparent loss or gain in the current accounting period and an offsetting gain or loss in the following period.

~~4.3.5.7~~5.3.4.5 Timing discrepancies, period to period, in closing meter readings and inventory information can be a major factor in properly establishing L/G for an accounting period.

~~4.3.5.8~~5.3.4.6 The closing tank gauge reading from the previous period should match the opening tank gauge reading for the current period.

~~**4.3.5.9** Tanks that are gauged for inventory and that are active at the time of gauging shall be gauged at the same time of the same day or stilled long enough to be gauged without liquid moving in or out.~~

~~4.3.5.10~~5.3.4.7 Accurate month-end inventory gauges are very important because they are used to balance and close out pipeline and/or terminal inventories and to issue customer reports and billing. Multiple customers may share the same storage in a ~~commingled~~ fungible tank, and L/G offsets from month to month can be difficult to allocate. Month-end gauges are also useful to identify trends that may reveal a bias (e.g., a systematic error).

~~**4.3.5.11** Line fill may contribute significantly to system inventory. If possible, line fill should be corrected for temperature and pressure. Pipelines should be completely empty or completely full at the beginning and end of the accounting period.~~

~~**4.3.5.12** Sampling in lines and tanks requires good mixing to ensure that a representative sample is obtained.~~

5.3.4.8 Sumps collect drips and drains from a number of sources and may add a bias to a system L/G if the sumps are emptied by pumping into a pipeline system without being measured. Usually, sump volumes are small enough to be significant. However, the volumes may be significant if sumps accumulate large volumes, such as frequent drain downs from provers or scraper traps.

5.3.4.9 Wax may deposit on pipe walls when a waxy crude liquid is cooled below the cloud point. Wax changes volume by a measurable amount when it changes from the liquid state to the solid state. This can affect line fill volume and, thereby, affect L/G. Even if wax does not deposit on the inside of pipe walls, the change from liquid to suspended microcrystalline solids results in a volume change in the overall liquid, and there may be a measurable difference between pipeline receipt volumes and delivery volumes.

5.3.4.10 Correction for the temperature of the liquid (CTL). The physical characteristics of given liquid(s) may not be accurately represented by the applicable volume correction tables, including API MPMS Chapter 11.1 or Chapter 11.2.4.

Examples of some additional system biases include, but are not limited to, the following:

- Inconsistent sampling techniques and/or containers (i.e., single cavity vs. piston cylinders)
- Methods of analysis (i.e., S&W by centrifuge vs. other methodologies)
- Variations between test results from different Labs
- Inconsistent product composition applied to various points of the system
- Inconsistent pressure in different line segments due to pumping capabilities or pipeline elevation profile
- Different types of meters used within same system
- Meter proving procedures
- Meter proving frequency
- Measurement systems - tanks vs. meters
- Mixing systems (i.e., static vs. powered)
- Temperature units (i.e., Fahrenheit vs Celsius)
- Pressure units (i.e., psia vs psig, or psi vs kPa)
- Liquid properties
- Viscosity

NOTE 1 Refer to Annex C for specifics associated with NGL quantity reconciliations.~~Refer to Annex D for the additional information on system biases and the examples of explainable Losses and Gains.~~

NOTE 2 Refer to Annex D for the additional information on system biases and the examples of explainable Losses and Gains. ~~Refer to Annex C for specifics associated with NGL quantity reconciliations.~~

~~5~~ Reporting

~~6 Apparent losses may result from shrinkage due to mixing stocks with significantly different gravities or chemical composition. Methods for evaluating shrinkage are given in API MPMS Chapter 12.3.~~

~~7 Changes in operating pressure, operating temperature, or fluid characteristics are indicators that an overage or shortage may be occurring. The following are some examples of sources of over/short inaccuracies:~~

~~8 a pipeline or valve leak,~~

~~9 a faulty relief system,~~

~~10 improper lineup,~~

~~11 errors in calculating volumes,~~

~~12 not applying a meter factor to the registered volume,~~

~~13 applying a meter factor not applicable to the operating flow rate and pressure,~~

~~14 comparing a temperature compensated (net) meter volume to a gross volume,~~

~~15 meter malfunction,~~

~~16 automatic gauge malfunction.~~

~~17 Data from SCADA systems can be very useful in identifying problems and trends.~~

~~18 Explainable Loss/Gain~~

~~19 General~~

~~20 Certain L/G inaccuracies can be explained and quantified, whereas others can be explained but not quantified. Likewise, minor meter imbalances or recurring hourly shortages/overages can be the result of many factors.~~

~~21 Pipeline pressure change, increase or decrease, will create a false over/short condition due to accumulated volume of pipeline varying with pressure.~~

~~22 Product interfaces cause a varying meter-in/meter-out reading as a result of relative density changes.~~

~~23 Seasonal temperature changes along the pipeline will affect metering via expansion or contraction of produce in line. Imbalances between locations can be caused when pipeline passes under a river and temperature of product is changed.~~

~~24 Small leak or puncture.~~

~~25 DRA-laden product.~~

~~26 Evaporation.~~

~~27 Volumetric shrinkage (see API MPMS Chapter 12.3).~~

~~28 Bias~~

~~29 Examples of system bias include, but are not limited to, the following:~~

~~30 Methods of analysis, i.e. S&W.~~

~~31 Different types of meters.~~

~~32 Meter proving procedures.~~

~~33 Measurement systems—tanks vs meters.~~

~~34 Fahrenheit vs Celsius.~~

~~35 Proving frequency.~~

~~36 Liquid properties.~~

~~37 Correction for the temperature of the liquid (CTL). The physical characteristics of given liquid(s) may not be accurately represented by the applicable volume correction table, e.g. API MPMS Chapter 11.1.~~

~~38 Wax deposition. Wax may deposit on pipe walls when a waxy crude liquid is cooled below the cloud point. Wax changes volume by a measurable amount when it changes from the liquid state to the solid state. This can affect line fill volume and, thereby, affect L/G. Even if wax does not deposit on the inside of pipe walls, the change from liquid to suspended microcrystalline solids results in a volume change in the overall liquid, and there may be a measurable difference between pipeline receipt volumes and delivery volumes.~~

~~39 Viscosity.~~

~~40~~6 ~~Line fill.~~

~~41~~

~~42 Tank capacity table error.~~

~~43 Tank bottom flexing.~~

~~44 Tank datum plate movement.~~

~~45 Inadequate meter backpressure.~~

~~46 Pressure: psia vs psig.~~

~~46.1~~6.1 Resolving the Loss/Gain

6.1.1 A loss investigation is successful when the cause has been identified and ~~the~~ appropriate actions are taken to resolve or correct the problem. A key role of the loss investigator is to thoroughly document the findings from background to resolution so there is a clear understanding of the problem, how the problem lead to a loss (or gain), and, most important, what is required to resolve the problem and prevent reoccurrence.~~ Generally, i~~ Investigative reports should provide detailed recommendations and responsibility assignments to ensure complete resolution.

6.1.2 Sometimes, due to any number of issues regarding measurement systems, the measurement reading will not be accurate and an adjustment for the measurement period in question should be made until the measurement system is either repaired or replaced. Such adjustments can be made based on the available secondary measurement systems, such as tank gauging or meter information from upstream or downstream of the inaccurate measurement system. The adjustments should be agreed upon by the affected parties and properly documented.

6.1.3 ~~In order to~~To troubleshoot the out-of-tolerance gains or losses, it is generally a good practice to collect and analyze all difference trend data available between primary and secondary measurement data. For example, a comparison of metered volumes with the corresponding shore tank received or delivered volumes on both ends of line. The trend will often show a change in deviation, which will indicate where to begin further investigation.

6.1.4 Once the cause of an excessive loss or gain has been identified and resolved, in certain cases it may be possible to go back and correct measurement tickets for the period of time affected by the inaccurate measurement. If the adjustments are agreed by all affected parties and follow the agreed upon procedures, contractual obligations, and the established rules and regulations (such as pipeline tariffs, etc.), tickets may be revised.

Two sets of data are often available for stock balances:

- **"Accounting month"** includes all transactions that entered the books during the month including adjustments, corrections, and late tickets from prior months.
- **"Current month"** includes only actual receipts, deliveries, and inventory changes that occurred during the month. It does not include late tickets or adjustments from prior months.

It is desirable to look at current month data because that data set tells us the most about the physical operation of a system. It tends to highlight the fundamental accuracy of a system, equipment malfunctions, and procedural errors.

Analysis of accounting month data can help to identify problems in ticket preparation and handling and other accounting type problems. It may not be necessary to be concerned about the occasional bobble, but recurring problems need to be identified and corrected.

7 Calculating System Uncertainties

7.1 It is useful to determine the uncertainty of the system to understand the capability of the overall gain/loss analysis.

7.2 The uncertainty of the system is~~could be~~ calculated as follows:

First, the Loss/Gain of the system is defined as Equation 10:

$$L/G_{system} = Stock_{Initial} + Inputs - Outputs - Stock_{Final} = \Delta Stock + Inputs - Outputs \qquad (10)$$

~~$LG\ System = Stock_{Initial} + Inputs - Outputs - Stock_{Final} = \Delta Stock + Inputs - Ouputs$~~

The second step is to calculate the uncertainty of the system as shown in Equation 11:

$$U_{LG\ System} = \sqrt{U_{\Delta S}^2 + \Sigma_i U_{Input_i}^2 + \Sigma_{Output_j}^2} \qquad (11)$$

:

~~$U_{LG\ System} = \sqrt{U_{\Delta S}^2 + U_{Inputs}^2 + U_{Outputs}^2}$~~

~~$U_{LG\ System} = \sqrt{U_{\Delta S}^2 + \sum_i U_{Input_i}^2 + \sum_j U_{Output_j}^2}$~~

~~(10)~~

where,

$U_{\Delta S}$ ~~UΔS~~ is the uncertainty of the variation in the inventory/stock measurement~~.~~

U_{Input} ~~UInput~~ is the uncertainty of the input measurements~~.~~

U_{Output} ~~UOutput i~~is the uncertainty of the output measurements~~.~~

7.3 System conditions may vary during the measurement process. Understanding those variations is important to determine their contribution to the overall uncertainty.

7.4 If the calculations of the uncertainty are too difficult to determine for the system (no instrument information, complex process, etc.), analysis of historical data should be performed. Care should be taken using historical data because biases and structural issues can become normalized.

7.5 If the scatter in data is already known for a given operation, then the uncertainty limits will be known, and any measurement that falls outside the limits corresponding to 95 % probability should be rejected. When only two measurements are available, and their difference exceeds the repeatability, then both measurements may be suspect. It should be stressed, however, that measurements should never be discarded freely. An attempt ~~should always~~shall be made to find a reason for the extreme values, after which corrective action can be taken.

7.6 Estimating overall uncertainty of the system and making the calculations available for all parties is essential for communications. A consistent basis of estimating uncertainty can help to avoid disputes and dispel delusions on the accuracy of the activities.

7.7 Reviewing the loss/gain and understanding the uncertainty of the system can provide~~s~~ insight into the level of improvement that can be achieved by investing into it (technology, procedures, training, etc.).

NOTE Refer to Annex A for the additional information on system uncertainty calculations.

8 Improving System Performance

This section is intended to provide guidance that could be used to improve system performance.

8.1 ~~It is possible that a~~Almost all measurement systems ~~could~~can be improved in one form or another. Improvements typically have associated operational expenses~~costs~~, which are decided on the basis of some acceptable level of system performance, or, in other words, the quantity~~costs~~ of the losses. It is important to understand that the uncertainties of a particular system are limited to the capabilities related to measurement.–

8.2 Individual measurement uncertainties are related to a particular point in time. Monthly reconciliations tend to reduce random errors, making bias visible for the measurement professional.

8.3 The uncertainty depends on the equipment and procedures in place.

8.4 An analysis of the measurement system can be used to define the current capability and the improvement that might be accomplished with upgraded equipment and procedures. Installing more accurate measurement equipment, using improved operational procedures, and instituting an ongoing training and witnessing program for measurement or operations personnel should improve system performance.

8.5 Pipeline measurement accuracy may take several months, or even years, to reach a performance level acceptable to the pipeline organization.

~~2 Reporting~~

~~2.1 Resolving the Loss/Gain~~

~~**2.1.1** A loss investigation is successful when the cause has been identified and the appropriate actions are taken to resolve or correct the problem. A key role of the loss investigator is to thoroughly document the findings from background to resolution so there is a clear understanding of the problem, how the problem lead to a loss (or gain), and, most important, what is required to resolve the problem. Generally, investigative reports should provide detailed recommendations and responsibility assignments to ensure complete resolution.~~

~~**2.1.2** Sometimes, due to instrument or mechanical failure of meters, the accurate measurement will become impossible and an adjustment for the measurement period in question will be required until the meter is either repaired or replaced. Such adjustments can be made based on the available secondary measurement data, such as tank gauging or meter information from upstream or downstream of the failed measurement equipment. The corrections or adjustments shall be agreed upon by the affected parties and properly documented.~~

~~**2.1.3** In order to troubleshoot the out-of-tolerance gains or losses, it is generally a good practice to collect and analyze all available secondary measurement data. For example, a comparison of metered volumes with the corresponding shore tank received or delivered volumes on both ends of line will often show a discrepancy at one point, which will indicate where to begin further investigation.~~

~~**2.1.4** Once the cause of an excessive loss or gain has been identified and resolved, in certain cases it may be possible to go back and correct measurement tickets for the period of time affected by the inaccurate measurement as far as the adjustments are justified and follow the agreed upon procedures, contractual obligations, and the established rules and regulations (such as pipeline tariffs, etc.).~~

~~**2.1.5** It is probably true that almost all measurement systems could be improved in one form or another. Unfortunately, improvements usually have associated costs. Justification for these costs is usually decided on the basis of some acceptable level of system performance, or, in other words, the costs of the losses. It is important to understand the capabilities of a particular system and what uncertainty to expect in the monthly loss numbers. The uncertainty is difficult to assess and usually depends on the equipment and procedures in place.~~

~~**2.1.6** An analysis of the measurement system can be used to define the current capability and the improvement that might be accomplished with upgraded equipment and procedures. Installing more accurate measurement equipment, using improved operational procedures, and instituting an ongoing training program for measurement or operations personnel should decrease pipeline losses.~~

~~**2.1.7** Pipeline measurement accuracy may take several months, or even years, to reach a performance level acceptable to the pipeline organization. To some extent, better performance may be obtained by improving procedures and practices and by training personnel in proper procedures and practices. Further improvement in performance may require additional or improved equipment, in which case, the relative economics shall be evaluated.~~

~~3 Calculating Statistical Uncertainties~~

~~**3.1** This section summarizes some of the statistical methods discussed in the API *MPMS* Chapter 13.2.~~

~~**3.2** A measurement taken under undefined or variable conditions will not yield meaningful statistics. In order to establish statistical control, great care shall be taken to ensure that factors, such as temperature and flow rate, are correctly measured and that all external influences have been identified.~~

~~**3.3** It is often difficult to establish statistical control quantitatively. It may be possible, however, to examine performance charts and calculate the maximum allowable range for a set of measurements obtained under the given operating conditions. At the very least, it is essential that the measurement procedure is clearly understood and that the equipment is fully operational.~~

~~**Caution—Once a set of "*n*" repeated measurements is obtained, the set should be examined for outliers. This can be done with Dixon Test (see API *MPMS* Chapter 13.1). If an outlier is detected, it should be discarded from the data set and further measurements made until a good set of data is obtained.**~~

~~**Caution—It should be determined that the extreme value was not due to a change in an uncontrolled variable such as temperature or flow rate.**~~

~~**3.4** If the scatter in data is already known for a given operation, then the uncertainty limits will be known, and any measurement that falls outside the limits corresponding to 95 % probability (this will be discussed shortly) may be rejected. When only two measurements are available, and their difference exceeds the repeatability, then both measurements may be suspect. It should be stressed, however, that measurements should never be discarded freely. An attempt should always be made to find a reason for the extreme values, after which corrective action can be taken.~~

~~**3.5** API *MPMS* Chapter 13.2 points out that “minimizing systematic and random errors, estimating remaining errors, and informing affected parties of errors” are becoming increasingly important to industry. A consistent basis of estimating the size and significance of errors is essential for communications between affected parties. A consistent basis of estimating and controlling errors can help to avoid disputes and dispel delusions on the accuracy of activities and equipment related to meter proving operations.~~

~~**3.6** A wide range of designs, equipment, and service operating conditions are experienced in meter proving operations. Because of these variations, it is impractical to establish fixed procedures for maintenance, calibration, and proving activities for all installations. Meter proving factors (meter factors) should be monitored to detect trends or sudden deviations as an indication of when to perform maintenance and/or calibration of measurement equipment.~~

~~**3.7** Stable operating conditions are particularly important during meter proving operations, as changes in any operating condition (flow rate, temperature, pressure, API gravity) will cause changes in meter factor. Therefore, operating changes during and between meter proving runs should be minimized so that any variations in meter pulses or meter factors are primarily due to performance of the meter and proving system. Meter factors or meter pulses for each run can be evaluated in sequence to determine if there is a time-related trend due to changing operational parameters or malfunctioning equipment.~~

~~**3.8** Throughout the application of statistical controls to pipeline operations, it is essential to remember that the goal is improved operation and understanding of systems. The use of any statistical process shall lead to an expected result. There is little to be gained from statistics for the sake of statistics.~~

~~**3.9** We often have two sets of data available for stock balances:~~

~~“Accounting month” includes all transactions that entered the books during the month including adjustments, corrections, and late tickets from prior months.~~

~~“Current month” includes only actual receipts, deliveries, and inventory changes during the month. It does not include late tickets or adjustments from prior months.~~

~~It is desirable to look at current month data because that data set tells us the most about the physical operation of a system. It tends to highlight the fundamental accuracy of a system, equipment malfunctions, and procedural errors.~~

~~Analysis of accounting month data can help to identify problems in ticket preparation and handling and other accounting type problems. It may not be necessary to be concerned about the occasional bobble, but recurring problems need to be identified and corrected.~~

Annex A
(informative)

Statistical and Uncertainty Calculations

This informative annex will present several ways to determine control limits to the L/G of a system using statistical or uncertainty calculations as a tool.

A.1 Calculation of Tolerances for a pipeline system based on uncertainties

This model is based on the determination of the uncertainty of the complete measurement system. The model encompasses all measurement systems involved in the transfer of the product. This is shown in Equation A.1:

$$Tolerance_{Batch} = \pm \sqrt[2]{U_{Input}^2 + U_{Output}^2}$$ ~~$Tolerance_{Batch} = \pm \sqrt[2]{U_A^2 + U_B^2}$~~ (A.1)

~~$Tolerance_{Batch} = \pm \sqrt[2]{U_A^2 + U_B^2}$~~

~~W~~Where,

U_{Input} ~~U_{Input}~~ UA and U_{Output} ~~U_{Output}~~ UB are the uncertainties of the two measurement systems involved in a sim~~m~~ple transfer.

This tolerance applies independently to each batch transfer through the pipeline.

If the measurement system is more complex, for example a pipeline with two or more inputs and one or more outputs, the equation can be expressed as follows in Equation A.2:

$$Tolerance_{Batch} = \pm \sqrt[2]{\sum_{i=0}^{n} U_i^2} \qquad (A.2)$$

~~$Tolerance_{Batch} = \pm \sqrt[2]{\sum_{i=0}^{n} U_i^2}$~~

W~~W~~here,

n ~~n~~ corresponds to the number of measurement systems involved in the transfer system.

To determine a tolerance for a certain period of time (for example, a month), ~~the following e~~Equation A.3 can be applied~~.~~:

$$Tolerance_{Period} = \pm \frac{Tolerance_{Batch}}{\sqrt[2]{n}} \qquad (A.3)$$

~~$Tolerance_{Period} = \pm \frac{Tolerance_{Batch}}{\sqrt[2]{n}}$~~

~~W~~Where,

n ~~n~~ is the number of batches transferred in the considered period.

To calculate the monthly product quantity balance by product we may use the following equation A.4:

$$\text{Accumulated Difference} = \sum \text{Input Volume} - \sum \text{Output Volume} \qquad \text{(A.4)}$$

To measure by tolerance index, use Equation A.5:

$$IT\% = \left(\frac{\sum \text{Input Volume} - \sum \text{Output Volume}}{\sum \text{Input Volume}} \right) \bullet 100\% \qquad \text{(A.5)}$$

Where,

IT is the Tolerance Index for the measurement system.

A.1.1 Calculation of Uncertainties for each batch~~Method~~

For control of quantities, a monthly tolerance for the balance in a pipeline is recommended. This monthly tolerance is based on the computed uncertainties of the measurement system. The measurement system in this scenario is defined as:

- Product Input (U_I: Input Measurement Uncertainty)
- Product Output (U_O: Output Measurement Uncertainty)

In this case, both systems have the same characteristics and operate under the same conditions, and it may happen that the same system is used for both the Input and Output measurements.

A.1.1.1 Determination of U_I and U_O

The input and output volumes of the pipeline are based on the Quantity Certificate or Meter Ticket agreed between the parties involved in the transfer, these reports are generated by the Flow Computer of the measurement system adjusted to 15 °C and 1 atmosphere (atm).

~~To calculate the monthly product quantity balance by product we may use the following equation A.4KPI (IT%):~~

~~(A.4)~~

~~$Accumulated\ Difference = \sum Input\ Volume - \sum Output\ Volume$~~~~To measure by tolerance index, use Equation A.5:~~

~~(A.5)~~

$$\cancel{IT\% = \frac{\sum Input\ Volume - \sum Output\ Volume}{\sum Input\ Volume} \times 100\%}$$

~~WWhere,~~

~~IT is the Tolerance Index for the measurement system.~~

In the case of multi-product pipelines, we should consider the calculation of the amount of product in the interface between batches of different products, except if a physical separator or “pig” is used to prevent the mixture between the two products, therefore Product A~~Diesel (DF)~~ and Product B~~Gasoline (GAS) products~~ –can be expressed with Equation A.6:

$$Vol.A_{Input} = Vol.BatchA_{Input} + Vol.BatchA_{InitialInterface} + Vol.A_{FinalInterface}$$

(A.6)

$$Vol.A_{Input} = Vol.BatchA_{Input} + Vol.A_{InitialInterface} + Vol.A_{FinalInterface}$$

~~$Vol.DF_{Input} = Vol.BatchDF_{Input} + Vol.DF_{InitialInterface} + Vol.DF_{FinalInterface}$~~ (A.6)

~~$Vol.DF_{Input} = Vol.BatchDF_{Input} + Vol.DF_{Initial\ Interface} + Vol.DF_{Final\ Interface}$~~

Where, ~~:~~

$Vol.BatchA_{Input}$ is ~~$Vol.BatchA_{Input}$~~ the volume of Product A that enters the Pipeline excluding the content in the Interface

$Vol.BatchA_{InitialInterface}$ is the ~~$Vol.A_{InitialInterface}$~~ Volume of Product A– in the Initial Interface, and

$Vol.A_{FinalInterface}$ i~~$Vol.A_{FinalInterface}$~~s the Volume of Product A– in the Final Interface

~~Vol.BatchDF$_{Input}$: Volume of DF that enters the Pipeline excluding the content in the Interface~~

~~Vol.DF$_{Initial\ Interface}$: Volume of DF in the Initial Interface~~

~~Vol.DF$_{Final\ Interface}$: Volume of DF in the Final Interface~~

The same analysis corresponds to the measurement of the pipeline outlet ($Vol.A_{Out}$) ~~($Vol.A_{Out}$~~ ~~$Vol.DF_{Out}$~~ ~~Vol.DF$_{Out}$)~~.

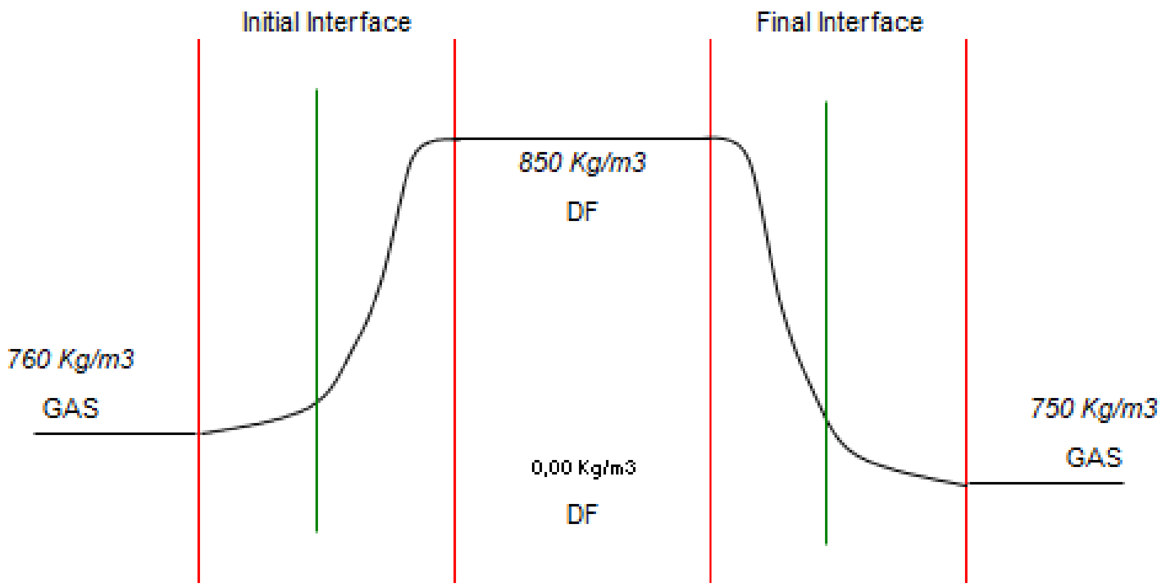


Figure **A.1** – **Example of interface volumes using Gasoline (GAS) and Diesel Fuel (DF)**

NOTE In the present example, the stocks inside the Pipelines were not considered as they don't affect the calculation.

A.1.1.2 Determination of Uncertainties of interfaces~~Mathematical Model~~

For the measurement of the Input and/or Output volumes excluding the Interfaces, use Equation A.7:

$$V_{15°,1atm} = \frac{P}{K_f} \times MF \times CTLm \times CPLm \qquad \text{(A.7)}$$

~~$V_{15°,1atm} = \frac{P}{K_f} \times MF \times CTLm \times CPLm$~~

The typical pipeline procedure for cutting an interface uses the following equations. These equations show the sources of uncertainty of interfaces.

For product measurement in the Initial Interface see Equation A.8:

$$Vol.A_{\text{Initial Interface}} = \frac{Vol_{\text{Initial Interface}}\left(\rho_{\text{Initial Interface}} - \rho_B\right)}{\rho_A - \rho_B} \qquad \text{(A.8)}$$

~~$(Vol.A_{InitialInterface}$Vol.DF$_{\text{Initial Interface}}$):~~

~~$Vol.DF_{Initial\ Interface} = \frac{Mass_{Initial\ Interface} - Vol_{Initial\ Interface} \times \rho_{GAS}}{\rho_{DF} - \rho_{GAS}}$~~

~~$= \frac{Vol_{Initial\ Interface} \times \rho_{Initial\ Interface} - Vol_{Initial\ Interface} \times \rho_{GAS}}{\rho_{DF} - \rho_{GAS}}$~~

~~$Vol.DFA_{Initial\ Interface} = \frac{Vol_{Initial\ Interface} \times (\rho_{Initial\ Interface} - \rho_{BGAS})}{\rho_{ADF} - \rho_{BGAS}}$~~

If this is the equation for the initial interface volume, then the uncertainty is a function of 3 sources (Volume of the interface, Product A density, and Product B density).

For product measurement in the Final Interface see Equation A.~~¥~~9:

$$Vol.A_{\text{Final Interface}} = \frac{Vol_{\text{Final Interface}}\left(\rho_{\text{Final Interface}} - \rho_B\right)}{\rho_A - \rho_B} \qquad \text{(A.9~~¥~~)}$$

If this is the equation for the final interface volume, then the uncertainty is a function of 3 sources (Volume of the interface, Product A density, and Product B density).

A.1.1.3 Uncertainty Calculations Assumptions

~~If this is the equation for the final interface volume, then the uncertainty is a function of 3 sources (Volume of the interface, Product A density, and Product B density).~~

~~Mathematical Model~~Uncertainty Calculations Assumptions

The following assumptions are used in the below calculations. Users should review the suitability of these assumptions as it relates to the equipment in the field.

- Linear approximation in the correction factors for temperature effects is sufficient.
- The meter is calibrated and traceable to ~~N~~national or ~~I~~international Standards, in perfect condition, properly maintained, is properly installed, and is used within its operating range.
- ~~The development of the calculation method of the Uncertainties of the Interface, is considered of the "ascending parabolic" type, as usually occurs in normal operating conditions (see previous graph).~~

In steps we determine first the sources of u~~U~~ncertainty, estimate the standard Uncertainty of each source, calculate the combined standard u~~U~~ncertainty and finally determine the ~~E~~expanded Uncertainty.

A.1.1.4 Measurement ~~uncertainty~~ Uncertainty of a ~~batch~~Batch

Table A.1 below shows an example of calculation measurement uncertainties in a single batch of product.

No	Source	Description	Origin Uncertainty		Distribution
1	Meter Pulse Generated	API 21.2 – 8.1.3 => ±2 in 200.000 pulses	2.00 pulses		R
2	Meter Factor (MF)				
	Stability	Manufacturer Specifications (± 0~~,~~.05 %)	± 0~~,~~.0005		N; k=2
	Linearity	Manufacturer Specifications (± 0.~~,~~15 %)	± 0.~~,~~0015		R
	Meter Calibration	5 runs – 0.~~,~~05 %	± 0.~~,~~00027		N; k=2
3	Compressibility Factor	API 11.1 - 4 => ±6~~,~~.5% at 95 % of confidence	± 0.~~,~~0000065 ~~–~~ ~~1/~~bar-1	± 0.~~,~~00000065 ~~5 –~~ ~~1/~~psi-1	N; k=2
4	Density at 15°C	API 9.4	± 3.~~,~~0 Kg/m3	± 0.5°API	R
5	Meter Temperature				
	Stability T°	Statistical data and experience:	± 0.~~,~~10 °C	±0.2°F	N; k=2
	Thermometer Resolution	API 7.4	± 0.~~,~~05 °C	±0.05°F	R
	Thermometer Calibration	API 7.4 - 10.5.2	± 0.~~,~~10 °C	±0.2°F	N; k=2
6	Meter Pressure				
	Pressure Stability	Statistical data and experience:	± 0.~~,~~10 bar	± 1.45 psi	N; k=2
	Pressure Meter Resolution	Manufacturer Specifications	± 0.~~,~~05 bar	± 0.73 psi	R
	Pressure Meter Calibration	It is adopted by experience: 0.25 % of the reading	± 0.~~,~~023 bar	± 0.33 psi	N; k=2

~~Relative Standard Uncertainty~~	~~0,.092 %~~
~~Degrees of freedom~~	~~233~~
~~Coverage Factor~~	~~1,.97~~
~~Relative Expanded Uncertainty~~	~~0,.181 %~~

Table A.1 – Measurement uncertainty of a batch from several sources

A.1.1.5 Interface measurement uncertainty

No	Source	Description	Origin Uncertainty		Distribution
1	Meter Pulse Generated	API 21.2 => ±2 in 200.000 pulses	2.00 pulses		R
2	Meter Factor (MF)				
	Stability	Manufacturer Specifications (± 0,05%)	± 0.0005		N; k=2
	Linearity	Manufacturer Specifications (± 0,15%)	± 0.0015		R
	Meter Calibration	5 runs – 0~~,~~.05%	± 0.00027		N; k=2
3	Compressibility Factor	API 11.1 - 4 => ±6~~,~~.5% at 95% of confidence	± 0.0000065 ~~1/~~bar-1	± 0.00000065 ~~1/~~psi-1	N; k=2
4	Interface Density	API 9.4	± 3.0 Kg/m3	± 0.5°API	R
5	Product A Density (DF)	API 9.4	± 3.0 Kg/m3	± 0.5°API	R

4	Product B Density (GAS)	API 9.4	± 3.0 Kg/m3	± 0.5°API	R
6	Meter Temperature	-			
	Stability T°	Statistical data and experience	± 0.10 °C	±0.2°F	N; k=2
	Thermometer Resolution	API 7.4	± 0.05 °C	±0.05°F	R
	Thermometer Calibration	API 7.4 10.5.2	± 0.10 °C	±0.2°F	N; k=2
7	Meter Pressure	-			
	Pressure Stability	Statistical data and experience	± 0.10 bar	± 1.45 psi	N; k=2
	Pressure Meter Resolution	Manufacturer Specifications	± 0.05 bar	± 0.73 psi	R
-	Pressure Meter Calibration	It is adopted by experience: 0.25% of the reading	± 0.023 bar	± 0.33 psi	N; k=2

~~Relative Standard Uncertainty~~	~~± 0,.709 %~~
~~Degrees of freedom~~	~~402~~
~~Coverage Factor~~	~~1.,97~~
~~Relative Expanded Uncertainty~~	~~± 1,.394 %~~

Table A.2 – Measurement uncertainty of an interface from several sources

A.1.1.6 Expression of Uncertainty U_E and U_S

The U_E ~~U_E~~ (expanded uncertainty) of the measurement of the volumetric meters ±0.181 % was calculated by multiplying the U_S ~~U_S~~ (combined standard uncertainty) ±0.092 % by a coverage factor k ~~k~~ 1.97, with an approximate confidence level of 95.45 % and a distribution t with "v" 233 degrees of freedom.

The U_E ~~U_E~~ of the interface measurement ±1.394 % was calculated by multiplying the U_S ~~U_S~~ ±0.709 % by a coverage factor k ~~k~~ 1.97, with an approximate confidence level of 95.45% and a t ~~t~~ distribution with "v" 402 degrees of freedom.

Although applicable to all transportation systems, in the pipelines particular case we have the final uncertainty of the system as the quadratic sum of the uncertainty of the measurement of the initial interface, the final interface and the volumetric meter resulting in Equations A.~~8~~10 and A.~~9~~11:

$$U_{SYSTEM} = \sqrt{\left(U_{InitialInterface} \times Vol_{InitialInterface}\right)^2 + \left(U_{FinalInterface} \times Vol_{FinalInterface}\right)^2 + \left(U_{Vol.Meter} \times Vol_{Batch}\right)^2} \quad \text{(A.~~8~~10)}$$

$$U_E[\%] = \frac{U_{SYSTEM}[lts]}{Vol_{InitialInterface} + Vol_{FinalInterface} + Vol_{Batch}} \quad \text{(A.11~~9~~)}$$

~~$U_{SYSTEM} = \sqrt{(U_{Initial\ Interface} \times Vol_{Initial\ Interface})^2 + (U_{Final\ Interface} \times Vol_{Final\ Interface})^2 + (U_{Vol.Meter} \times Vol_{Batch})^2}$~~

~~$U_{SYSTEM}[\%] = \frac{U_{SYTEM}[lts]}{Vol_{Initial\ Interface} + Vol_{Final\ Interface} + Vol_{Batch}}$~~

The contribution of ~~I~~interfaces can be analyzed as shown in Table A.3:

% Interface / Total Volume	Uncertainty (Meter + Interface)	Uncertainty (Meter + Interface) / Uncertainty Vol. Meter

0.5 %	0.181 %	100 %
1.0 %	0.181 %	100 %
1.5 %	0.182 %	100 %
2.0 %	0.183 %	100 %
2.5 %	0.184 %	101 %
3.0 %	0.186 %	102 %
3.5 %	0.189 %	104 %
4.0 %	**0.192 %**	105 %
5.5 %	**0.203 %**	112 %
6.5 %	**0.213 %**	117 %
7.5 %	**0.224 %**	123 %
8.5 %	**0.236 %**	130 %
9.5 %	**0.249 %**	137 %
10.0 %	**0.256 %**	141 %

Table A.3 – Example Effects of Interfaces on Total Batch Uncertainty

Therefore, we accept that when the Interface represents 4 % or more of the total volume transferred, its measurement uncertainty will be considered to "justify" possible deviations in the tolerances per batch, since from said value, its contribution begins to be significant (the system uncertainty varies by approximately 5 %). The same does not happen in the m~~M~~onthly ~~T~~tolerance where it is negligible regardless of its contribution.

A.1.2 Tolerances

A.1.2.7 Batch Tolerance

Batch tolerance is the tolerance calculated from the different uncertainties present in the product quantification within the different measurement elements composing the entire system.

~~Uncertainty of a volumetric meter in a pipeline system: ± 0.181 %~~

Depending on the number of measurement systems that can intervene in the transfer, we obtain the uncertainty and therefore the tolerance per batch for each section and for the entire system.

It should be considered that these values correspond to the ~~worst case~~worst-case condition (considering for a batch, that all inputs and outputs contribute to the uncertainty of the system) which can be optimized (considering for a batch only the inputs and outputs that intervened in it, with which it would be variable and its monitoring therefore much more complex). See Equation A.~~10~~12.

$$Tolerance_{Batch} = U_{System} = \pm\sqrt{\sum_{i=1}^{n} U_i^2}$$

(A.~~10~~12)

~~$$Tolerance_{Batch} = U_{System} = \pm\sqrt{\sum_{i=1}^{n} U_i^2}$$~~

Where,

i ~~i~~ corresponds to each measurement system that affects the entire pipeline (whether it delivers or receives product).

Considering the measurement of interfaces in the pipelines, when these represent a percentage equal or greater than 4 % of the total volume transferred, the tolerance limits ~~will~~can be extended according with Table A.1.

A tolerance per batch is appropriate because:

- Only with punctual control of each batch it will be possible to continuously improve the quality of the measurements. A monthly limit would only allow us to take corrective action after one month of the occurrence. On the other hand, it may happen that in a month the balance has been closed correctly and yet it has operated inefficiently.
- A process is under statistical control if its statistical control limits at 95 % confidence (2σ) are within the tolerances established for the process (in this case for each batch).

A.1.2.8 Monthly Tolerance

It is calculated from the tolerance per batch and the number of monthly transfers of a product (number of batches for that product), among the Operational Units considered, with a confidence level of 95 % for the interval.

As in our case we work with a Monthly Accumulated Balance, the differences that are recorded in the measurement of a batch should be canceled (that is, a positive or negative trend would highlight the presence of a systematic error in the system), we adopt Equation A.~~11~~13:

$$Tolerance_{Monthly} = \frac{Tolerance_{Batch}}{\sqrt{n}}$$

(A.~~11~~13)

~~$Tolerance_{Monthly} = \frac{Tolerance_{Batch}}{\sqrt{n}}$~~

W~~W~~here,

n ~~n~~ is the number of batches transferred during the month.

A.1.3 Example

Given the pipeline system as pictured in Figure A.2 and its corresponding balance for the last 16 batches, provided in Table A.4, the tolerance can be determined. The uncertainty of the measurement system for unit 1, unit 2 and unit 3 are all as describe in examples above. For this example, the uncertainty of one metering unit is ~~consider~~considered to be ±0.182 %.

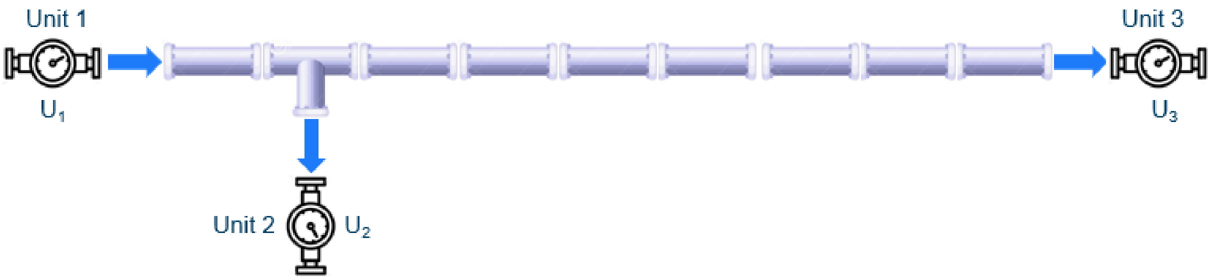


Figure A.2—Example of a pipeline with two delivery points

BATCH	UNIT 1	UNIT 2	UNIT 3	Difference	Diff %	Accumulated Volume
1	3,997,580	0	3,999,437	1,857	0.046 %	1,857
2	6,000,650	0	6,003,757	3,107	0.052 %	4,964
3	3,998,920	3,992,279	0	-6,641	-0.166 %	-1,677
4	4,000,300	0	4,005,035	4,735	0.118 %	3,058
5	3,997,060	0	3,970,952	-26,108	-0.653 %	-23,050
6	6,005,170	0	6,026,551	21,381	0.356 %	-1,669
7	12,000,380	1,988,940	10,006,462	-4,978	-0.041 %	-6,647
8	2,000,530	0	2,007,682	7,152	0.358 %	505
9	10,007,770	0	10,001,597	-6,173	-0.062 %	-5,668
10	6,505,820	0	6,531,327	25,507	0.392 %	19,839
11	8,500,160	0	8,469,007	-31,153	-0.366 %	-11,314
12	5,199,810	0	5,201,293	1,483	0.029 %	-9,831
13	3,999,590	0	4,010,229	10,639	0.266 %	808
14	10,000,030	0	9,993,969	-6,061	-0.061 %	-5,253
15	12,992,150	4,989,810	8,005,208	2,868	0.022 %	-2,385
16	4,999,780	0	5,003,664	3,884	0.078 %	1,499
TOTAL	**104,205,700**	**10,971,029**	**93,236,170**	**1,499**	**0.001 %**	

Table A.4 – Example of Balance in a Pipeline System

1. Determine the Tolerance for one batch using Equation A.~~12~~14:

$$Tolerance_{Batch} = U_{System} = \pm\sqrt{\sum_{i-1}^{n} U_i^2} = \pm\sqrt{U_1^2 + U_2^2 + U_3^2}$$

(A.~~12~~14)

~~$Tolerance_{Batch} = U_{System} = \pm\sqrt{\sum_{i=1}^{n} U_i^2} = \pm\sqrt{U_1^2 + U_2^2 + U_3^2}$~~

Since the three systems are considered to be similarly designed:

$$U_1 = U_2 = U_3 = \pm 0.181\%$$

$$Tolerance_{Batch} = U_{System} = \pm\sqrt{0.181\%^2 + 0.181\%^2 + 0.181\%^2}$$ ~~$U_1 = U_2 = U_3 = \pm 0.181\%$~~

~~$Tolerance_{Batch} = U_{system} = \pm\sqrt{0.181\%^2 + 0.181\%^2 + 0.181\%^2}$~~

$Tolerance_{Batch} = U_{System} = \pm 0.314\%$ ~~$Tolerance_{Batch} = U_{system} = \pm 0.314\%$~~

2. Determine the Tolerance for the period analyzed using Equation A.15:

$$Tolerance_{Period} = \frac{Tolerance_{Batch}}{\sqrt{n}} \tag{A.15}$$

~~$Tolerance_{Period} = \frac{Tolerance_{Batch}}{\sqrt{n}}$~~

$Tolerance_{Period} = \pm\frac{0.314\%}{\sqrt{16}} = \pm\frac{0.314\%}{4} = \pm 0.078\%$ ~~13~~

~~$Tolerance_{Period} = \pm\frac{0.314\%}{\sqrt{16}} = \pm\frac{0.314\%}{4} = \pm 0.078\%$~~

3. The next step is to detect the outliers, by applying the tolerances determined in previous step. This is done by applying the batch tolerance to each batch, and the system tolerance to the final volume accumulated.

BATCH	UNIT 1	UNIT 2	UNIT 3	Difference	Diff %	Tolerance	Accumulated Volume
1	3,997,580	0	3,999,437	1,857	0.046%	Inside	1,857
2	6,000,650	0	6,003,757	3,107	0.052%	Inside	4,964
3	3,998,920	3,992,279	0	-6,641	-0.166%	Inside	-1,677
4	4,000,300	0	4,005,035	4,735	0.118%	Inside	3,058
5	3,997,060	0	3,970,952	-26,108	-0.653%	Outside	-23,050
6	6,005,170	0	6,026,551	21,381	0.356%	Outside	-1,669
7	12,000,380	1,988,940	10,006,462	-4,978	-0.041%	Inside	-6,647
8	2,000,530	0	2,007,682	7,152	0.358%	Outside	505
9	10,007,770	0	10,001,597	-6,173	-0.062%	Inside	-5,668
10	6,505,820	0	6,531,327	25,507	0.392%	Outside	19,839
11	8,500,160	0	8,469,007	-31,153	-0.366%	Outside	-11,314
12	5,199,810	0	5,201,293	1,483	0.029%	Inside	-9,831
13	3,999,590	0	4,010,229	10,639	0.266%	Inside	808
14	10,000,030	0	9,993,969	-6,061	-0.061%	Inside	-5,253
15	12,992,150	4,989,810	8,005,208	2,868	0.022%	Inside	-2,385
16	4,999,780	0	5,003,664	3,884	0.078%	Inside	1,499
TOTAL	**104,205,700**	**10,971,029**	**93,236,170**	**1,499**	**0.001%**	**Inside**	

Table A.5 – Example of Determination of Outliers in a Pipeline System

In this example, the totals at the bottom of the Table A.5 show that the system is within the tolerance determined (0.001 % vs ±0.078 %).

In case, as the system is out of tolerance, an investigation with the out of tolerance batches should be initiated.

In the other scenario, when the system is within tolerance, there may be several batches out of the control limits, which may be investigated. It is possible to assume that those batches that are out of the limits, it is because of poor density cut process.

A.1.4 Frequency of revision of the study

It is advisable to conduct a review of the study in any of the following conditions:

- Changes in Measurement Instruments (other characteristics or technologies).
- Changes in the densities of the products that may affect the interfaces.

A.2 Statistical Calculations of a System

A.2.1 Calculating Standard Deviation

The normality assumption means that the collected data follows a normal distribution. Before applying these calculations, the population of data should agree with the normal distribution. But the periodic calculations of system L/G are more likely the result of biases of the measurements than normal random error. Despite this issue, considering system L/G as normal distributed is the best approach available.

To determine Standard Deviation, refer to API *MPMS* Chapter 13.3 Annex E. The general standard deviation equation is defined in Equation A.164:

$$s^2 = \sum_{i=1}^{n} \frac{(x_i-\bar{x})^2}{n-1} \tag{A.164}$$

For example:

Month	**L/G, %**	x_i	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
1	0.12	0.12	0.002	0.000004
2	0.15	0.15	0.032	0.001024
3	0.11	0.11	–0.008	0.000064
4	0.08	0.08	–0.038	0.001444
5	0.13	0.13	0.012	0.000144
Sum		0.59		0.002680

$$\bar{x} = \frac{0.59}{5} = 0.118$$

$$s = \pm\sqrt{\left(\frac{0.00268}{4}\right)} = \pm 0.026$$

Table A.6 – Sample Calculation of Mean and Standard Deviation

A.2.2 Standard Deviation Method to set Upper and Lower Control Limits

A.2.2.1 General

Refer to the section above to calculate the standard deviation.

The next calculations are an example of how to determine an upper/lower control limit for a L/G data series. For the next example, it was decided to use the year 1 information to determine the control limits, and then, apply these new limits to year 2 information.

Month	L/G (Year 1)	L/G (Year 2)
January	-0.006 %	0.017 %
February	-0.019 %	-0.010 %
March	0.017 %	0.007 %
April	-0.013 %	0.001 %
May	0.011 %	0.000 %
June	-0.008 %	0.005 %
July	0.015 %	0.037 %
August	0.022 %	-0.011 %
September	-0.019 %	0.004 %
October	-0.011 %	0.003 %
November	-0.015 %	-0.006 %
December	-0.012 %	0.003 %

$$s = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1}} = \pm 0.015\%$$

Table A.7 – Sample Calculation of Estimated Standard Deviation

Once the standard deviation has been determined, the action and warning limits can be set based on multiples of this deviation.

$$UCL = 3 \times s = +0.045\%$$

$$LCL = -3 \times s = -0.045\%$$

$$UCW = 2 \times s = +0.030\%$$

$$LCW = -2 \times s = -0.030\%$$

In the Figure A.3 below, action limits (red lines) and warning limits (yellow lines) are shown:

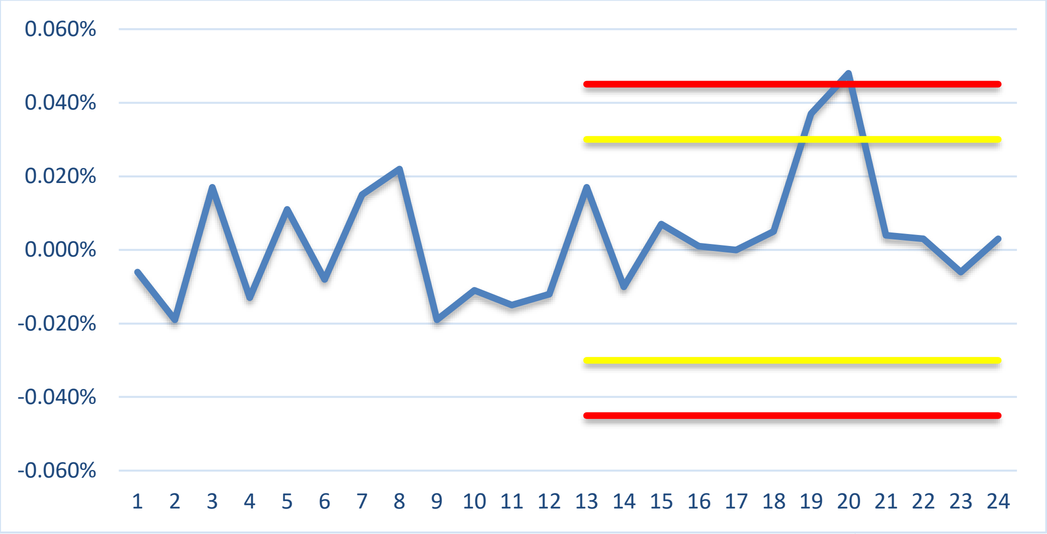


Figure A.3

Year 1 information is considered to be representative of the L/G process.

Based on the year 1 information, limits are determined to control future differences. From year 2 and forward, the months that are out of the control limits should be investigated.

A.2.2.2 Correlation Coefficient

The strength of the correlation between two variables can be measured statistically with the correlation coefficient calculated per the Equation A.17~~5~~:

$$Correl(X,Y)=\frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \qquad \text{(A.17~~5~~)}$$

Where,

$\bar{x}$ and $\bar{y}$ are the sample means AVERAGE (array 1) and AVERAGE (array 2).

Correlations range from −1 to +1. Numeric values close to the end points indicate strong negative or positive correlation and values close to 0 indicate weak or no correlation.

A correlation can sometimes be found between the volume throughput in a tank farm vs L/G for the tank farm or between gains or losses and the monthly throughput on a pipeline segment (see Table A.8 and Figure A.3).

Month	**Pipeline Throughput X**	**Monthly L/G Y**
1	25,300	−755
2	45,300	−445
3	25,200	−141
4	117,050	−142

5	95,000	−24
6	104,600	−166
7	323,200	250
Correl(X,Y) = (X1:X7,Y1:Y7) = 0.77		

Table A.8 – Example of Calculation of a Correlation Coefficient

This example would be considered a moderate positive correlation.

NOTE When reporting correlation, it is important to indicate positive or negative, whichever is the case.

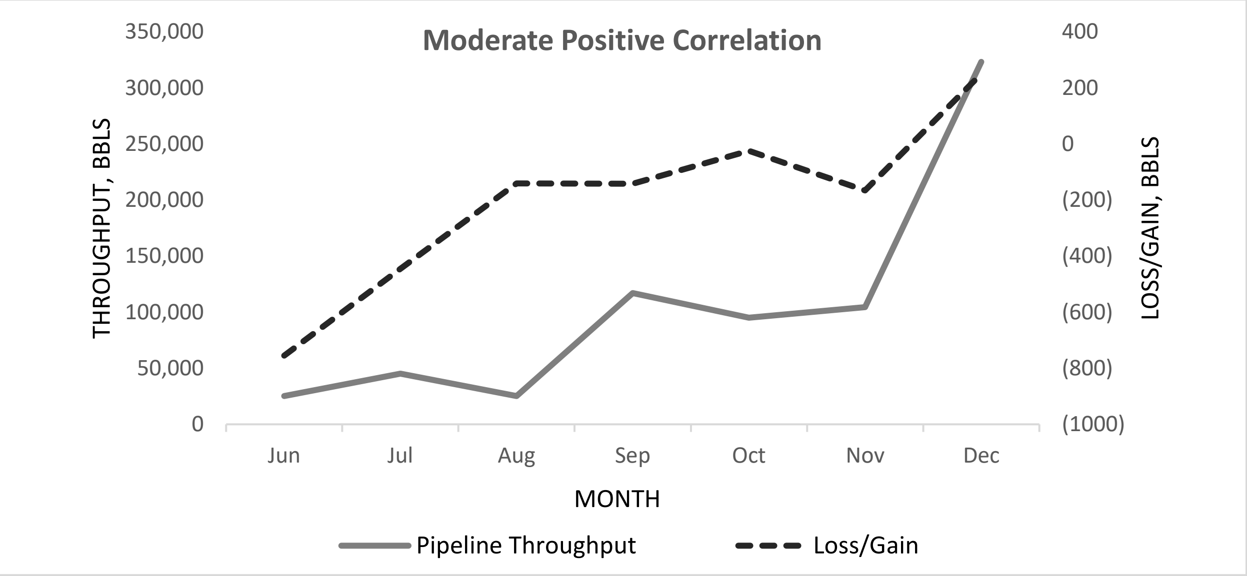


Figure A.4 – Example of Correlation Between Two Data Sets

A.3 Least Squares Method for Calculating Linear Regression Lines

A linear regression line is a straight line that represents the "best fit" of a straight line to the data and takes the form of Equation A.18:

$$Y = a + bX$$

(A.1~~6~~8)

Where,

Y is the dependent variable, e.g., L/G;

X is the independent variable, e.g., time period (month, etc.);

a and *b* are constants derived from the data by the Least Squares Method and apply only to that data set.

The Least Squares Method is a statistically derived pair of equations for determining the values of the constants *a* and *b*. The equations are as follows in Equations A.19 and A.20:

$$b = [\Sigma xy - n(X_b)(Y_b)]/[\Sigma X^2 - n(X_b)^2] \qquad (A.19)$$

$$a = (Y_b) - b(X_b) \tag{A.20}$$

Where,

X_b and Y_b	are the means (i.e. arithmetic averages) of all the X values and all the Y values in the data set;
X_b and Y_b	are read as “X bar” and “Y bar” and are commonly written with a small horizontal bar over the “X” and the “Y” instead of the subscript “b.” The subscript form is used when the bars could be lost in typing and/or editing.

Use of the Least Squares Method is most easily illustrated with an example of a system with a leak shown in Figure A.5.

The data before the loss, which in this example occurred about the seventh month, are used to develop a regression line which represents the typical behavior of the curve before the leak. The regression line is used to project what the system *L*/*G* would have been if the leak had not happened. In this example the leak was found and repaired in the eleventh month, and the accumulated loss by that time is 790 barrels. If no liquid had been physically lost, the projected cumulative *L*/*G* would have been 640 barrels as estimated from the projected regression line. The difference of 150 barrels is the estimated loss due to the leak.

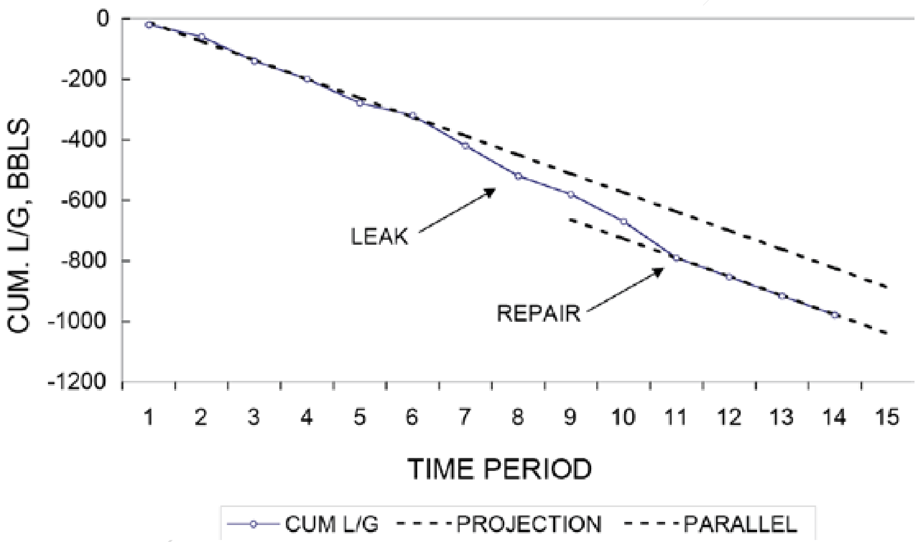


Figure A.5 – System with a leak

Using the data from the first six data points of Figure A.5, the calculations are as shown in the following Table A.9.

X (Month)	**Y (Cum. L/G)**	**X^2**	**XY**
1	–20	1	–20
2	–60	4	–120
3	–140	9	–420
4	–200	16	–800
5	–280	25	–1400
6	–320	36	–1920
$\sum X = 21$	$\sum Y = -1020$	$\sum X^2 = 91$	$\sum XY = -4680$

$n = 6$
$(X_b) = \sum X/n = 21/6 = 3.5$
$(Y_b) = -1020/6 = -170$
$b = [\sum XY - n(X_b)(Y_b)]/[\sum X^2 - n(X_b)^2]$
$= [-4680 - (6)(3.5)(-170)]/[91 - (6)(3.5)^2]$
$= -63.4$
$a = (Y_b) - b(X_b) = -170 - (-63.4)(3.5) = 51.9$
Thus, Cum. L/G = 51.9 – (63.4×Month). This equation was used to calculate the values for the projection line plotted in Figure A.4.

Table A.9

~~NOTE~~ All values shall be numerical. For example, months shall be 1, 2, 3, etc., not January, February, March, etc.

Annex B
(informative)

Interpreting Control Charts

B.1 Various States of Process

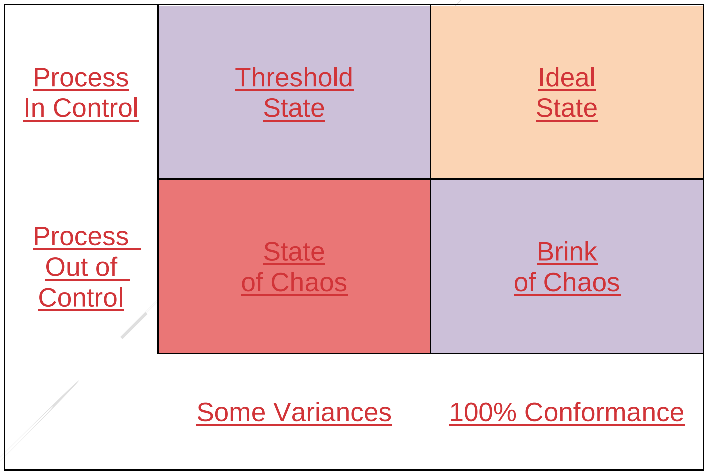
B.1.1 Processes fall into one of four states: 1) the ideal, 2) the threshold, 3) the brink of chaos and 4) the state of chaos (Table B.1).

When a process is at its "Ideal State," it is statistically controlled and produces 100 percent conformance. Over time, the process has demonstrated stability and target performance. This process is predictable, and the results are as expected.

The "Threshold State" is defined as a process that is statistically controlled but nevertheless produces occasional changes. This procedure produces a consistent degree of variations and has limited capabilities. This process, while predictable, does not always satisfy expectations.

The state of "Brink of Chaos" denotes a process that is out of statistical control but not beyond tolerance. To put it another way, the process is unexpected, yet the results nevertheless fulfill expectations. The absence of variations gives the illusion of security, but such a process can develop variances at any time. It's only a matter of time before it happens.

The "State of Chaos" is the fourth process state. The process is not statistically controlled in this case, resulting in unpredictably high amounts of volatility.



Process In Control	Threshold State	Ideal State
Process Out of Control	State of Chaos	Brink of Chaos
	Some Variances	100% Conformance

Table B.1—Four Process States

Every process will at some point fall into one of these stages, but it will not stay there. All procedures will eventually devolve into chaos. When a process reaches a level of chaos, companies usually start working on improving it (although they would be better served to initiate improvement plans at the brink of chaos or threshold state). Control charts are a reliable and useful tool to utilize as part of a strategy to detect the degradation of a natural process.

B.1.1 Control charts are the way an L/G system communicates, so it is important to know how to interpret control charts. Control charts are a statistical process control tool used to determine if a process is in a state of control. If an L/G system is in statistical control, most of the data points will be near the centerline, some may be close to the control limits and no points will be beyond the control limits. It is acknowledged that pipeline systems would be expected to follow a log-normal distribution rather than a normal distribution, however the 8 control chart rules listed in Table B.2 and further in section

B.2 of this Annex B may provide indications that there are special-cause variations present. These rules can distinguish between a shift and a pattern. Within the rules, where σ = standard deviation,

- Zone A is between 2σ and 3σ (normally occurs 4.3 % of the time)
- Zone B is between 1σ and 2σ (normally occurs 27.2 % of the time)
- Zone C is between the centerline and 1σ (normally occurs 68.3 % of the time)

Rule	**Rule Name**	**Shift/Pattern**
1	Beyond Limits	One or more points beyond the control limits
2	Zone A	2 out of 3 consecutive points in Zone A or beyond
3	Zone B	4 out of 5 consecutive points in Zone B or beyond
4	Zone C	7 or more consecutive points on one side of the centerline (in Zone C or beyond)
5	Trend	7 consecutive points trending up or trending down
6	Mixture	8 consecutive points with no points in Zone C
7	Stratification	15 consecutive points in Zone C
8	Over-control	14 consecutive points alternating up and down

Table B.2—Control Chart Rules

B.1.2 These control chart rules represent different situations resulting in different types of patterns. Table B.3 summarizes the rules by the type of pattern.

Pattern Description	**Rules**
Large shifts from the average	1, 2
Small shifts from the average	3, 4
Trends	5
Mixtures	6
Stratification	7
Over-control	8

Table B.3—Control Chart Rules by Pattern Type

The value of a control chart is in its capacity to distinguish between common-cause variations and special-cause variations.

Common-cause variations are characterized by:

- Consistent over time
- Phenomena constantly active within the system
- Variation expected probabilistically

- Irregular variation within a historical experience base; and
- Lack of importance in individual high or low values

Common-cause variations are the noise within the system.

Special-cause variations are characterized by:

- Not Consistent over time
- New, unanticipated, developing or previously neglected phenomena within the system
- Variation inherently unpredictable, even by chance
- Variation outside the historical experience base; and
- Evidence of some inherent change in the system or our knowledge of it

Special-cause variations almost always arrive as a surprise. It is a signal that there is an issue.

A special-cause variation is a variation that may be corrected by changing a component or process, whereas a common-cause variation is equivalent to noise in the system and specific actions cannot be made to prevent the variation.

B.2 Control Chart Rules

B.2.1 Rule 1 (One or more data points beyond the control limits) states that any data point that falls outside the control limits may be the result of a special cause (e.g., equipment failure, procedural error, etc.) and should be investigated immediately to determine the cause. Signals from rule 1 takes top priority and the other rules will provide little additional information. Special causes often lead to correction tickets and should be investigated as soon as possible before memories fade, the data becomes dated, and the investigation becomes more difficult. Figure B.1 depicts two points that meet rule 1.

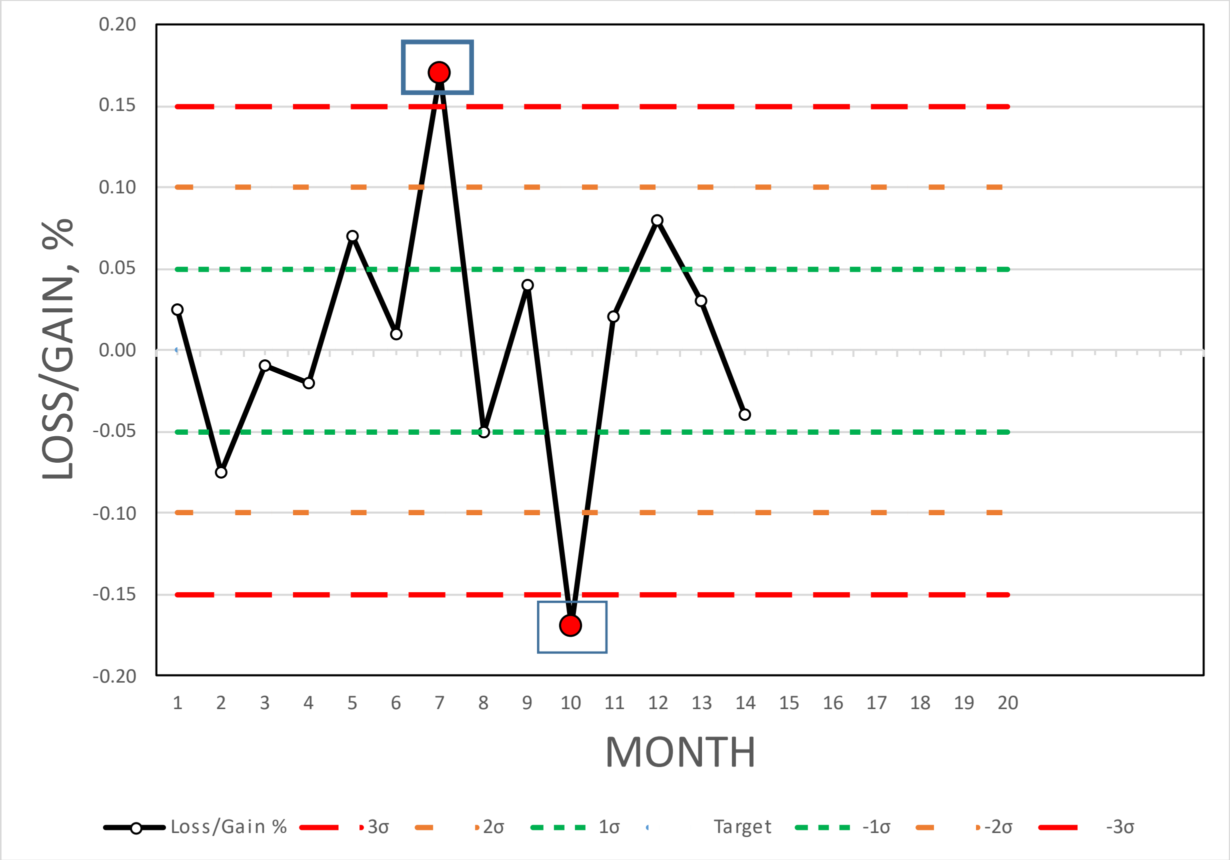


Figure B.1 – Rule 1 – One or more data points beyond the control limits

B.2.2 Rule 2 (Zone A test - 2 out of 3 consecutive points in Zone A or beyond) represents sudden, large shifts from the average as shown in Figure B.2. This rule is applied on the same side of the centerline. The mismeasurement of inventory could cause the shifts. Like rule 1, these shifts are often one-time occurrences of a special cause – like travel time increase due to having a flat tire when driving to work.

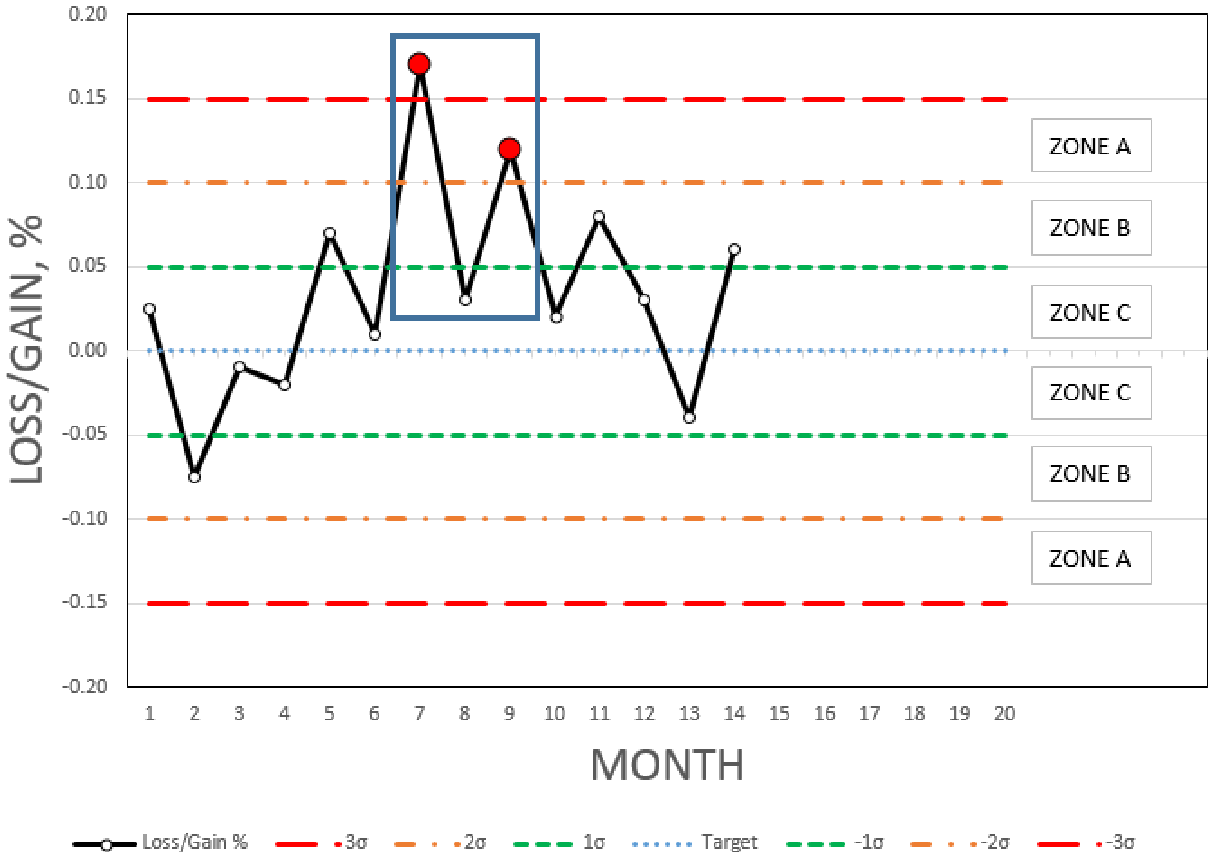


Figure B.2 – Rule 2 – Zone A test – 2 out of 3 consecutive points in Zone A or beyond

B.2.3 Rule 3 (Zone B test - 4 out of 5 consecutive points in Zone B or beyond) represents smaller shifts that are sustained over time which is depicted in Figure 6.- Like rule 2, this rule is applied on the same side of the centerline.– The key is that the shifts are sustained over times longer than the time frames of Rules 1 and 2.

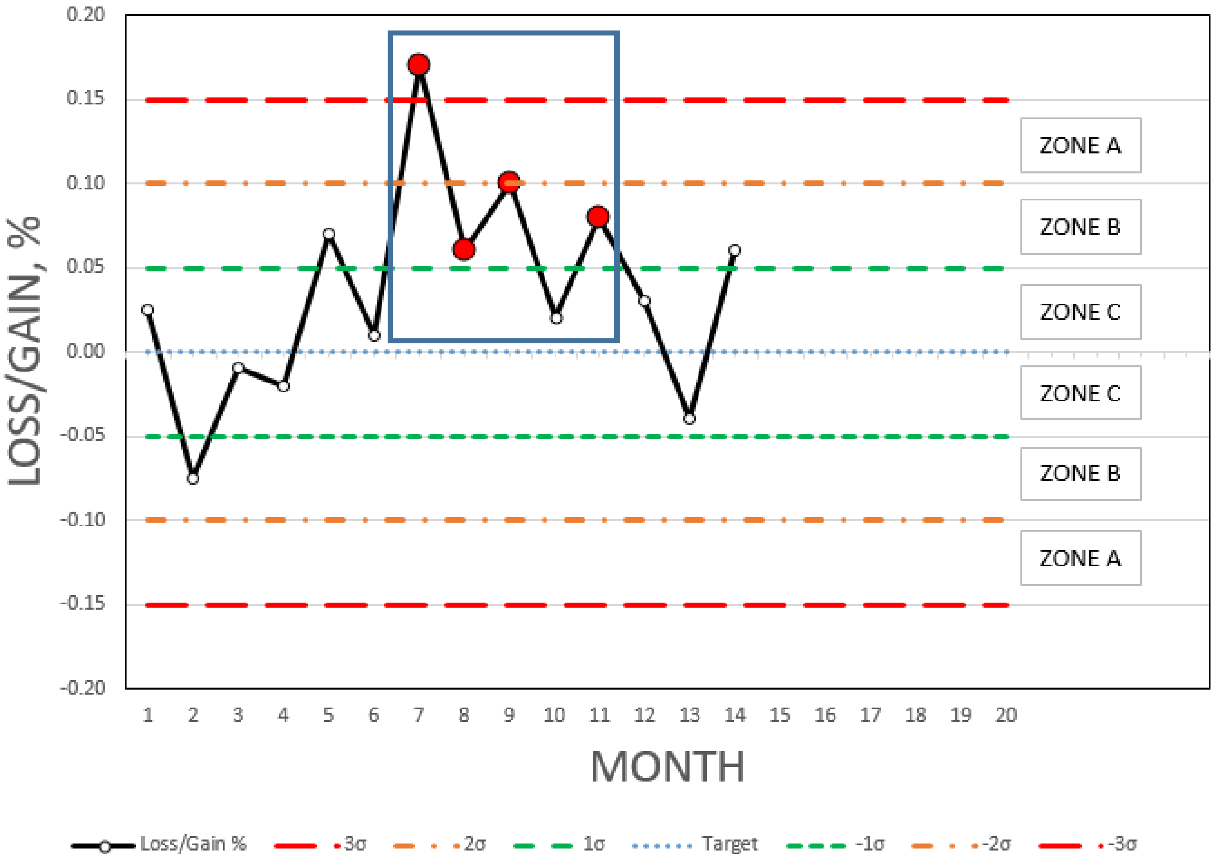


Figure B.3 – Rule 3 – Zone B test – 4 out of 5 consecutive points in Zone B or beyond

B.2.4 Rule 4 (Zone C test - 7 or more consecutive points on one side of the centerline (in Zone C or beyond)) indicates that some prolonged bias exists as seen in Figure B.4. –A change in base prover volume could cause this shift in performance. –The key is that the shifts are sustained over times longer than the time frames of Rules 1 and 2.

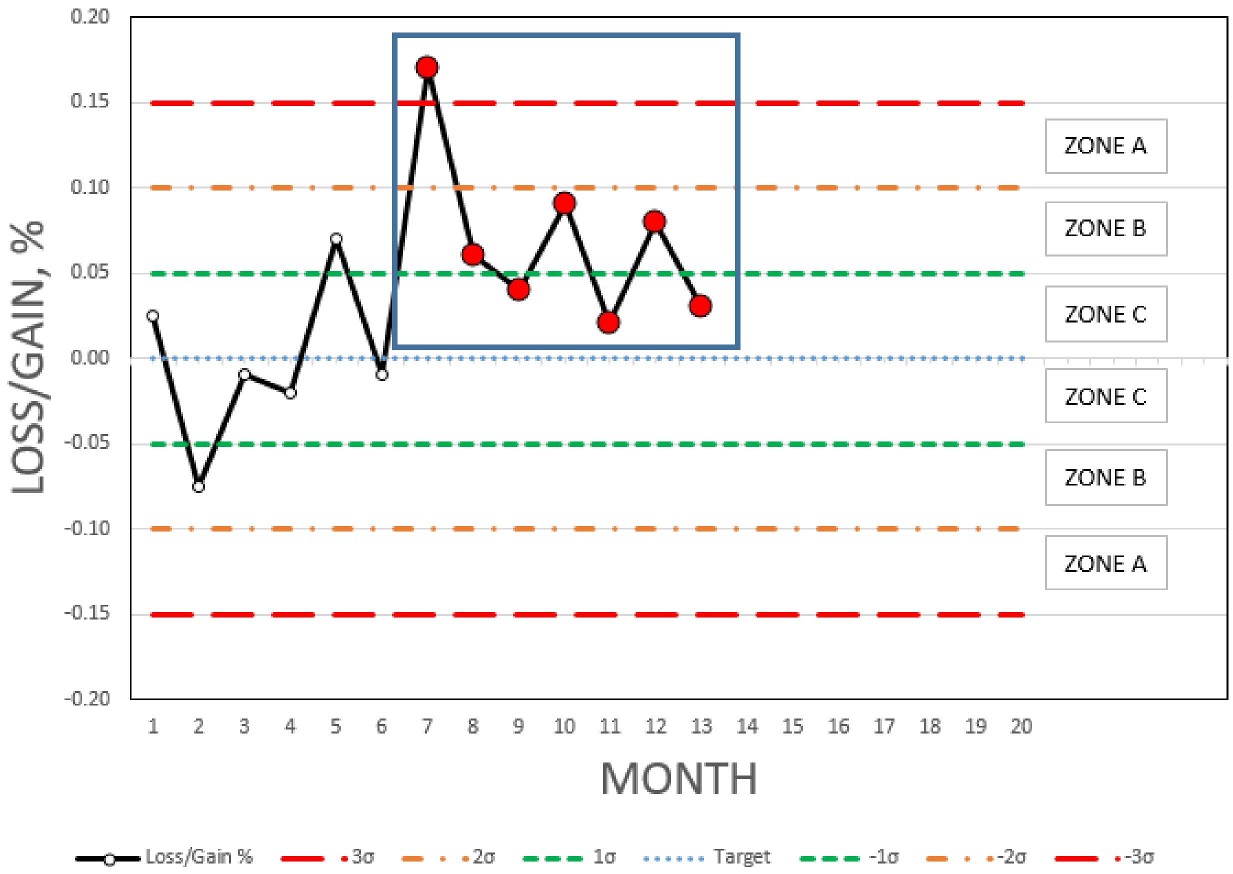


Figure B.4 – Rule 4 – Zone C test – 7 or more consecutive points on one side of the centerline (in Zone C or beyond)

B.2.5 Rule 5 (Trend - 7 consecutive points trending up or trending down) represents a process that is trending in one direction. Neither the zones nor the centerline comes into play for this test. For example, meter wear could cause this type of trend. Seven consecutive points trending in one direction (up or down) indicate a loss of control. For some systems, even fewer points in a row may be significant warning. Examples might be leaking tanks (in which case the losses are real) or meters that are wearing badly and are not being proved often enough (which are book losses or gains). An upward trend is no better than a downward trend. Either condition is out of control. A system gain can be just as bad as a system loss. Losses and gains occur because of some deficiency in measurement. Figure B.5 illustrates two cases of rule 5.

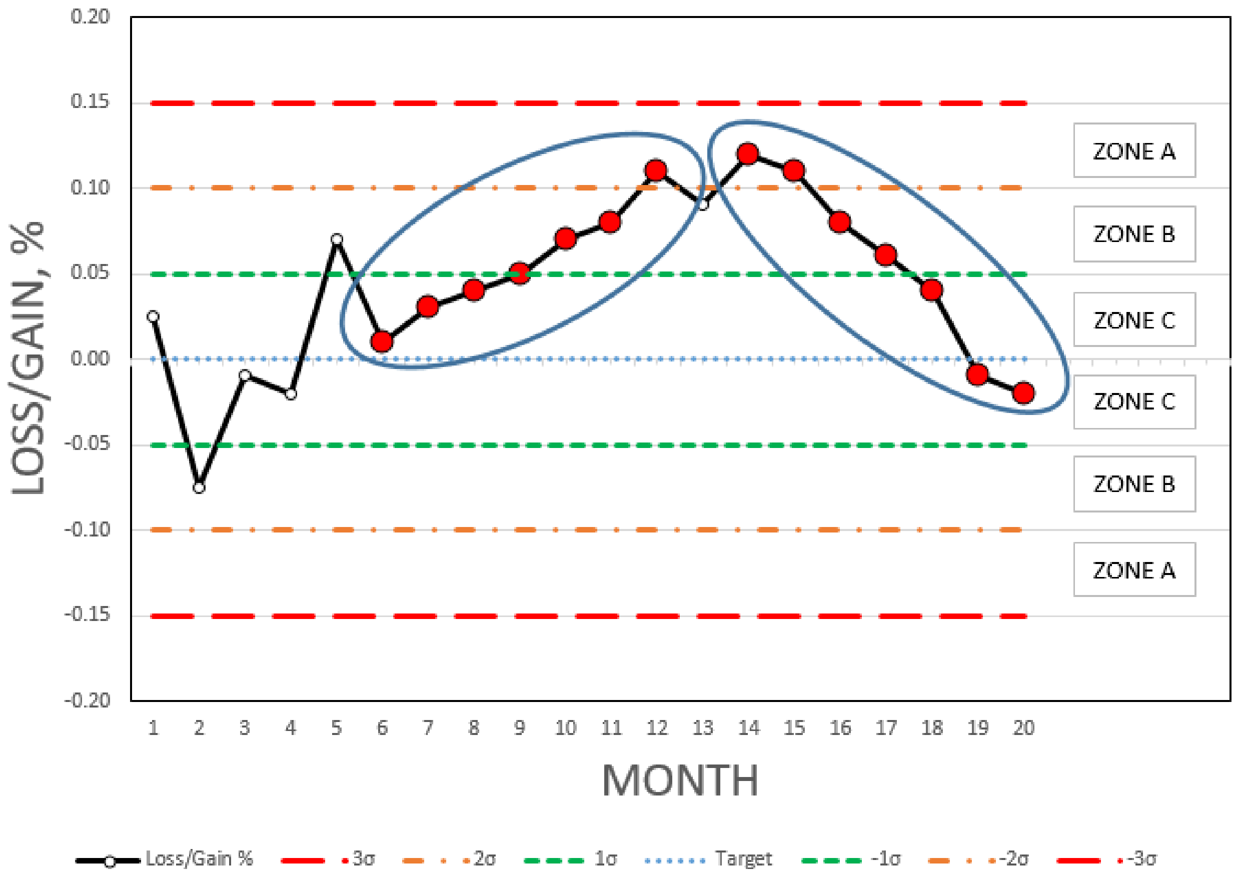


Figure B.5 – Rule 5 –Trend – 7 consecutive points trending up or trending down

B.2.6 Rule 6 (Mixture - 8 consecutive points with no points in Zone C) is the tendency to avoid the centerline. A mixture may exist when the data is from two different special causes and are plotted on a single control chart. As shown in Figure B.6, the absence of points near the centerline is identified as a mixture pattern. Jumping from above to below while missing the first standard deviation band (Zone C) is rarely random. A large change in throughput volume can cause a mixture pattern. Another example is taking data from different crews. Crew 1 operates at a different average than crew 2. The control chart could have crew 1 in zone B or beyond above the average and crew 2 in zone B below the average – with nothing in zone C. Changing average flow rate without proving may also cause a mixture pattern.

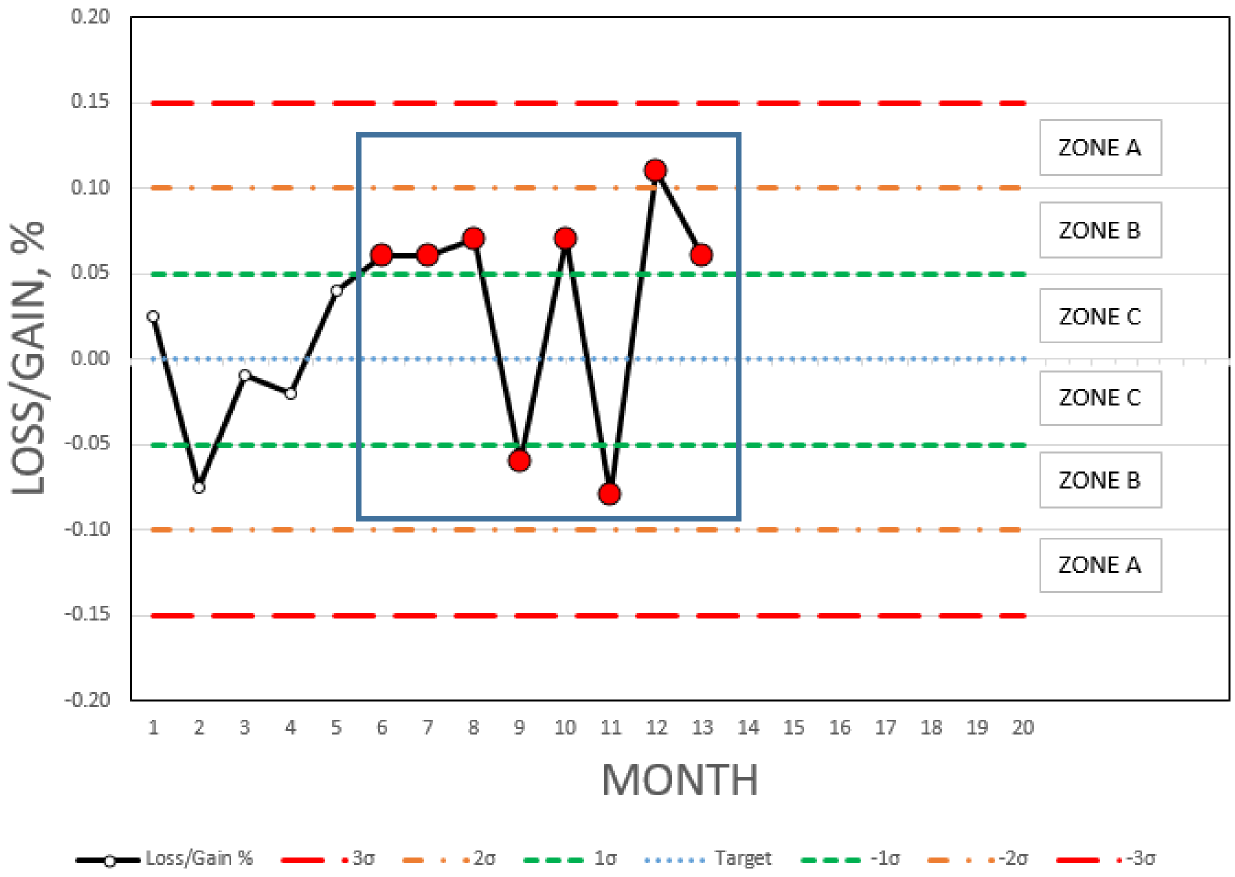


Figure B.6 – Rule 6 – Mixture – 8 consecutive points with no points in Zone C

B.2.7 Rule 7 (Stratification - 15 consecutive points in Zone C) also occurs when you have multiple processes, but you are including all the processes in a subgroup. This can lead to the data "hugging" the average – all the points in zone C with no points beyond zone C as represented in Figure 10. If possible, break the system down into smaller segments or by components (i.e., Regular and Premium versus combining them into Mogas). This stratification may also be an indication that the control limits are too wide.

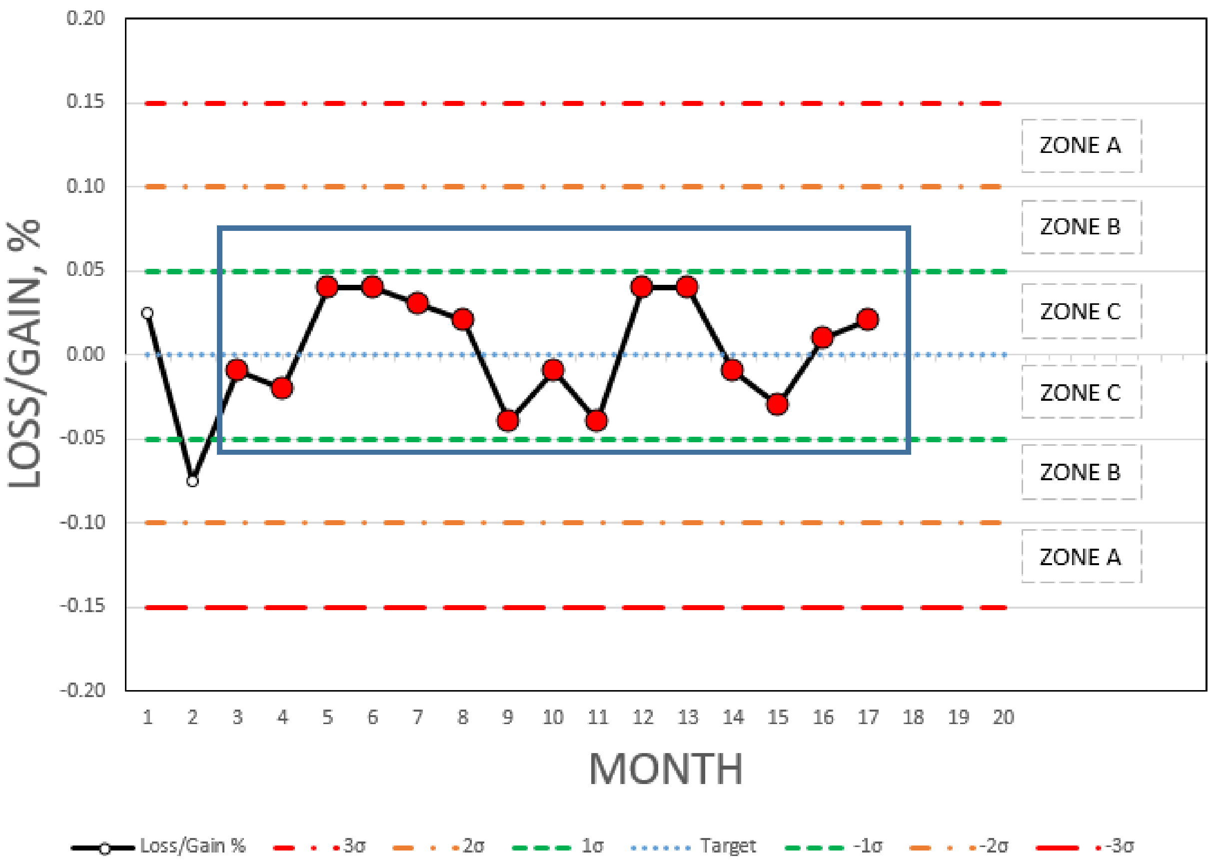


Figure B.7 – Rule 7 – Stratification – 15 consecutive points in Zone C

B.2.8 Rule 8 (Over-control - 14 consecutive points alternating up and down) is often due to over adjustment. Neither the zones nor the centerline comes into play for this test. This is often called “tampering” with the process. Adjusting a process that is in statistical control actually increases the process variation. This much oscillation is beyond noise. The rule is concerned with directionality only. The position of the centerline and the size of the standard deviation have no bearing. For example, an operator is trying to hit a certain value. If the result is above that value, the operator makes an adjustment to lower the value. If the result is below that value, the operator makes an adjustment to raise the value. Figure B.8 displays rule 8.

Figure B.8 – Rule 8 – Over-control – 14 consecutive points alternating up and down

If the data tends to swing back and forth as shown in Figure B.9, the system is cyclic. This may result in a saw-tooth pattern. If the cause of the cycles could be eliminated, the system should be able to achieve a state of better control with narrower control limits.

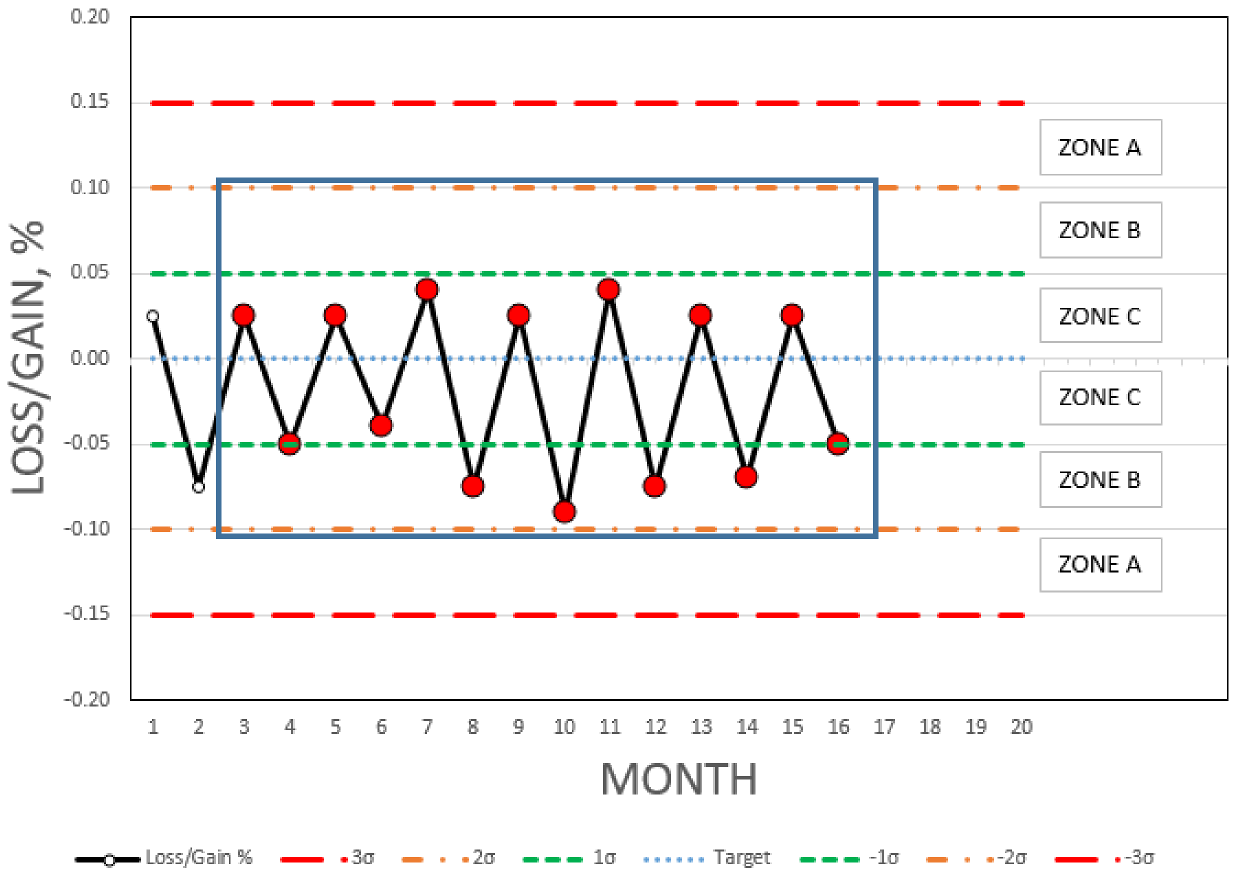


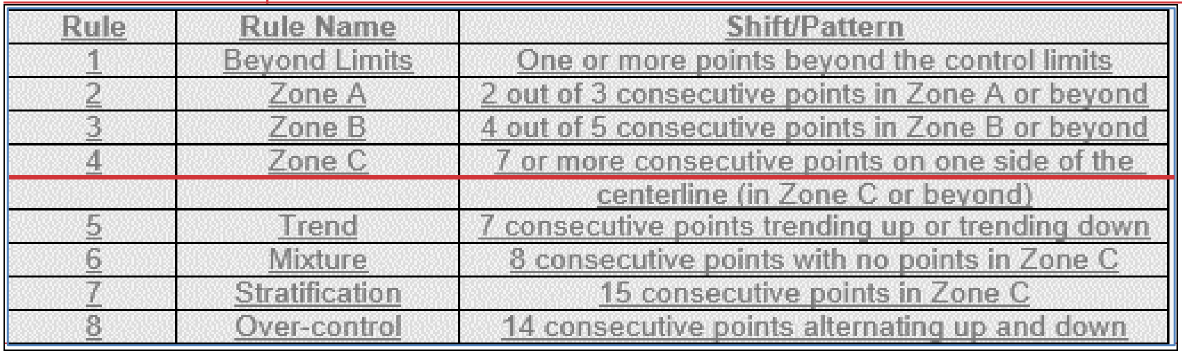
Figure B.9 – Rule 8 – Cyclic Pattern

B.2.9 It is difficult to list all possible causes for each pattern type because special causes (just like common causes) are very dependent on the type of process. Maintenance processes have different issues than procedural processes. Different types of control charts look at different sources of variation. Still, it is helpful to show some possible causes by pattern description. Table B.4 attempts to do this based on the type of pattern.

Pattern Description	**Rules**	**Possible Causes**
Large shifts from the average	1, 2	New person doing the job (training issue) Wrong setup (flow computer) Measurement error (i.e., tank gauging, blocked strainer, leaking valve, etc.) Process step skipped or not completed Power failure Equipment breakdown Line fill changes
Small shifts from the average	3, 4	Change in product properties Change in work procedure or frequency Different measurement device/calibration (new prover volume) Different crews Change in maintenance procedure Change in setup procedure Sampling and testing issues
Trends	5	Equipment wearing Temperature effects (cooling, heating)
Mixtures	6	More than one process present (e.g., shifts, crews, equipment, and measured products.) Changing average flow rate without proving Large change in throughput volume
Stratifications	7	More than one process present (e.g., shifts, crews, equipment, and measured products.) Control limits too wide
Over-control	8	Tampering by operator Alternating measured products

Table B.4 — Possible Causes by Pattern Type

Analyzing a control chart for special cause variation can be facilitated by using categories. Table B.5 lists the potential special causes to consider. When stratification is identified (Rule 7), it is generally due to one of two issues. The operators are truncating the measurements, or the process has improved significantly, which will require the recalculation of the statistical control limits.



Rule	Rule Name	Shift/Pattern
1	Beyond Limits	One or more points beyond the control limits
2	Zone A	2 out of 3 consecutive points in Zone A or beyond
3	Zone B	4 out of 5 consecutive points in Zone B or beyond
4	Zone C	7 or more consecutive points on one side of the centerline (in Zone C or beyond)
5	Trend	7 consecutive points trending up or trending down
6	Mixture	8 consecutive points with no points in Zone C
7	Stratification	15 consecutive points in Zone C
8	Over-control	14 consecutive points alternating up and down

Category	**RULE 1**	**RULE 2**	**RULE 3**	**RULE 4**	**RULE 5**	**RULE 6**	**RULE 7**	**RULE 8**
Measurement Equipment	-	-	-	-	-	-	-	-
damaged equipment	X	X	X	X	-	-	-	-
equipment failure/breakage	X	-	-	X	-	-	-	-
gradual equipment failure	-	-	-	-	X	X	-	-
sudden equipment failure	X	-	-	-	-	-	-	-
improper equipment maintenance	X	X	X	-	-	X	-	X
improper setup	X	X	X	X	-	X	-	X
improper start-up	X	-	-	-	-	-	-	-
intermittent equipment failure	-	X	-	-	-	X	-	X
equipment wear	-	-	X	X	X	X	-	-
power interruption	X	-	-	-	-	-	-	-
Operating Environment	-	-	-	-	-	-	-	-
temperature gradually drifting too low/high	-	-	-	-	X	X	-	-
pressure gradually drifting too low/high	-	-	-	-	X	X	-	-
temperature shifted too low/high	X	X	X	X	-	X	-	-
pressure shifted too low/high	X	X	X	X	-	X	-	-
temperature intermittently too low/high	-	-	-	-	-	X	-	X
pressure intermittently too low/high	-	-	-	-	-	X	-	X
Measurement Process	-	-	-	-	-	-	-	-
equipment has not stabilized	X	-	-	-	-	X	-	-
inadequate work procedures	X	-	-	-	-	X	-	X
incorrect process parameters	-	X	X	X	-	X	-	X
missed process step	X	-	-	-	-	X	-	X
new process	X	-	-	-	-	X	-	X
new process parameters	-	X	X	X	-	X	-	X
process has degraded	-	-	X	X	-	-	-	-

process has improved	_	_	X	X	_	_	_	_
process is slowly degrading	_	_	_	_	X	_	_	_
process is slowly improving	_	_	_	_	X	_	_	_
two or more processes	_	_	_	_	_	X	_	_
Inspection	_	_	_	_	_	_	_	_
damaged inspection, measuring, and testing equipment	X	X	X	X	X	X	_	X
inspection, measuring, and testing equipment not adequate for the intended use	_	X	X	_	X	X	_	X
inspection, measuring, and testing equipment not properly calibrated	X	X	X	X	_	X	_	_

Table B.5 – Potential Causes by Rule

Category	**RULE 1**	**RULE 2**	**RULE 3**	**RULE 4**	**RULE 5**	**RULE 6**	**RULE 7**	**RULE 8**
Measured Products	_	_	_	_	_	_	_	_
change in product properties	X	_	_	X	_	X	_	_
change in components	X	_	_	X	_	X	_	_
mixed product (shrinkage)	_	X	X	_	_	X	_	X
mixed components	_	X	X	_	_	X	_	X
variation in the product	_	_	_	_	X	X	_	_
variation in the components	_	_	_	_	X	X	_	_
Operator	_	_	_	_	_	_	_	_
inadequate training	X	X	X	X	X	X	_	X
multiple shifts	_	_	_	_	_	X	_	_
new operators	X	X	X	X	_	X	X	X
operator interrupted or distracted	X	X	X	X	X	X	X	_
operator not waiting for the process to stabilize before making process adjustments	_	_	_	_	_	_	X	X
operator overcompensating when making process adjustments	X	_	_	_	_	_	X	X
Shift/crew change	_	X	X	X	_	_	_	_

Table B.5 (continued) – Potential Causes by Rule

B.2.10 It is good practice to determine whether a system is stable and in control. A system is generally considered to be in control if the data are all within control limits that have been established from the data. Data points outside the control range indicate poor control. A system is said to be stable if the data exhibit only random fluctuations around the centerline without trends. Adding trend lines to the control charts may give an indication of how the L/G system is performing over time and provide additional information. Figures B.10 and B.11 are the Rule 1 and Rule 5 figures with a linear trend line.

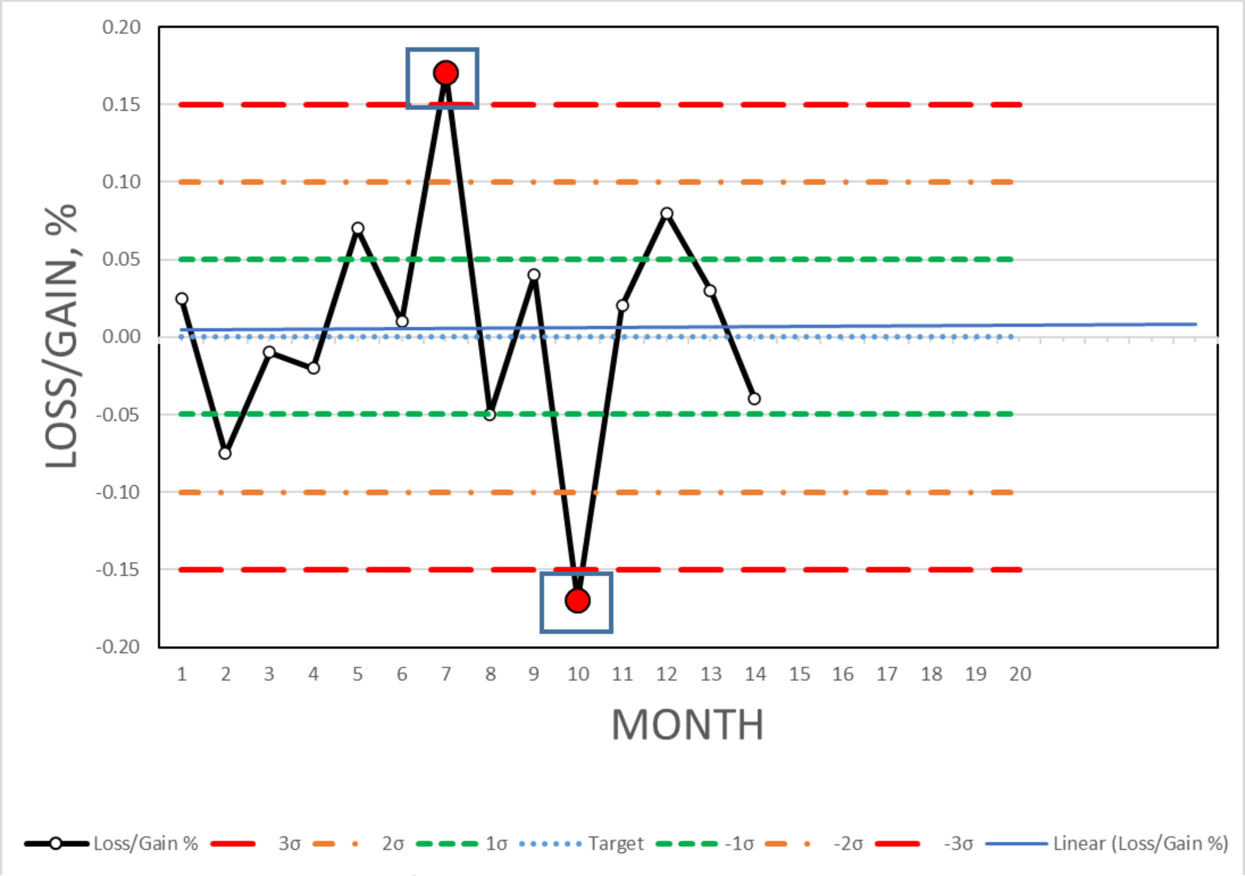


Figure B.10 – Rule 1 with Trend Line

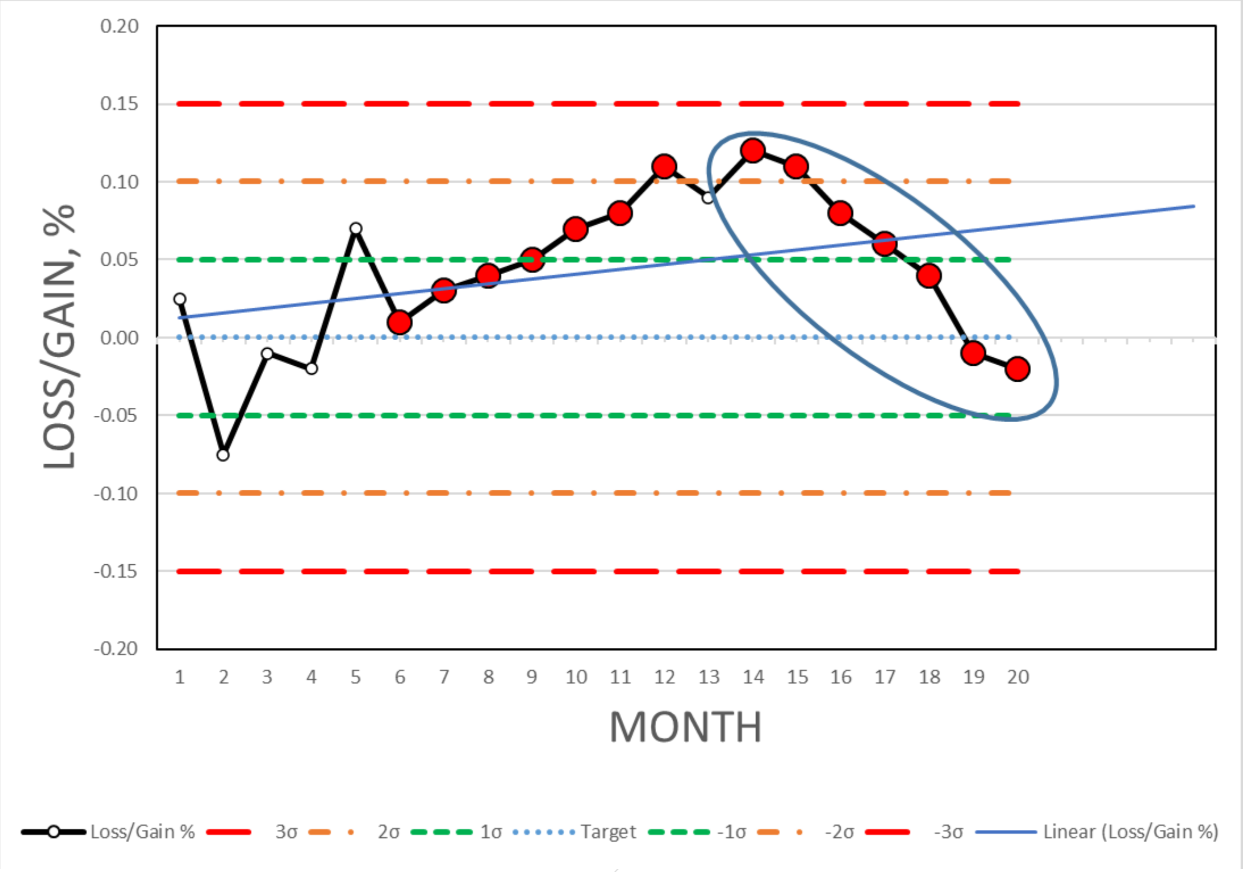


Figure B.11 – Rule 5 with Trend Line

B.2.11 A histogram can be created to depict the distribution of the zones over a time period. A histogram works best when there are at least 20 data points. If the sample size is too small, each bar on the histogram may not contain enough data points to accurately show the distribution of the data. Things to look for in histograms are:

- Skews – the majority of the data are located on one side of the histogram
- Multiple modes – more than one peak
- Outliers – data far away from the other data values
- Fit – ideally, a histogram should follow a normal distribution and look like a bell curve

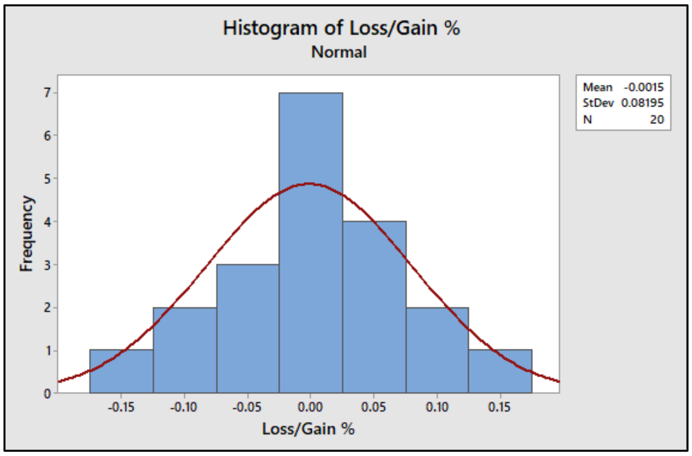


Figure B.12 - Histogram for data in Table B.6

Month	Loss/Gain %	3σ	2σ	1σ	CL	-1σ	-2σ	-3σ
1	0.03	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
2	-0.12	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
3	-0.01	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
4	-0.02	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
5	0.07	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
6	0.01	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
7	0.17	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
8	-0.05	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
9	-0.12	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
10	-0.17	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
11	0.02	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
12	0.08	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
13	0.03	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
14	-0.04	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
15	-0.08	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
16	0.01	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
17	-0.02	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
18	0.05	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
19	0.01	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15
20	0.12	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15

Table B.6 – Example data

B.2.12 An Individual and Moving Range (I-MR) chart can also be created to monitor the mean and variation of the process. The I chart is simply the control chart discussed above and the MR chart data is the absolute value of the change from one data point to the next. Control chart rules 1, 4, 5 and 8 can be applied to the MR chart. I-MR charts are useful when there are homogeneous batches and repeat measurements vary because of measurement errors.

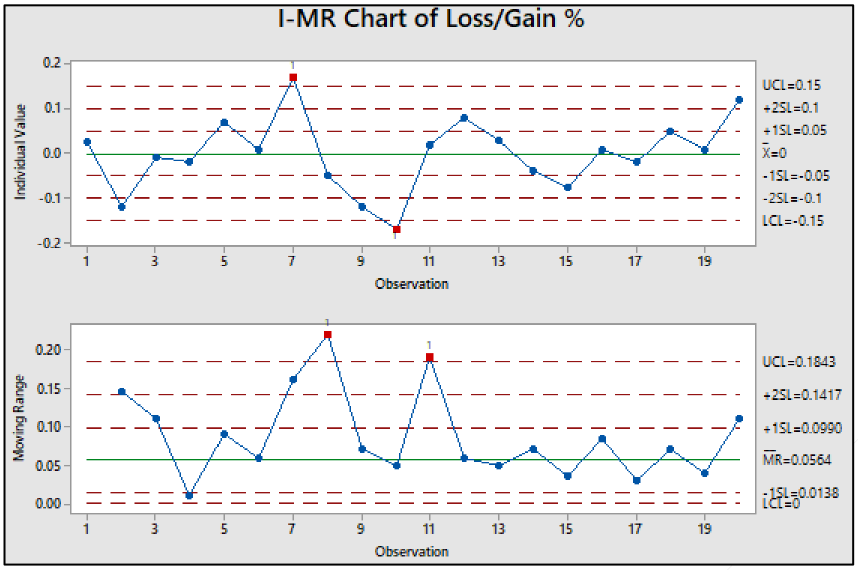


Figure B.13 – I-MR Chart Using Histogram Data

B.2.13 The performance of a system may change, positively or negatively, due to deliberate process changes, such as new equipment, improved procedures, increased/decreased maintenance frequencies or tolerances, etc. ~~Sometimes, though, a~~A system ~~will~~can change without any apparent reason. Any process change, be it deliberate or unplanned, ~~will~~may ~~usually~~ show up as a change in performance.

Whenever the data clearly shows a sustained change, the centerline and control limits should be changed accordingly as presented in Figure B.14. ~~Note that the~~The process ~~must~~should be stable before it can be centered at a target value, or its overall variation (control limits) can be reduced.

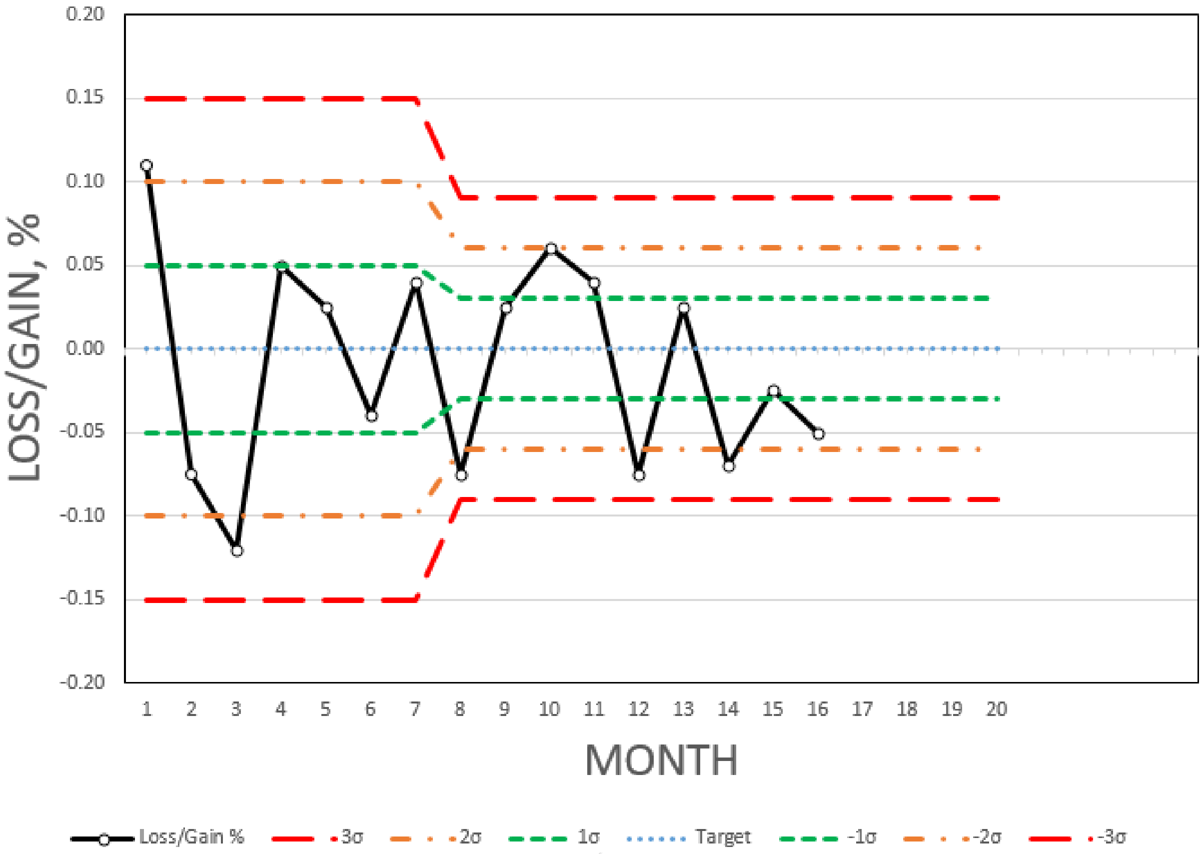


Figure B.14 – Control Chart with a Change in the Process

Caution should be taken if data suggests increasing limits or shifting the centerline as to not build in a bias, as shown in Figure B.15. Instead, the L/G system should be investigated for special causes.

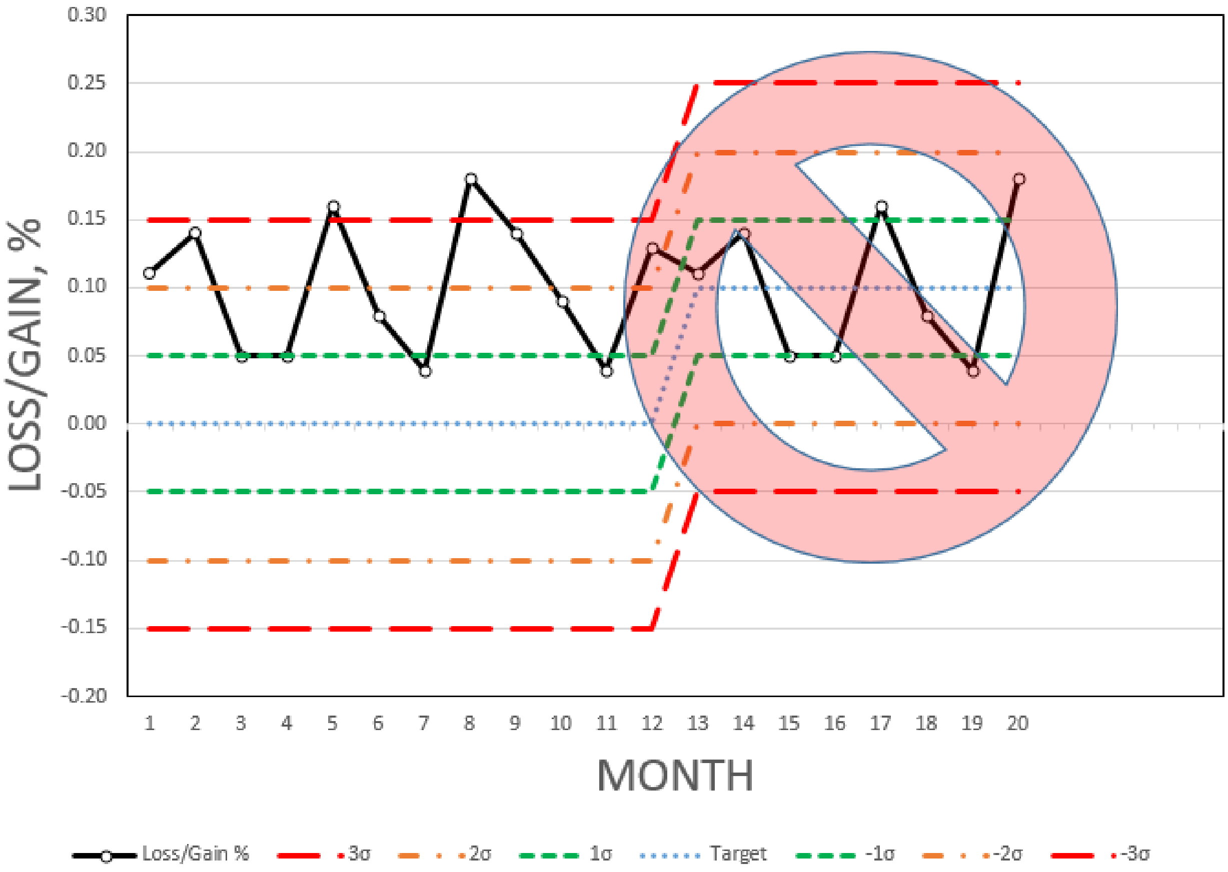


Figure B.15 – Control Limits Change with Unexplained Bias

Annex C
(informative)

Special Considerations for NGL System Balancing

While many of the procedures of determining and tracking gains and losses are the same, some of the operational practices and equipment used for NGL measurement and storage differ from standard crude oil, refined product, or petrochemical measurement.

C.1 Characteristics of NGLs

Natural Gas Liquids (NGLs) are hydrocarbons that are separated from natural gas in the form of liquids. These include ethane, propane, butanes, and natural gasoline. The proper reconciliation of pipeline quantities for NGLs is critical for accurate accounting and operational efficiency.

NGLs have unique properties that influence their measurement and reconciliation:

1. **Variable Composition**: NGLs are often a mixture of different hydrocarbons, each with its own density and vapor pressure.
2. **Temperature and Pressure Sensitivity**: NGLs can exist in both liquid and vapor phases, depending on the temperature and pressure, making accurate measurement challenging.
3. **High Volatility**: Due to their volatility, NGLs can experience significant volume changes with small variations in temperature and pressure.

NGLs present unique challenges for pipeline quantity reconciliation due to their variable composition and phase behavior. One critical aspect of accurate measurement and reconciliation is the choice between mass meters and volumetric meters.

Special care shall be taken when measuring mixed NGL streams due to a phenomenon called ‘solution-mixing error’. When metering NGL mixes in volume, especially mixes that are high in ethane content (more than 2 % to 5 % ethane), losses will occur when the smaller molecules fill the voids between larger molecules, resulting in lower volumes. When metering in mass, these properties are identified as units of mass. When the stream composition is identified, these units of mass can be converted to volume without this loss.

The amount of potential loss depends upon the stream composition. With Y-Grades that are high in ethane content, the potential for apparent loss can be substantial. With heavier component or high purity streams, when the effect of shrink is relatively insignificant the volumetric measurement is considered acceptable. With heavier component mixtures (C6+), compressibility and thermal expansion and contraction are not as significant as with lighter component mixtures. With high purity streams, predictions from EOS models have lower uncertainty than with diverse mixtures.

Another issue with using conventional volumetric methods involves the ability to correct the stream for the effects of temperature and pressure. Mixed NGL streams, especially of very light composition, do not readily fall into a particular category that is suited for a certain set of correction tables. Inherent errors can be introduced due to the varying expansion rates of the different products within the stream.

To help to eliminate these issues, measurement by mass is often the preferred method.

NOTE Refer to API MPMS Chapters 14.4 and 14.7

C.2 Mass Measurement of NGLs

C.2.1 Direct Mass by Coriolis Meter

Direct mass mainly involves the use of a Coriolis meter, since it is the only meter capable of a mass pulse output. With this method, the entire data stream, from the meter to the end device, should be programmed to accept and calculate mass quantities. The mass to volume calculations are most often not done in the flow computer, but in the accounting system.

The prover volume will be converted to mass when proving a direct mass meter. This involves the accurate determination of the flowing density at the prover to calculate the prover's displaced mass instead of volume.

Direct mass eliminates some of the potentials for error that exist with the inferred mass. Since the Coriolis meter's pulse output is in mass rather than volume, the need to convert meter volume to mass is eliminated, as well as the need for density to convert volume to mass. See Equation C.1:

$$Q_m = IM_m \times MF_m \qquad \text{(C.1)}$$

~~***Qm = IMm x MFm,***~~

Where,~~:~~

Q_m is total mass~~*Qm – Total mass*~~

IM_m is ~~IMm – I~~indicated mass from ~~Cc~~Coriolis meter when configured in mass, and

MF_m is the ~~MFm – M~~meter factor when Coriolis meter is configured in mass

C.2.2 Direct Mass by Truck Scales

Another method of direct mass measurement involves hauling NGL product by truck and using drive-on scales to determine mass.

High quality multi-celled truck scales can be certified down to a very precise level. It is common to see a scale rated for 120,000 lbs. certify to within 40 lbs. or 0.03 %. Like other equipment used for custody transfer, the scales shall be periodically certified.

C.2.3 Inferred Mass

Inferred mass measurement utilizes a conventional volumetric meter but does not apply temperature and pressure corrections as in traditional volumetric methods. To accurately calculate mass, the system must also determine the density in real-time. Using the volumetric meter's indicated volume, the flowing density, the meter factor, and the density correction factor (DMF), the mass of the fluid can be precisely calculated. This approach ensures accurate mass measurement by integrating these critical factors into the calculation process. See Equation C.2:

$$Q_m = IV \times MF_v \times P_f \times DMF \qquad \text{(C.2)}$$

Where~~:~~,

Q_m *– Total mass*

IV ~~*IV*~~ *– Meter indicated volume (pulses/K factor)*

MF_v *– Meter factor when meter is configured in volume*

P_f *– Flowing density, uncorrected*

DMF *– Density meter factor.*

~~A.1~~C.3 Composition Determination Scenarios for NGL Pipelines

Accurate reconciliation of NGL pipeline quantities involves various scenarios for determining product composition, each requiring specific approaches and technologies:

~~A.1.1~~C.3.4 Inlet and Outlet Composition Measurement

Install gas chromatographs or online analyzers at both the inlet and outlet points of the pipeline to continuously monitor the composition of NGLs entering and exiting the system. This setup provides real-time data on composition changes, essential for accurate reconciliation. Usually, gas chromatographs in liquid service involve a means to vaporize the sample immediately before it is injected into the unit for analysis.

~~A.1.2~~C.3.5 Intermediate Points Measurement

For long pipelines, installing additional measurement points along the pipeline helps in monitoring composition changes due to potential phase transitions or mixing from different sources. Intermediate measurements provide a more detailed understanding of composition variations along the pipeline.

~~A.1.3~~C.3.6 Batch Analysis

In situations where continuous measurement is not feasible, periodic batch sampling and analysis can be performed. Samples are taken at regular intervals and analyzed using laboratory gas chromatography to determine the composition. While less real-time, this method still provides valuable data for reconciliation purposes.

~~A.1.4~~C.3.7 Density and Pressure Correlation

Continuous density and pressure measurements can be used to infer composition changes. By correlating density and pressure data with known composition profiles, operators can estimate the composition of NGLs in real-time, supplementing direct composition measurements.

~~A.1.5~~C.3.8 Composition-Based Volume Correction

Use composition data to apply specific volume correction factors that account for the unique properties of the NGL mixture. This approach ensures that volume measurements are adjusted accurately for temperature and pressure variations based on the current composition.

~~A.2~~C.4 Composite Sampling

~~To preserve the integrity of the sample, particularly the light components of NGLs, it is important to use sampling devices that can maintain the pressure conditions of the pipeline. The sample receptacle shall be designed to withstand the operational pressures of the pipeline, ensuring that all components of the NGL mixture remain in their liquid phase during the sampling process.~~ Proper pressure maintenance during NGL sampling is crucial to avoid the loss of lighter ~~volatile~~ components, ~~thereby ensuring~~so that that the sample remains representative of the actual pipeline contents.

NOTE Refer to API Chapter 8.2 / ASTM D4177 “Standard Practice for Automatic Sampling of Petroleum and Petroleum Products” for standard practices and installation recommendations.

C.5 Converting Mass to Volume

API MPMS Chapter 14.4 / GPA 8173, ~~'~~*Converting Mass of Natural Gas Liquids and Vapors to Equivalent Liquid Volumes*~~'~~, outlines the procedures to calculate mass of each component in NGL mixture, and then convert mass to volume. The following components in Table C.1 are shown in pounds/gallon, and can be found in the GPA-2145 table and are at 60 ºF and equilibrium vapor pressure.

Component	lb / gal
CO2	6.8129
Methane (C1)	2.5000

Ethane (C2)	2.9704
Propane (C3)	4.2285
iso-Butane (iC4)	4.6925
n-Butane (nC4)	4.8706
iso-Pentane (iC5)	5.2120
n-Pentane (nC5)	5.2584
Hexanes and heavier (C6+) *	Shall be determined from extended analysis.

Table C.1 – Liquid Densities of NGL Components

NOTE Refer to GPA-2186 "Method for the Extended Analysis of Hydrocarbon Liquid Mixtures Containing Nitrogen and Carbon Dioxide by Temperature Programmed Gas Chromatography"

C.6 Densitometers

Refer to API 9.4, –'*Continuous Density Measurement under Flowing Conditions*,' for installation and maintenance recommendations for densitometers.

C.7 Line Fill and Line Pack Volumes

By accurate accounting for Line Fill and Line Pack in the reconciliation process, operators can achieve more precise control over their pipeline operations, ensuring accurate measurement and management of NGL quantities. While Line fill refers to the volume of NGLs required to fill the entire length of the pipeline, Line pack reflects the compressible nature of NGLs under varying pressure conditions. When pressure and temperature changes occur, it can significantly affect the volume of the product within the NGL pipeline.

NOTE For further information, refer to GPA Midstream Guideline PFPDM-23 "Guidelines for Pipeline Fill, Pack, and Determination Methodology"

C.8 Pressurized Tanks

Pressurized tanks used for delivering and receiving Natural Gas Liquids (NGLs) are designed to handle the specific properties and requirements of these hydrocarbon mixtures. These tanks shall maintain appropriate pressure levels to keep NGLs in the liquid phase, preventing vaporization and ensuring safe and efficient transfer to and from pipelines. The tanks are constructed to withstand high pressures typically required to keep NGLs in a liquid state. They shall be built according to relevant industry standards and regulations to ensure safety and durability.

Accurate level measurement systems are integrated to monitor the volume of NGLs in the tank continuously. Maintaining a consistent temperature is crucial as NGLs can be sensitive to temperature changes. The tanks may include insulation and temperature control systems to prevent excessive heating or cooling. To manage unexpected pressure surges and prevent over-pressurization, the tanks are equipped with pressure relief valves and safety mechanisms.

C.9 Refrigerated Tanks

Refrigerated NGL tanks are specialized storage units designed to keep NGLs at low temperatures to maintain them in a liquid state, which reduces the pressure requirements compared to pressurized tanks. Accurate measurement and monitoring of refrigerated NGL tanks are crucial for safe and efficient operations, as well as for precise reconciliation of quantities.

These are some key characteristics of Refrigerated NGL Storage Tanks:

C.9.1 Level Measurement

Non-contact radar level gauges are commonly used for measuring the liquid level in refrigerated NGL tanks. They provide accurate and reliable measurements even under cryogenic conditions.

Float and Tape Systems are also used to measure the liquid level in tanks. These systems are also used in some installations, providing a mechanical means of level measurement that is reliable under low-temperature conditions.

C.9.2 Temperature Measurement

Accurate temperature sensors are installed at various levels within the tank to monitor the temperature of the NGLs. Maintaining a consistent low temperature is crucial to prevent vaporization.

Thermocouples and RTDs (Resistance Temperature Detectors) are commonly used types of temperature sensors that offer precise measurements in cryogenic environments.

C.9.3 Pressure Measurement

Installed at different points in the tank, pressure transmitters monitor the internal pressure to ensure it remains within safe limits. The pressure shall be controlled to prevent boiling and maintain the liquid state of NGLs.

C.9.4 Density Measurement

Densitometers measure the density of the NGLs, which can vary with temperature and composition. Accurate density measurements are essential for converting volume measurements to mass.

C.9.5 Volume Calculation

Using the level, temperature, and density data, the volume of NGLs in the tank is calculated. This involves applying correction factors for temperature and density to ensure accurate volume determination.

C.9.6 Composition Analysis

Regular sampling of NGLs is necessary to analyze their composition. This helps in determining the exact proportions of different hydrocarbons, which is critical for density calculations and reconciliation.

Continuous composition online analyzers can provide real-time data on the NGL mixture, improving the accuracy of volume and mass calculations.

C.10 NGL Reconciliation priorities

During the NGL reconciliation process, priority should be given to mass balance first (if feasible), followed by volume balance.

Hydrocarbon vapors in large empty vessels can complicate accurate quantity determination.

Balancing issues can include:

- If the mass does not balance, it likely indicates a meter error or another product loss issue.
- If the volume does not balance, it usually points to a physical property discrepancy.

NOTE Refer to the relevant API and GPA standards (such as API MPMS Chapter 11.2.5 / GPA 8117, API MPMS Chapter 14.4 / GPA 8195, API MPMS Chapter 11.2.4 / GPA 8217, etc.) for guidance.

~~**Annex BNOTE All values shall be numerical. For example, months shall be 1, 2, 3, etc., not January, February, March, etc.**~~

~~B.1 Standard Error of Estimate~~

~~For the statistics mentioned in this document, the standard error of estimate of a given statistic is equal to the uncertainty of that statistic. The statistic could be a mean, slope, standard deviation, or any other statistic that is~~

~~calculated. The user desiring a more in-depth discussion of this and other statistics should consult API *MPMS* Chapter 13.~~

~~Annex C~~Annex D

(informative)

Troubleshooting Guide for Liquid Pipeline Measurement Operations

See the Troubleshooting Guide in Excel attachment to this document.

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