Computational Pipeline Monitoring for Liquids

API RECOMMENDED PRACTICE 1130
FIRST EDITION, SEPTEMBER 2007

REAFFIRMED, APRIL 2012

AMERICAN PETROLEUM INSTITUTE

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Pipeline Segment

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, D.C. 20005, standards@api.org.

Contents

Introduction

Computational Pipeline Monitoring (CPM) is a term that was developed by the API to refer to software-based, algorithmic monitoring tools that are used to enhance the abilities of a Pipeline Controller to recognize hydraulic anomalies on a pipeline. These anomalies may be indicative of a pipeline leak or commodity release. CPM systems are often generically called leak detection systems. However, pipeline leak detection can be accomplished by a variety of techniques such as: aerial/ground line patrol; third party reports; inspections by company staff; hydrocarbon detection sensors; SCADA monitoring of pipeline conditions by Pipeline Controllers; and software-based monitoring. To provide a clear reference, the term CPM was developed to specifically cover leak detection using software-based algorithmic tools. Simple monitoring tools such as observations of meter over-short reports, observations of pressure deviations and observation of flow rate deviations, without use of an inference engine and alert algorithm, although providing valuable information to the Controller, are not considered to be CPM systems because they do not meet the definition of CPM.

This is the first edition of API RP 1130 issued as a recommended practice. The first edition of API 1130 was published in 1995. The second edition was published in 2002. Between the first and second editions and now between the second and this RP, the users of this information (e.g. Pipeline Operators, system developers, system integrators and the regulators) have had an opportunity to use and evaluate the document. Their suggestions for improvements, correcting of inconsistencies and error elimination have been considered and incorporated in this latest edition.

All editions of this document have been written by Work Groups of the API Cybernetics Subcommittee. The purpose of the work was to develop an API recommended practice for CPM as it is used in the liquids pipeline industry. This update includes input from all committee members as well as a broad community of CPM system developers and system integrators.

The five-year cycle of re-writing and re-authorizing API RP 1130 is necessary under API standard rules and is especially important because the document is referenced in the federal pipeline safety regulations which are discussed in the following section.

Computational Pipeline Monitoring for Liquids

1 Scope

1.1 Purpose

This recommended practice focuses on the design, implementation, testing and operation of CPM systems that use an algorithmic approach to detect hydraulic anomalies in pipeline operating parameters. The primary purpose of these systems is to provide tools that assist Pipeline Controllers in detecting commodity releases that are within the sensitivity of the algorithm. It is intended that the CPM system would provide an alarm and display other related data to the Pipeline Controllers to aid in decision-making. The Pipeline Controllers would undertake an immediate investigation, confirm the reason for the alarm and initiate an operational response to the hydraulic anomaly when it represents an irregular operating condition or abnormal operating condition or a commodity release.

The purpose of this recommended practice is to assist the Pipeline Operator in identifying issues relevant to the selection, implementation, testing, and operation of a CPM system. It is intended that this document be used in conjunction with other API standards and applicable regulations.

1.2 Contents

This recommended practice includes definitions, source and reference documents, concepts of data acquisition, discussion of design and operation of a pipeline as related to CPM, field instrumentation for CPM purposes, alarm credibility, Pipeline Controller response, incident analysis, records retention, maintenance, system testing, training, considerations for setting alarm limits, trending and recommendations for data presentation. The relationship between the Pipeline Controller and the CPM system is also discussed.

1.3 Scope Limitations

This recommended practice is not all-inclusive. The reader must have an intimate knowledge of the pipeline system and may have to refer to other standards for background or additional information.

This recommended practice was written considering single phase, liquid pipelines. However many of the principles apply to liquid pipelines in intermittent slack line flow or liquid pipelines that may have permanent slack line flow. Slack line operation creates uncertainties in pressure and flow. For these operating conditions, the user of API RP 1130 will have to carefully consider what parts of API RP 1130 do and do not apply.

This recommended practice also may not apply to the special case of determining leaks during shut-in conditions that occur when the line is shutdown (sometimes called static conditions). For example, a Volume Balance CPM cannot evaluate volume loss if there is no flow through the meters during a line shutdown.

It is recognized that no one particular CPM methodology or technology may be applicable to all pipelines because each pipeline system is unique in design and operation. In addition, detectable limits are difficult to quantify because of the unique characteristics presented by each pipeline. Limits must be determined and validated on a system-by-system and perhaps a segment-by-segment basis.

CPM is intended to enhance human judgement when some type of intervention or shutdown of the affected pipeline segment(s) is warranted. Effective operation of a pipeline requires that the Pipeline Controllers be familiar with the pipeline and all the tools at their disposal. CPM can also enhance human judgement during decisions to activate remotely controlled valves and directing field staff to re-position hand operated valves on the pipeline.

This recommended practice complements but does not replace other procedures for monitoring the integrity of the line. CPM systems, as well as other commodity release detection techniques, have a detection threshold below which commodity release detection cannot be expected. Application of the information in this recommended practice will not reduce the threshold at which a commodity release can be detected. For example, trained Pipeline Controllers analyzing SCADA-presented operating data can be effective at detecting certain sizes (i.e. larger) of commodity releases. Third party reports, pipeline patrols, and employee on-site examinations can also be effective procedures when used to verify the integrity of the pipeline within their range of applicability.

It is important to note that this recommended practice is in keeping with standard industry practice and commonly used technology; however, it is not intended to exclude other effective commodity release detection methods.

Annex A provides a discussion of CPM thresholds and other information related to understanding pipeline leaks and practical detection limits for commodity releases.

1.4 Transportation Systems

This recommended practice is written for liquid onshore or offshore trunkline systems but much of this content may be applicable to other piping systems such as selected gathering systems, production flow lines, marine vessel loading/ unloading, and tank terminaling operations. CPM has typically been applied to steel pipeline systems but may be applied to pipelines constructed of other materials such as PVC, polyethylene, fiberglass, and concrete. The successful application of CPM may be limited by the characteristics of these other materials.

Pipeline systems vary widely in their physical characteristics including: diameter, length, pipe wall thickness, internal roughness coefficient, pipe composition, complexity of pipe networking, pipeline topology, pump station configuration, and instrumentation (quality, accuracy, placement). These same pipeline systems can also be categorized by operational factors such as: flow rate; magnitude and frequency of rate/pressure fluctuations; blending; batching; batch stripping schemes; product type; product fluid characteristics (viscosity, density, sonic velocity, bulk modulus, vapor pressure); pressure, temperature; and heat transfer.

1.5 Regulatory Considerations

Users of API RP 1130 should be familiar with the regulations that cover hazardous liquid pipelines. These regulations may apply at municipal, state or federal levels. For example, since the first edition of API 1130, the US Department of Transportation, Pipeline and Hazardous Materials Safety Administration have included a reference to API 1130 in 49 *CFR* Part 195. During the life of the second edition of API 1130, Federal regulations for leak detection were established for high consequence areas.

A Pipeline Operator should base their leak detection project decisions upon a structured qualitative and/or quantitative method for identifying and assessing risks. The CPM methodology selected should be evaluated against what characteristics of the pipeline are known and what is required by the methodology to provide acceptable results.

Listed below are direct regulatory references to CPM and leak detection within 49 *CFR* Part 195. These are the principle references, but the list may not be all-inclusive. Since regulations are periodically updated, users of API RP 1130 should be aware that specific regulatory references may change or be supplemented in the future.

195.2	*Definitions, Computation Pipeline Monitoring*
195.134	*Design Requirements, CPM Leak Detection*
195.444	*Operation and Maintenance, CPM Leak Detection*
195.452(i)(1)	*Integrity Management, General Requirements*
195.452(i)(3)	*Integrity Management, Leak Detection*
195.452(i)(4)	*Emergency Flow Restricting Devices*

Within regulations, there may be a specific reference to CPM or leak detection. The reference may also be indirect as in the regulatory requirement for the closing of remote valves (or activation of flow restricting devices) where a CPM system may be used as one of the triggers for that activation, particularly in high consequence areas.

CPM systems may be employed when the requirement states:

— A Pipeline Operator must have a means to detect leaks on its pipeline system and to protect high consequence areas.

— The Pipeline Operator must evaluate the capability of its leak detection means and modify it as necessary to provide a sufficient level of protection (i.e. the CPM may be adjusted to account for the operational mode or characteristics of the pipeline segment including shut-in). Ideally, factors such as length and size of the pipeline, type of product carried, the pipeline's relationship to high consequence areas, the swiftness of leak detection, the location of nearest response personnel, the pipeline’s leak history, and risk assessment results, must be considered.

This document provides guidance that will be helpful in addressing regulatory requirements but it does not claim to be all-inclusive in that regard. The Pipeline Operator should thoroughly understand the regulations and work with the regulators and their agents to satisfy all related requirements and maintain pipeline safety.

2 Applicable References

API RP 551, *Process Measurement Instrumentation*

API RP 1112, *Developing a Highway Emergency Response Plan for Incidents Involving Hazardous Materials*

API RP 1113, *Developing a Pipeline Supervisory Control Center*

API Publ 1149, *Pipeline Variable Uncertainties and Their Effects on Leak Detectability*

API Publ 1161, *Guidance Document for the Qualification of Liquid Pipeline Personnel*

API Std 1164, *Pipeline SCADA Security*

API RP 1165, *Recommended Practice for Pipeline SCADA Displays*

API *Manual of Petroleum Measurement Standards* (sections on metering, calibration and proving)

CSA CAN/CSA-Z662-03[1], *Oil and Gas Pipeline Systems, Annex E, Recommended Practice for Leak Detection*

US DOT 49 *CFR* (Code of Federal Regulations) Part 195[2]

NOTE API Publication 1155, *Evaluation Methodology for Software Based Leak Detection Systems* has been removed from the applicable references because it is being withdrawn by API. In particular, API Publ 1155 contained a pertinent excellent discussion of leak detection performance metrics. So this information is not lost, the pertinent sections of API Publ 1155 have been copied with minor modification into Annex C of this recommended practice.

[1]Canadian Standards Association, 5060 Spectrum Way, Suite 100, Mississauga, Ontario, L4W 5N6, Canada, www.csa.ca.
[2]US Department of Transportation, 400 7th Street, S.W., Washington, D.C. 20590, www.dot.gov.

3 Definitions

3.1
abnormal operating condition
A term used in the 49 *CFR* Part 195 regulations. Part 195 states: Abnormal operating condition means a condition identified by the Operator that may indicate a malfunction of a component or deviation from normal operations that may:

a) Indicate a condition exceeding design limits; or

b) Result in a hazard(s) to persons, property, or the environment.

3.2
accumulator data
A SCADA data value that represents an accumulated quantity, usually volume in liquid pipeline service.

3.3
accumulator freeze
A feature of some SCADA protocols that allow all volumetric data to be captured at virtually the same time. It may be used to eliminate time skew in volumetric data analysis.

3.4
Acoustic/Negative Pressure Wave CPM
This type of CPM system senses the acoustic signal or pressure wave that occurs when the pipe wall is compromised and the product escapes through the hole in the pipe. Acoustic/Negative Pressure Wave CPM utilizes Signature Recognition techniques. Additional description is offered in Annex B.

3.5
alarm
A notification to the Pipeline Controller that a hydraulic anomaly has been detected that is outside pre-set limits. The event requires a response from the Pipeline Controller. Alarms are usually displayed in a prominent manner with an audible signal to the Pipeline Controller. This may be declared visually and/or audibly.

3.6
alarm acknowledgement
An action by the Pipeline Controller, signifying that the alarm event is recognized.

3.7
alert algorithm
A part of a CPM system that evaluates the inferred measurements (calculated or accumulated in the inference engine) compares against the thresholds and issues a CPM alarm.

3.8
analog data
A SCADA data value that represents some measured quantity, e.g. temperature or pressure.

3.9
analog deadband
A SCADA parameter that defines the increment of change in an analog value that is significant. A monitored analogue value change that is less than the deadband will be ignored.

3.10
calibration
For this document, the activities in which instrumentation and measurement are proved.

3.11
communication failure
An interrupt in SCADA messaging usually between the Control Center Computer RTU, PLC or Flow Computer. It may be a loss of communication either by total outage of the communication link or by failure of the remote site to respond to data required by the Control Center Computer.

3.12
communications messaging protocol
The specific format of the data communicated amongst the Control Center Computers, RTUs, PLCs, and Flow Computers in a SCADA system.

3.13
commodity release
A loss of fluid from the pipeline. Within the context of this recommended practice, a commodity release when referenced to leak rate, must be above the leak threshold of the particular CPM system and pipeline. Other industry terms are product release or pipeline leak.

3.14
Compensated Mass Balance CPM
Similar to Modified Volume Balance but that which considers the bulk modulus and temperature modulus properties of the actual fluid batches in the pipeline. Compensated Mass Balance systems utilize Conservation of Mass principles. Additional description is offered in Annex B.

3.15
Computational Pipeline Monitoring or CPM

An algorithmic monitoring tool that alerts the Pipeline Controller to respond to a detectable pipeline hydraulic anomaly (perhaps both while the pipeline is operating or shut-in) which may be indicative of a commodity release.

3.16
Conservation of Mass
The principle as applied to liquid flow in pipelines, that states that the time rate of mass inflow to a pipe segment minus the time rate of mass outflow equals the time rate of mass increase (decrease is considered as a negative increase) in the pipe segment. The rate of mass outflow includes any leaks that may exist in the pipe segment.

3.17
data archiving
A SCADA system feature that records data in an historical database under some pre-defined data management process.

3.18
data quality
A SCADA system feature that creates status bits that are attached to reflect the validity of process data.

3.19
drag reduction agent
An additive used in liquid pipelines to reduce friction loss. Also referred to as “DRA.”

3.20
event log
A SCADA system feature that creates a permanent record of changes to the pipeline and the system’s state in chronological order.

3.21
excursion alarm
An alarm that indicates that the CPM system has detected a hydraulic anomaly that is outside the defined limits. Typically, a SCADA system generated event that alerts the Pipeline Controller to an analog data value that has been detected outside a pre-set range. Also called a threshold or range alarm.

3.22
false alarm
A commonly misused term in the context of CPM systems to refer to alarms that are not caused by an actual commodity release or other emergency or abnormal operating condition.

3.23
filter
A device or algorithm to remove unwanted components from a process signal. Also called signal conditioning.

3.24
fluid properties
The characteristics of the fluid that describe its hydraulic behavior including: density; viscosity, compressibility (or bulk modulus); coefficient of thermal expansion; thermal capacity. Many CPM techniques also need to consider the effects of pipeline drag reducers on fluid properties.

3.25
historical data
Data that have been retained for later retrievable, typically maintained by a SCADA system's data archival subsystem.

3.26
hydraulic anomaly
An irregular operating condition on the pipeline or abnormal operating condition that is explainable through the systems hydraulics.

3.27
inference engine
A part of the CPM system that accumulates data, performs calculation (e.g. line hydraulics) and provides outputs to the alert algorithm.

3.28
integrity scan
A special message in a 'Report-by-Exception' SCADA communication protocol that verifies that the Control Center Computer has an accurate picture of field data. Since only changed data are reported form the field in such a protocol, lost messages could result in inaccurate data in the Control Center Computer. Some systems require an "all data" or other health check response on a scheduled basis to achieve data integrity in 'Report-by-Exception' systems.

3.29
irregular operating condition
On a pipeline, in the context of CPM, would be an infrequent event during which the pipeline may be operated in a way that is not normal, e.g. a one-off operation. An irregular operating condition is a challenge to the CPM in that it may require new logic in the CPM to handle the event. In a severe case, an irregular operating condition may become an abnormal operating condition.

3.30
leak declaration
The declaration that is made if a Pipeline Controller has reasons to suspect that a commodity release is occurring on the pipeline.

3.31
Line Balance CPM
Line Balance CPM compares the measurement of measured volume entering the system to the measured volume exiting the system or meter-to-meter reading comparison. Line Balance CPM systems utilize Conservation of Mass principles. Additional description is offered in Annex B.

3.32
manual data override
When manual entries are input in lieu of actual field data values.

3.33
Mass Balance
A mathematical process that considers the fluid injected, delivered and the change in inventory of the pipeline so all of the fluid is accounted for.

3.34
Material Balance
A mathematical procedure based upon the laws of Conservation of Mass and fluid mechanics, which is used to determine if a commodity release has occurred on a pipeline system. May also be called Mass Balance.

3.35
Modified Volume Balance (MVB) CPM
An enhancement of Volume Balance CPM that compares the measurement of corrected volume entering the system to the volume exiting the system and accounts for changes in the inventory of the pipe. MVB CPM systems utilize Conservation of Mass principles. Additional description is offered in Annex B.

3.36
Newtonian (non-Newtonian) fluids

Newtonian fluids have predictable viscosity characteristics. Viscosity can be calculated for various temperatures and pressures. Non-Newtonian fluids have unpredictable viscosity characteristics that cannot be easily calculated. Most fluids that exhibit non Newtonian characteristics are Newtonian above some particular temperature.

3.37
noise
An unwanted component in a process signal. Noise may be reduced by filtering.

3.38
no reply
A state in SCADA communications in which the RTU or PLC does not make a valid response to the Control Center Computer's request for process data. "No Replies" are expected some percentage of the time depending on the design of the communication channel.

3.39
non-leak alarm
A CPM alarm that indicates a degraded performance of the CPM system and/or a leak alarm that is not associated with an actual commodity release, but may indicate a problem with inputs to the CPM system, which causes the CPM to indicate a leak. This type of alarm is a data failure or diagnostic alarm. All CPM alarms have a cause and should be investigated (see 6.1).

3.40
polling
One method by which the Control Center Computer can acquire field data by issuing sequential requests to field Data Acquisition Devices (e.g. RTUs, PLCs, and Flow Computers). These requests, called polls typically proceed in a continuous cyclic manner across many field locations.

3.41
Pipeline Controller
A person who is responsible for the monitoring, or monitoring and direct control of a pipeline. A Controller may defer action to others, but still be the responsible and primary individual to monitor and detect abnormal conditions. This is the accepted industry term for this position (as outlined in API 1118). Other industry terms used are Operator, Operations Coordinator or Dispatcher.

3.42
pipeline rupture
In the context of Computational Pipeline Monitoring (CPM), a rupture is a pipeline leak that releases a large quantity of the contents of the pipe, or a large portion of pipeline flow-rate. A rupture will occur when there is a significant breach of the pipe wall or major loss of containment of the product within the pipe.

3.43
Pressure/Flow Monitoring CPM
That which examines the relationship between various sensors outputs and applies an algorithm to determine if they indicate an anomaly. Pressure/Flow monitoring CPM usually utilizes Signature Recognition techniques. Additional description is offered in Annex B.

3.44
protocol
The specifications of the message structure between RTU or PLC and Control Center Computer are collectively referred to as the communications protocol.

3.45
Quiescent protocol
One type of SCADA communication protocol in which the RTUs and PLCs initiate messages containing process data for transmission to the Control Center Computer. Such messages can be triggered by a change in process data or created on a time-driven basis. Also called Unsolicited protocol.

3.46
Rate of Change (ROC)
A calculated value that reflects the change in an analog data value per unit time.

3.47
Real Time Transient Model (RTTM) CPM
That which instrument data and physical characteristics of the pipeline and fluids transported, then employs hydraulic calculations to determine the in/out balance, inventory and instantaneous flow in segments of the pipeline. An RTTM uses a Conservation of Mass CPM technique although it is possible to utilize Signature Recognition in a RTTM Additional description is offered in Annex B.

3.48
return to normal
The transition from alarm to normal state that signifies that an alarm condition has ended.

3.49
Remote Terminal Unit or RTU
A SCADA system component, typically installed at a field site that gathers process data from sensors for transmission to the Control Center Computer. The RTU or PLC also accepts control command messages from the Control Center Computer and transforms those commands to electrical output signals. Also a generic term that refers to any device that can respond to requests for information from a Control Center Computer or PLC or can send unsolicited information in a non-polled environment.

3.50
Report-by-Exception
A feature of some SCADA communication protocols that intends to improve communication efficiency by reporting only the data that has changed since the previous poll.

3.51
SCADA
An acronym for Supervisory Control and Data Acquisition, the technology that makes it possible to remotely monitor and control pipeline facilities.

3.52
scan time
The time interval between two consecutive polls to Data Acquisition Devices on a SCADA communication channel. Also called polling time.

3.53
segments
A shorter part of a pipeline section. A segment is bounded by defined by instrumentation (e.g. meter) or other physical features of the pipeline (e.g. valves).

3.54
sensitivity
A composite measure of the size of a leak that a CPM system is capable of detecting and the time required for the system to issue an alarm in the event that a commodity release of that size should occur. This term is fully defined and discussed in Annex C.

3.55
shut-in
A pipeline that is not operating (fluid is not entering or leaving the pipe) at the time it is shut-in. Valves may be closed to prevent fluid flow when the pipeline is shut-in.

3.56
single phase
A fluid state, either liquid or gaseous, based upon commodity, vapor pressure, pipeline pressure and temperature.

3.57
slack line
The condition where a pipeline segment is not entirely filled with liquid or is partly void. May also be called column separation.

3.58
Statistical Analysis CPM
A mathematical method of handling the CPM related instrument outputs from the pipeline. Statistical analysis CPM systems can utilize either Conservation of Mass techniques or Signature Recognition techniques or both techniques.

Additional description is offered in Annex B.

3.59
status data
A SCADA data value that represents the operational state of an item of field equipment.

3.60
steady state conditions
The pipeline hydraulic condition that exists when all the pipeline operating parameters remain nearly constant over a period of time. There is no mass inventory change in the pipe segment, Conservation of Mass demands that the rate of mass inflow be identical to the rate of mass outflow.

3.61
system
An entire entity such as a complete pipeline. Segments (see above) are subset of a system.

3.62
threshold
An upper or lower established value for a particular parameter (e.g. a defined pressure value). When a threshold is exceeded the actual parameter value is outside the range of the define value (usually above or below the threshold). A threshold may be fixed (i.e. its value does not change) or dynamic (where the value changes in time).

3.63
time skew
The variation in reporting times from one Data Acquisition Devices to another in a polled SCADA communications protocol. In a polled system, the variation in reporting time from one Data Acquisition Devices to another.

3.64
time tag
A SCADA system feature that records the time that a measurement or event occurs along with the data.

3.65
time tag error
The difference between the time the actual measurement was made and the time tag associated with the measurement.

3.66
transient operating conditions
That which exists when any pipeline parameter is changing in time. Unsteady flow or transient flow is a general state of flow of which steady flow is a special case. In unsteady flow, pressure changes cause changes in mass inventory in the pipeline. This change takes place simultaneously in two main forms: liquid compression and density change, and pipe cross-sectional area change.

3.67
Volume Balance CPM
Comparison of the corrected volume of fluid entering the system to the corrected volume exiting the system. It is an enhancement of Line Balance CPM. Volume Balance systems utilize Conservation of Mass principles. Additional description is offered in Annex B.

4 Technical Overview

This section discusses the generic types of CPM technologies and applications, provides a list of desirable CPM features, and mentions important issues concerning the fluids transported.

4.1 Leak Detection Technology

The CPM systems present field data and calculated information for the Pipeline Controller to evaluate and take appropriate action. The degree of complexity in processing field data varies from simple comparisons of a particular parameter relative to a threshold limit to more extensive analysis of multiple parameters with interlocking and/or dynamic threshold limits. All CPM algorithms are based on certain design and implementation assumptions to:

— Compensate for pipeline operational and/or configuration uncertainties.

— Reach an acceptable compromise between accuracy and speed of solution.

These assumptions need to be completely understood for a successful CPM implementation.

Applications that use sensors (or leak detectors) to directly detect a commodity release are called *externally based* systems. Applications that indirectly detect or infer commodity releases are called *internal based* systems.

4.1.1 Externally Based Leak Detection Systems

This recommended practice does not consider externally based pipeline leak detection systems (often called leak detectors) that operate on the non-algorithmic principle of physical detection of an escaping commodity. In these systems, the local detector sends an alarm signal to the Control Center for display and annunciation. Externally based applications are excluded from the discussion of CPM since they do not meet the requirement of performing computation on field parameters for inferring a commodity release.

Common types of externally based systems or devices are:

— Fiber optic hydrocarbon sensing cables.

— Dielectric hydrocarbon sensing cables.

— Acoustic emissions detectors.

— Hydrocarbon (vapor) sensors (including those with vapor pick-up tubes).

4.1.2 Internally Based CPM Systems

CPM systems that are internally based utilize field sensor data that monitor internal (and perhaps related external) pipeline parameters. The particular application may utilize some or all of the measured data such as: pressure, temperature, viscosity, density, flow rate, product sonic velocity, and product interface location. These inputs are then used for inferring a commodity release by computation.

There are two primary technologies used in CPM systems: Conservation of Mass or Mass Balance methods; and Signature Recognition methods. Conservation of Mass methods work on the principle that whatever enters the pipeline must be equal to whatever exits the pipeline adjusted for change in inventory of the pipeline. Signature Recognition methods consider the relationships of system pressure and/or flow or recognize anomalies in sensor outputs on the pipeline.

The types of internally based CPM techniques are defined in Section 3 definitions and further described in Annex B. There are a number of commonly used names for CPM system. These are:

— Line balance methods (Line Balance, Volume Balance, Modified Volume Balance, Compensated Mass Balance).

— Real Time Transient Model.

— Pressure/Flow Monitoring.

— Acoustic/Negative Pressure Wave.

— Statistical Analysis.

Each of the CPM applications has its strengths and limitations. For example, some CPM methods are more sensitive to measurement repeatability and drift, while other approaches may require extensive configuration efforts and tuning. No one technology will be suitable for all pipeline applications. More than one technology or application may be employed to provide a CPM that can more broadly cover the pipeline operating conditions.

4.2 Selection Consideration

Each CPM methodology contains different combinations of features with varying degrees of capability and sophistication. CPM performance is contingent on the interrelationship of many factors such as: measurement capabilities, communications reliability, pipeline operating condition, and product type. Under appropriate circumstances, commodity release detection will benefit by employing multiple CPM techniques or applications for validation or redundancy. The independence of parameters used in some methodologies potentially allows for independent validation or redundancy. The following is a list of desirable CPM features and functionality that improve the performance of the CPM system or add to the utility of a CPM system.

The CPM features listed below are not in any particular order nor is there any attempt to weight the importance of each. It must be noted that no one methodology or particular application possesses all of these features and certain features will be more appropriate for specific pipeline systems.

The CPM system may:

— Possess accurate commodity release alarming.

— Possess high sensitivity to commodity release.

— Allow for timely detection of commodity release.

— Require minimal software configuration and tuning.

— Be able to perform its CPM functions with existing sensors and instruments (or does not have special or additional requirements for instrumentation).

— Be minimally impacted by communication outages or by data failures, however provide alarming based on a degraded mode of operation and during an abnormal operating condition (see 6.1.1).

— Accommodate complex operating conditions and be configurable to complex pipeline networks.

— Be available during transients.

— Perform an imbalance calculation on meters over a configurable set of time constants.

— Possess dynamic alarm thresholds.

— Possess dynamic liquid pack constant.

— Accommodate commodity blending.

— Account for heat transfer.

— Provide the pipeline system's real time hydraulic pressure profile, recognizing MAOP and elevation violations.

— Accommodate intermittent or permanent slack line conditions, avoiding inactivity of calculations during the transient condition.

— Perform shut-in analysis utilizing temperature, pressure and product compressibility, dynamically adjusting thresholds to accommodate a revised hydraulic pressure profile.

— Accommodate all liquid hydrocarbons.

— Identify a release with appropriate mile post location or the nearest station.

— Have the ability to display pressure history versus time for each line pressure location along a pipeline.

— Allow provisions to substitute manual override to specific status or analog data types during periods when input data may be unavailable (e.g. communication outage, measurement failure, maintenance, etc.).

— Provide composite indication of data attributes associated with supporting field inputs and calculated data.

— Minimize the number of alarms by requiring supporting, and preferably independent, commodity release confirmation.

— Identify the leak rate.

— Accommodate commodity measurement and inventory compensation for various correction factors (temperature, pressure, density, meter factor).

— Provide batch tracking including interface and anomaly markers. Compute bulk modulus, and perform inventory compensation.

— Performance of database queries at minimal time frames of 5 seconds.

— Validate commodity release alarms using redundant analysis within the same method as well as redundant analysis between methods.

— Accommodate status changes, pressure adjustments or other typical hydraulic norms without generating alarms.

— Account for effects of drag reducing additive.

— Provide the necessary documentation for Pipeline Operations Control Center to support self guided navigation, maintenance, alarm definition, and theory of operation.

— Provide a leak probability analyser to weigh all of the components of a leak (line-pack loss, pressure/flow deviation, meter shortage) to assist a Pipeline Controller to qualify a leak declaration.

— If necessary, provide an interface to allow alarming of a stand alone CPM application to be integrated into the Pipeline Controller's primary alarm processing system.

— Provide audit trails of CPM actions taken by Pipeline Controllers and system developers.

— Have the ability to allow self testing without affecting performance while the test is underway (see 6.2.1).

4.2.1 Performance Metrics

Selection of a CPM system for a given pipeline involves evaluation of the required and expected (or estimated) performance of the system. Other aspects such as commercial considerations (e.g. use of a common system in a Control Center with multiple pipelines) or economic criteria (e.g. capital and operating cost of the CPM) may need to be considered but these are not discussed herein.

The following categorizes and describes performance metrics for selection consideration. During the selection, the Pipeline Operator may place more weight or importance on one metric or another. Generally a system should achieve a satisfactory balance between all four of these performance metrics. For a more complete description of these metrics please read the excerpts from API Publ 1155 which are included in this document as Annex C.

— *Reliability*. This is defined as a measure of the CPM's ability to render accurate decisions about the possible existence of a leak on the pipeline while operating within an envelope established by the CPM design. A system is considered more reliable if it consistently detects actual leaks without generating incorrect declarations. For example, in the selection criteria above, the feature “Be available during transients” would be a reliability consideration.

— *Sensitivity*. This is defined as a composite measure of the size of a leak that a system is capable of detecting and the time required for the system to issue an alarm in the event that a leak of that size should occur. For example, in the selection criteria above, the feature “Possess high sensitivity to commodity release” would be a sensitivity consideration.

— *Accuracy*. The validity of leak parameters estimates such as leak flow rate, total volume lost, type of fluid lost and leak location are indications of CPM accuracy. For example, in the selection criteria above, the feature “Allow for timely detection of commodity release” would be an accuracy consideration.

— *Robustness*. This is defined as a measure of the CPM’s ability to continue to function and provide useful information even under changing conditions of the pipeline (i.e. transients) or in conditions where data are lost or suspect. A system is considered robust if it continues to function under less than ideal conditions. Note the distinction between reliability and robustness: reliability is a measure of performance within a specified operations envelope; robustness is a measure of the effective size of the operational envelope. For example, in the selection criteria above, the feature “Be minimally impacted by communication outages or by data failures, however provide alarming based on a degraded mode of operation” would be a robustness consideration.

4.3 Commodity Properties

Commodity properties must be considered when the particular CPM application can be impacted by the fluid properties of the commodity being shipped. For CPM applications to work properly, the fluid must be in fully liquid phase or in a homogenous mixed phase so that it can be mathematically characterized. These are typical Newtonian fluids, which comprise most crude oils and refined products. These fluids may also be characterized via their density and bulk modulus, which are independent of viscosity. Other fluids, such as high paraffin crude oils or heavy crudes that may be highly viscous may exhibit non-Newtonian fluid characteristics. These fluids may be mathematically represented but only by using complex equations. If the fluid is transmix or a batch interface, then the CPM approach must be able to accommodate the unusual commodity properties. Highly Volatile Liquids (HVLs) are in liquid phase if temperature and pressure are sufficient to maintain the fluid above the critical point. HVLs are more compressible than crude oils, thereby making it more difficult for some CPM applications to discern hydraulic anomalies from normal pipeline operations.

5 Infrastructure Supports for CPM

A CPM is not a stand alone system. It depends upon field instrumentation, communications, and may be dependent on Supervisory Control and Data Acquisition (SCADA) infrastructure as a data source(s) and a vehicle to convey information to the Controller (e.g. CPM data presentation and passing of CPM alarms). CPM systems utilize real-time data and may have other dependency interactions if the CPM is linked to a data historian.

5.1 Field Instrumentation and Measurement

This portion of the recommended practice discusses or notes good operating practice in the selection, installation, calibration and maintenance of the field instrumentation and the measurement that is necessary to adequately support a CPM system.

NOTE Different CPM applications may require specific types of instrumentation or levels of performance. Therefore, instrumentation costs may vary significantly for each method. Some methodologies may need specialized instrumentation that is only used by the CPM (e.g. a viscometer). An Operator may want to consider the best practices for equipment and instrument installation as they related to CPM (e.g. using buried temperature probes to avoid ambient factors). Other possibilities may be installation of fluid property measurement instruments at injection points where fluid properties are variable and perhaps the installation of additional pressure sensors at intermediate locations.

5.1.1 Selection of Instrumentation and Measurement

Different CPM applications may require specific types of instrumentation and measurement for levels of performance. Therefore, instrumentation and measurement costs may vary significantly for each method. Some methodologies may need specialized instrumentation and measurement that is only used by the CPM.

API Publication 1149, *Pipeline Variable Uncertainties and Their Effects on Leak Detectability* outlines the importance of instrumentation and measurement to CPM performance. The calculations of API Publ 1149 can demonstrate that additional and more accurate instrumentation and measurement increase CPM effectiveness and the calculations can be used to determine where the most cost effective improvements can be made. Such analysis may be used repeatedly over the life of the pipeline system to achieve incremental performance improvement. The software developers or CPM providers may also be able to advise a Pipeline Operator on which instruments and measurements drive the CPM or influence the capabilities of the CPM applications as well as advise on what effects additional or upgraded instrumentation and measurement will have upon the CPM system.

The quality of instrument data can affect the CPM system. Instruments should be selected considering the required measurement accuracy. Ranges and specifications should be carefully matched to pipeline operating design, pressure, flow, temperature, density, viscosity, and so on to make best use of the instrument manufacturer's stated accuracy and linearity. Since instrumentation accuracy is generally stated in terms of percent of full range, the smallest available range greater than the desired range is the preferred choice. There is no value in over specification of instrumentation and measurement accuracy if CPM performance will be limited by the instrumentation or measurement loop accuracy, or repeatability and resolution of the SCADA system.

5.1.2 Installation of Instrumentation and Measurement

Instrumentation and measurement should be installed in accordance to the manufacturer’s recommendations and consider stated accuracy and linearity. A Pipeline Operator may want to consider the industry best practices for instrumentation and measurement equipment and installation as it relates to CPM. For example:

— Using buried temperature probes to avoid ambient factors.

— Installing density and/or viscosity monitors at injection points where fluid properties are variable.

— Installing additional pressure sensors at intermediate locations along the pipeline system.

The placement of instrumentation in relation to the process equipment is important, and location should consider variations in operating conditions. Critical CPM instruments should be placed at locations where they will not be isolated during normal pipeline operations. For most CPM systems pressure, temperature and flow are the most important data. Pressure should be measured where it best represents pipeline conditions and flow should be measured in an area where it can accurately be measured. For example, for inferential meters, at a location where there is a well-developed flow profile. Temperature must be taken in a location that is representative of the majority of the product in the line or it may generate errors greater than results achieved without the input.

The design of the instrumentation process piping and the instruments should be located to include provision for convenient testing and calibration of instruments with minimum disruption of pipeline operations (see API Recommended Practice 551, *Process Measurement Instrumentation*).

5.1.3 Calibration and Maintenance of CPM Instrumentation and Measurement

The quality of instrumentation and measurement data can affect the CPM system. A CPM system that has adequate instrumentation and measurement to achieve the desired commodity release sensitivity may be limited in its effectiveness if the CPM receives inaccurate data (e.g. inaccurate data caused by instrument drift or by loss of the instrument output).

To maximize and maintain CPM performance, each pipeline company should prepare a CPM instrumentation list and a maintenance and calibration plan with procedures. This plan should recognize the importance of the CPM system to provide safe operation of the pipeline and provide for the priority repair of CPM critical instrumentation and measurement. It is possible that the plan could result in instrumentation and measurement calibration practices that may exceed the requirements of applicable regulations.

In the CPM instrumentation and measurement calibration and maintenance plan, procedures should be developed to co-ordinate the test and re-calibration of field instrumentation with Pipeline Controllers and CPM system maintenance personnel, since re-calibration may affect availability and performance of the system. The procedures should include the date, time, person's initials, and the events performed during the test. Instrumentation and measurement should be calibrated in accordance with manufacturer's recommendations and calibrations should be traceable to National Institute for Standards and Testing. Operating experience should provide the basis for determining an appropriate test and re-calibration fixed interval. However, the CPM system itself, may be in some cases the best indication of the necessity to test and re-calibrate a particular instrument or measurement at a random interval

5.1.4 Signal Conditioning

Noise is that part of the signal received that does not represent the quantity being measured. Noise exists to some degree in all measured data. Noise may reduce the performance of the CPM system.

All practical means should be employed to reduce mechanical or electrical sources of noise at the instrument.

5.2 Communications

This portion of the recommended practice discusses or notes communication factors that can affect the quality and timeliness of the data required by the CPM system as well as the performance of the CPM system.

CPM systems must be implemented with an understanding of all aspects of the underlying communication infrastructure (e.g. the communication medium and error detection used, communication message structure and timing and communication deadbands as all CPM systems require reliable communications).

5.2.1 Communications Medium and Error Detection

All data communications media are subject to noise and interference that may cause data corruption. There is a varying degree of quality between the different forms of communication media used and Pipeline Operator should note the quality of their communication medium infrastructure.

Virtually all SCADA systems are designed to detect and reject communication corrupted messages. 'Data quality bits,' (sometimes called data attributes) that are available through the SCADA system can be useful to indicate lost messages and other information about the data (e.g. off-scan, alarm inhibited, manually entered, etc.). Ideally these status data should be used by the CPM system to identify missing, suspect or conditional data.

5.2.2 Communications Message Structure, Data Collection and Timing

SCADA systems gather data from field instrumentation using such Data Acquisition Devices known as Remote Terminal Units (RTU), Programmable Logic Controllers (PLC), Field Data Acquisition Servers (FDA), and/or Flow Computers (FC). Each of these Data Acquisition Devices may be interchanged for specific applications on the pipeline system. In this recommended practice the term RTU is used to cover all of these Data Acquisition Devices. The specifications of the messages between these devices and the SCADA system or the Control Center Computers are collectively referred to as the communications protocol. The CPM system should be implemented with an understanding of the underlying communications protocol.

The communications is said to be 'polled' when the SCADA system or Control Center Computer requests data from each field location in turn. The time interval required to poll all field locations and return to the first field location is referred to as ‘poll time’ or ‘scan time.’ To improve the scan time on slower communication channels and to gain efficiency on the communications channel, some protocols permit the field locations to respond with only the data that had changed since the previous poll. Such protocols are referred to as ‘Report-by-Exception.’ In polled systems the variation in reporting times from one field location to another is called ‘time skew.’ The software developers or CPM providers may also need to consider the impact of time skew in the data.

Communications may also be nonpolled, meaning this protocol is a variation of Report-by-Exception. The approach may also be called ‘Quiescent’ or ‘Unsolicited.’ This protocol operation refers to Data Acquisition Devices which report without being polled either on a time scheduled basis or when field data changes. See 5.2.3 ‘Analog Deadband’ for a description of analog data change. For Report-by-Exception protocols that use this approach, have no defined scan time so the age of a particular item of data may be in question. To deal with this situation, some SCADA systems generate ‘time tags,’ either in the RTU at the time data changes or in the Control Center Computer at the time the data is received. Time tags may be used by CPM systems designed to analyze transient conditions in the pipeline.

Some SCADA systems are capable of capturing instantaneous volumetric measurement simultaneously at all locations. This feature is usually called ‘accumulator freeze’ or ‘data snapshot’ and effectively permits all volume data to be interrogated at one reference time. CPM systems not equipped to handle time tags may use this method to eliminate time skew.

5.2.3 Analog Deadband

Measured variables from instrumentation are typically called SCADA ‘analogs.’ Report-by-Exception protocols and Quiescent systems that report changed data sometimes permit ‘analog deadbands.’ When the analog deadband is enabled, the value of the analog must change more than the deadband value before the new value is reported.

Analog deadbands are generally used to reduce traffic on the communications channel. Flicker or step changes in the analog signal will appear to be a valid change in data in Quiescent and Report-by-Exception systems. Deadbands, however, introduce a level of noise that may be counter productive for particular CPM methodologies that analyze the flicker for pattern changes.

When the precision of the SCADA system's analogtodigital conversion hardware exceeds the repeatability of the sensor, it is appropriate to reduce the precision using an analog deadband. Care must be taken not to use an excessively large analog deadband since this technique effectively reduces the precision of the analog value.

5.3 SCADA

The SCADA system is a computer based system. The Data Acquisition function includes gathering real-time data through a communication network. Control functions include controlling field devices. In addition, SCADA processes, displays, and/or may archive data, and provides warnings and alarms to the Pipeline Controller.

Generally, CPM systems use data gathered by the SCADA system, but some systems may gather data independently. Automated CPM systems may be interfaced bi-directionally with the SCADA system to receive pipeline data as it becomes available and to provide data back to SCADA or return alarm conditions to the SCADA system for alarm management utilities. Automatic transfer of the data makes it possible for the CPM system to analyze the data at a much faster rate. Such automation requires that all necessary data are available from the SCADA system or other sources (e.g. scheduling computer) particularly when needed.

The data processing function in the SCADA system is responsible for converting the data to a format suitable for display and use by applications such as CPM systems. This section describes data processing features that affect CPM system as well as the performance of the CPM system.

5.3.1 Time Tagging

Time tags record when a particular data point was last updated. Some systems generate the time tags in the RTU, but it is more common for the SCADA system or Control Center Computer to create the time tag at the time the data are either acquired or processed. Time tags, preferably originating at the RTU, can be used by the CPM system to reduce the effect of time skew, especially for accumulator values when a data freeze function is not available.

5.3.2 Data Quality

Data quality information may be stored with processed data. Typical data quality values that effect CPM systems include:

— 'Non-updated' or 'old data' caused by a RTU that is not responsive.

— 'Off-scan,' when a RTU has been taken off-line.

— 'Manual data' when manually entered data override interrogated values.

— 'Range error' when an analog value falls outside specified hardware limits.

— 'Alarm inhibited,' when the data is inhibited from alarming, even if out of tolerance (typically used during maintenance activities).

Data quality values may be used by the CPM system to help recognize and compensate for suspect data.

5.3.3 Analog Processing

Analog values typically represent measured variables such as pressure, temperature, density, viscosity or flow rate, but can also represent items such as tank levels. The analog values are usually compared to predefined threshold values to detect when the values fall outside the desired range. (e.g. operating and emergency limits). The Rate Of Change (ROC) is a calculated value, which is defined as the change of an engineering unit value per predefined time period. On Quiescent and Report-by-Exception systems, some type of smoothing algorithm, independent of the scan time, is usually needed to prevent the calculation of unrealistic ROC values for particular CPM approaches.

CPM systems generally rely on the scaled analog values and may also use sensors inputs that are external to the pipeline, i.e. ground temperature.

5.3.4 Status Processing

Status data record the state of an item of field equipment. Status pairs such as on/off or opened/closed can be stored in one binary digit or bit.

CPM systems may need status information to determine pipeline configurations or, if transient conditions are the result of change in equipment state. An event log, if available, may be a good source of information when interpreting CPM alarms.

5.3.5 Accumulator Processing

Accumulator values represent an accumulated total of some process quantity since the start of the totalization process. In liquid pipeline SCADA service, accumulators are typically used to record volumetric or mass quantities passing a given point in the pipeline system.

5.3.6 Alarm Processing

Alarms are a special case of events that indicate a transition into an abnormal state. The return transition to the normal state is generally referred to as 'return to normal'. Alarms can be either transitory or continuous in nature. Transitory alarms have no return to normal state and are simply an indication that something has occurred (e.g. two minute warning before a batch arrives, “pig signal” that a scraper has passed a station, etc.).

5.4 Data Presentation

Data presentation capabilities vary widely depending on the SCADA/CPM system. The contents of this section are intended to assist the pipeline company in achieving the best possible results in the existing system.

Effective presentation of Operating and CPM data should enable the Pipeline Controller to more easily identify and interpret hydraulic anomalies. Therefore this section is primarily concerned with the presentation of data from a CPM system.

5.4.1 Display Ergonomics

The software developer, CPM provider, or CPM integrator should carefully consider the aspect of display of the CPM system and alarms to the users, especially Pipeline Controllers, and consider using industry standards and/or recommended practices. API RP 1165 should be consulted. Other considerations should include:

— If possible, the CPM displays should have the same format and functionality as the SCADA displays so the usage is familiar to the Pipeline Controller. Consideration should be given to differentiating the SCADA or CPM displays so the Pipeline Controller will know which is being viewed.

— Where the Control Center has multiple consoles and pipelines, the CPM displays should be similar for each pipeline.

— The display should be designed to work well with the particular CPM methodology (e.g. uppercase letters may be more readable on some screens and applications). If other tasks are on the same CRT, care should be taken to prevent interference with the monitoring of the CPM system.

5.4.2 Trending

Trending operating parameters (e.g. flow rate, pressure, viscosity, density, deviation and temperature) from the SCADA system and/or from the CPM may help determine what caused a CPM alarm. If trending is employed, the trend needs to cover a long enough duration to see values from before the CPM alarm occurred right through to the time when the alarm ends, or the current time. Trending analog values can aid in the troubleshooting of alarms in CPM systems because the analog devices alone cannot always give all of the information needed to make a correct leak declaration. Tabular trends are not as easy to analyze as graphical trends, but are still effective ways to display historical data.

5.4.3 Alarm Display

Alarms (for both SCADA and CPM) should be presented as both audible and visual. Alarms should have different colors if there are different categories of alarms. Visual alarms should be presented in such a way as to persist for some period of time, especially so as not to be overwritten irrevocably by newer alarms. Acknowledged alarms that are still in the alarm state should remain readily available to the Pipeline Controller. Audible alarms can be varied for different categories of alarms.

Acknowledged and unacknowledged alarms should be available to the Pipeline Controller without using several steps to get to the alarms. A time stamp should be part of the alarm when it is displayed.

Provision should be made against an alarm being easily defeated, or inhibited without just cause. The use of screen savers or any other screen blanking is strongly discouraged.

SCADA systems may have other types of alarm related displays (e.g. chronological alarm logs/files; unacknowledged alarm summaries; and summaries of points in an unusual state).

CPM alarms should be consistent with SCADA system alarms and should have an appropriate priority.

5.5 Integration of CPM and SCADA

CPM systems may be closely integrated with the SCADA system. When CPM alarms and processed data are sent back to SCADA, they can be integrated into the standard SCADA displays. Maintaining a familiar method of data presentation will facilitate proper interpretation of the data by the Pipeline Controller. In addition, it is the preferred configuration because it allows the Pipeline Controllers to view and analyze CPM data and alarms in conjunction with SCADA activities and events.

If the CPM and SCADA systems cannot be integrated, the CPM alarms should be displayed so that they will be readily noticed. In either case alarms should be logged and retained.

Non-integrated systems should provide event and alarm retention for the CPM. All displays and data should be easily accessible by the Pipeline Controller to aid in operations of the CPM system along with the SCADA system. The hardware design should provide sufficient resources, either by organization of displays or providing sufficient CRTs to display needed information for analyzing alarms.

5.6 Data Historian

Ideally, CPM systems may store data values to a historical database. Historical information retrieval is valuable for re-play of the CPM: to examine or analyze normal operation, irregular operating conditions, or abnormal operating conditions; for Controller training; or to validate and sometimes improve sensitivity, accuracy and robustness of CPM.

A combination of historical and re-play data may provide the ability in some systems to recreate a series of events in a CPM system.

6 CPM Operation, Maintenance, and Testing

This section describes the CPM operation, maintenance, testing, data retention, Pipeline Controller training, and documentation for a CPM system.

6.1 CPM Operations

CPM systems employ an inference engine and an alert algorithm that are defined for a given pipeline and its instrument and measurement data, configuration data, and product accounting data. The inference engine may use hydraulic calculations or it may calculate data to infer the pipeline parameters. The alert algorithm considers inferred data and/or actual data and should issue an alarm if a limit is exceeded (e.g. a mass conservation algorithm or a statistical algorithm's defined limits).

In the context of CPM, an alarm is an automated or manual signal or other presentation of data concerning an abnormal or emergency event on the pipeline to the Pipeline Controller (via a SCADA system Pipeline Controller interface, a separate interface, or manual tabulation sheets). An alarm could be triggered by many causes including equipment or data failure, an abnormal operating condition or a commodity release. Since there is the potential that the alarm information identifies conditions that need attention other than a commodity release, the pipeline company procedures should require that all CPM alarms be evaluated. The causes of the Pipeline Company CPM alarms are not usually determined by a separate piece of software, (i.e. an expert system) that provides the cause or probability of cause, but by the Pipeline Controller or CPM support person. Simply understanding the cause of the alarm condition on a monitored pipeline may not be the end of the alarm evaluation.

For an operating CPM system, the following types of CPM alarms need to be considered.

6.1.1 Types of CPM Alarms

In this recommended practice, CPM alarms are subdivided into three classes, which are: data failure; irregular operating condition; and possible commodity release. Ideally the categorization of the alarm into one of these three classes should be made by the CPM system as the categorization of the alarms help justify the CPM system credibility and sensitivity of the CPM system. Many CPM systems provide just one type of alarm and so in this case the determination of the cause and categorization of alarm should be made by the person who evaluates the alarm (the Pipeline Controller or perhaps jointly with a CPM support person) or by a separate piece of software (i.e. an expert system) that provides the cause or probability of cause. Automatic alarm cause evaluation would be a desirable CPM system feature.

— *Data Failure Alarms.* This class of alarm would occur when critical CPM input data are missing or are determined to be incorrect. This class of alarms may also be called system impaired alarms. Also included in this type of alarm may be alarms that occur when the CPM system fails. An example of missing input data would be a communication failure at a metering location. An example of incorrect data would be a pressure instrument that consistently reports values that have no hydraulic relation to other pressure and flow data on the pipeline. In this case the instrument may be out of calibration or locked at a fixed value. These incidents may be presented as types of data failure alarms. These data failure alarms could be automatically generated by the SCADA system, CPM system, or as manual entries in a Pipeline Controller's shift log. Some CPM systems would indicate the impact the data failure has on continued CPM operation. The impact of this class of alarm could range from no effect to the disabling of the CPM commodity release detection threshold. In the case where the CPM system has failed, the impact would be total loss of this type of leak detection. The identified failure of one or a series of measured or calculated data points should not trigger a leak declaration. Ideally, the internal CPM analysis utility should be able to identify data failures and alert the Pipeline Controller that this problem exists.

  The procedures that the Pipeline Controller should follow under this situation would be defined by the individual pipeline company for the particular CPM system.

— *Irregular Operating Condition Alarms*. This class of alarm may be generated when a data set is outside normal operating ranges, fails all tests for a data failure condition, and does not meet all tests for a possible commodity release. These alarms may also be called diagnostic alarms. This class of alarm is intended to provide a second diagnostic condition between normal pipeline operation and a possible commodity release leak declaration. These diagnostic alarms could be automatically generated by the SCADA system or the CPM system. If the alert algorithm subsection of the CPM system cannot determine to a set level of certainty that a commodity release situation does exist, then some CPM systems may declare an irregular operating condition alarm. The purpose of this class of alarm is to minimize incorrect leak declarations. The irregular operating condition alarm would notify a Pipeline Controller of a problem that requires immediate investigation. For example, this type of alarm would occur during slack line or column separation on a pipeline which seldom experiences this condition.

  The procedures that the Pipeline Controller should follow under this situation would be defined by the individual pipeline company for the particular CPM system. The irregular operation condition alarm may supply data to the Pipeline Controller to aid in the situation analysis.

  Continued refinement in this area, which represents a significant technological challenge, may ultimately reduce the numbers of this class of alarm, allowing the CPM system to properly classify more alarms as data failure or possible commodity releases.

— *Possible Commodity Release Alarms*. In the case where the CPM system indicates a possible commodity release, an alarm should be generated by the CPM system. In most cases, the final determination of whether the alarm indicates a commodity release should be made by a Pipeline Controller who will use the CPM and SCADA system output to determine with a reasonable level of certainty that a commodity release situation does exist and is not a data failure alarm or an irregular operating condition alarm. In the case of closed loop control (which may be possible on some pipeline systems) the CPM system could automatically initiate action to shutdown the pipeline.

NOTE Automatic closed-loop control response to alarm conditions that includes automatic valve closure requires a careful study of the pipeline hydraulics prior to implementation. Automatic valve closures can potentially result in excessive surge pressure in liquid pipeline systems. If automatic valve closures are implemented, then ideally the Pipeline Controller would have the capability to override the automatic system for just cause.

6.1.2 Alarm Response Considerations

Many CPM systems provide just one type of alarm, a commodity release alarm. The operational responses to a CPM system alarm need to consider these factors:

— All CPM alarms have a cause.

— CPM alarms will be probabilistic, and need to be assessed in light of the current sensitivity threshold.

— Past instances of alarm causes can be a useful guide in alarm evaluation but every alarm should be evaluated individually and assumptions of previous causes should not be readily made.

Operational response to a CPM system alarm would normally include:

— Investigation of the cause and initiation of action will likely following a company procedure.

— Shutdown of the pipeline based upon a Pipeline Controller decision or a method which will not compromise the integrity of the pipeline.

6.1.3 CPM System Credibility and Review

A CPM system design goal is to maximize the system sensitivity to leaks (or to find all leaks within the threshold of the system) and to minimize the occurrence of a leak declaration until the alert algorithm within the CPM indicates, with a high probability, the presence of an actual commodity release.

System credibility may be enhanced by occurrence of a certain number of CPM alarms that can be expected because of a condition on the pipeline (e.g. failure of a meter). The Pipeline Controllers will understand the reason for such alarms and will know that the CPM system is functioning. However, an excessive number of alarms will detract from system credibility and may create complacency. It is suggested the cause and the number of CPM alarms should be reviewed on a periodic basis as to attempt to reduce the number of CPM alarms without affecting system credibility. The number of commodity release alarms can be a determining factor in the sensitivity of the CPM system. There is a balanced relationship between the number of commodity release alarms and the sensitivity of the CPM system.

6.2 System Testing

This section outlines testing methods and intervals to be considered for a CPM system. Testing of CPM systems is performed to establish a baseline of achieved performance for new CPM systems, or when there are changes to the CPM or the pipeline system that warrant re-evaluation of system performance, or for periodic evaluation of actual system performance.

The primary purpose of testing is to assure that the CPM system will alarm if a commodity release occurs. Another purpose of testing may be to assure that data failure alarms and irregular operating condition alarms function as expected. The text that follows will not discuss CPM testing for other than commodity release alarms.

Prior to testing, careful planning should be considered as to the reasons for the test and methods that will be employed and the process and procedures that will be followed. The test should be well managed to make sure it achieves the desired results.

Consideration should be given to the potential for a reduced level of pipeline monitoring during a CPM system test. The Pipeline Controllers should be alert to the possibility of an actual commodity release that could occur simultaneously with the CPM system test and that an actual commodity release may be disguised or misdiagnosed during the test interval.

6.2.1 Testing Methods

CPM systems should be tested to alarm state with actual or simulated commodity removal. The test method and testing parameters should be chosen to be representative of line operating conditions.

Possible methods of testing include but are not limited to:

— Removal of test quantities of commodity from the line.

— Editing of CPM configuration parameters or SCADA inputs to simulate commodity loss (software simulations) or a desired hydraulic condition.

— Altering an instrument output that is critical to the CPM: e.g. altering a meter factor to simulate a volume imbalance, or a pressure output to simulate a hydraulic anomaly.

CPM tests may be ‘announced’ or ‘unannounced.’ An announced test is started with the awareness of the Pipeline Controller and tests only the CPM system. An unannounced test is started without the knowledge of the Pipeline Controller and tests the CPM system as well as the response of the Pipeline Controller. Generally, unannounced tests are used only if the performance of the CPM system has been established by previous successful announced tests.

The location of the test may be varied from one test to the next so the CPM system experiences leak tests at various locations. This may increase the confidence in the capabilities of the CPM system. In addition, the test may be performed at more than one withdrawal or simulated withdrawal rate or operating condition so the time and leak rate response of the CPM can be evaluated over a range of possible leak scenarios.

6.2.2 Initial Tests during CPM Commissioning

A new CPM system should be tested to verify that it has achieved the design or expected performance and to establish a baseline of performance. Throughout the installation and commissioning procedure, there may be a number and variety of tests. These tests would be to ascertain the ability of the CPM system to function under varying operating conditions that are indicative of line operations. Initial tests may use simulated commodity releases. Consideration may be given to testing by actual removal of commodity from the pipeline for the final system test because the final test before acceptance will establish the baseline.

Subsequent CPM implementations on similar pipelines that employ the same CPM methodology may be able to use different initial test methods and may be able to take advantage of CPM work and testing on other pipelines.

Initial CPM tests should be rigorous and be planned and executed using good engineering and technical judgment on issues such as test methods employed, commodity loss rates, and situations to be simulated.

Testing, operating experience, offline modeling, or an API Publ 1149 type analysis or other theoretical analysis of the CPM/pipeline fit may establish the CPM baseline.

6.2.3 Periodic Retesting

CPM retesting of applications will be necessary on a periodic basis to meet regulations or to confirm the continued effectiveness of the CPM. Retesting will be documented in test records.

CPM applications should be tested on a 5-year interval to confirm the CPM system's continued effectiveness. More frequent testing should be done if there is a change in regulations that require retesting. It may not be necessary to test each pipeline system that uses the same CPM application, but consideration may be given to rotation of the tested pipeline and to varying the location of the test from one test to the next. Testing should be conducted in a manner consistent with producing results that are repeatable from test-to-test to assure that the leak threshold of detection does not vary widely or increase over time. The retest may use the same method employed in the initial tests or may use another test method.

Operational use of a CPM system, such as successful detection of a commodity release, may be an acceptable substitute for periodic retesting if it demonstrates continued effectiveness of the CPM. A successful identification of an actual commodity release, by an in-production CPM, shall be considered as sufficient for resetting of the 5-year retesting interval.

Subsequent tests may not be as rigorous as the initial tests. If no changes have been made to the pipeline or the CPM during the retest interval the re-test will be a confirmation test only.

6.2.4 Change-driven Testing

CPM systems should be retested following significant changes to ensure that the performance of the CPM system is not impacted. Pipeline Operators must use discretion in deciding what constitutes a significant change that may affect the CPM. Examples of significant changes could include, but are not limited to:

— Major pipeline or software configuration changes or addition of features.

— Abnormal pipeline operating conditions.

— New versions of the CPM software.

— Instrument and measurement additions or changes.

— SCADA system updates.

The decision to perform change-driven testing will be based upon individual analysis of the possible effect on performance and on a line-by-line basis. Consideration should be made as to how to document, if necessary, this analysis. In the case of pipeline configuration changes, testing similar to initial or periodic testing should be considered. Other changes may be tested using an actual commodity release data set, a data set from a leak test, a test simulation or other off-line system testing.

In all cases the persons responsible for the CPM will determine which method is best suited to test the CPM system following significant changes.

The results of change-driven testing may not be recorded in test records. However, when the test is documented in accordance with 6.2.6, such tests may be considered a periodic retest and will set the start of a new testing interval.

6.2.5 CPM Systems Self Testing

Some CPM systems may be capable of running self-diagnostics on a scheduled basis. Such diagnostics may monitor the health of the CPM system and may create CPM alarms. This may be a desirable system feature if the disruptive effect of these alarms on the Pipeline Controllers can be minimized.

CPM systems self tests do not meet the criteria for periodic retesting or change-driven testing.

6.2.6 Test Records

Records detailing the reasons for the tests, the test parameters and methodology and the test results should be recorded and retained for initial tests and for retests. These details of at least two previous tests should be retained. Details of any actual commodity release, if that event is considered as a retest should be retained at least as a part of the two previous tests.

The pipeline company or operator policy will dictate the requirements for documentation of tests. Considerations for what information to include in the test records include:

— Date, time and duration of the test.

— Technical reasons for the test that documents the reasons the test is to be performed and why the methodology and particular parameters have been chosen.

— Method, location and description of the commodity withdrawal when used.

— Operating conditions at the time of the test.

— Details of any alarms generated during the test.

— Analysis of the performance of the CPM system and, for unannounced tests the effectiveness of the response by operating personnel.

— Documentation of corrective measures taken or mitigated as a result of the test.

6.3 Operating Issues

For an operating CPM system, the following issues need to be considered:

6.3.1 Security

Refer to API Std 1164 for general security provisions. Additional security privileges should be added for any CPM user interface device, parameter, alarm inhibit, and/or limit which could interfere with or degrade the performance of the CPM function.

6.3.2 Parameter Changes

Provisions should be made against any alarm, parameter, and or sensor being inhibited without just cause.

System changes can be made in a number of ways. These changes should be coordinated or otherwise managed. It is desirable that any changes be audited and the changes should not go on-line or active until validation is complete. Any parameter or function that requires validation after the change should not be immediately incorporated in the on-line production system, but instead should be accessible and tested only in an off-line mode, if possible.

An audit trail should be maintained to include date, time, parameter, original setting, new setting, and person performing the change.

All CPM alarms and Pipeline Controller initiated commands and events, which are part of data retention, may be stored in hard copy or “read only” format. All “read only” files should be protected from loss and unauthorized tampering.

The pipeline operating company should develop and implement a revision and release policy for software and firmware used within a CPM system.

Consideration may be given to allow the Pipeline Controller to make changes to parameters that are important in day-to-day or shift specific operation. The CPM system design may include provisions to allow the Controller to modify and adjust parameters within fixed boundaries. Changes by the Pipeline Controller that affect the long term operation of the CPM system should not be allowed.

The ability to make changes in the CPM system boundaries should only be accessible to authorized personnel and under the control of appropriate written procedures. Such changes should be recorded in either an automatic log in the shift log.

6.3.3 Pipeline System Maintenance Activities

The Pipeline Controller should be informed or have an indication whenever a CPM system sensor is inhibited and or disabled which causes the system to operate in a degraded mode. This may include the sensor's calibration problems, communications problems, and software failures. This indication when identified could be provided by the SCADA system or other data gathering methodology if not integral to the CPM system.

Provisions should be made to minimize the effect of maintenance on the performance of the CPM system during periods of hardware, software and field equipment maintenance and system upgrades.

System maintenance should be performed under the control of maintenance procedures, which address the effect of field and system maintenance on CPM performance. The procedure may also address the communications requirements between maintenance personnel and the Pipeline Controller.

6.4 CPM System Data Retention

The retention of data and reports from a CPM system may be governed by several factors including the requirements of regulations, company policy, engineering and operations requirements and the Pipeline Controller training requirements. Careful consideration of what should be retained over and above that required by regulations is recommended. The considerations should also include what types of data and information may be useful or helpful in the future (e.g. a dataset from a leak or leak test that can be used to verify CPM performance after changes have been made to the system). Include verbiage input and output somewhere around the datasets.

In any case, all occurrences of a leak declaration should be historically documented and Pipeline Controller response evaluated. Historical retention periods may vary from Pipeline Operator to Operator.

6.5 Pipeline Controller Training and Retraining

The users of the CPM system (i.e. the Pipeline Controllers) and any CPM support staff require appropriate CPM training. CPM alarms may be the most complex type of alarm experienced by the Pipeline Controller. Specific training and reference material is necessary to prepare the Pipeline Controller to adequately recognize and respond to these alarms. This requires both a knowledgeable perspective on the alarms themselves as well as the nature of the alarms. The American Petroleum Institute has created a publication (API Publ 1161) for Controller Training that considers many important related training issues outside the scope of this recommended practice.

The training plans may include;

— Periodic reviews and or knowledge testing of the Pipeline Controller.

— Review of training material to be accurate and thorough.

Retraining may be aided by review of known cases where the irregular operating condition alarms or abnormal operating conditions have occurred and possible commodity release alarms have been generated.

The following technical areas may be considered (only as they relate to the CPM system):

— *Hydraulics*. A Pipeline Controller should be trained in the basic concepts of pipeline steady state hydraulics as they relate to the CPM system. The variances of hydraulic pressure due to elevation profiles, batches of differing density, temperature effects, and DRA. The Controller should also be trained in the basic relationship of pressure and temperature during shut-in conditions.

  A Pipeline Controller should be trained to recognize the effects of pump start-ups/shutdowns, valve operation switch, pressure setpoints and other everyday activities, which cause transient conditions. Any of these will cause a system flow or pressure transient to appear potentially affecting CPM thresholds leading to non- leak alarming.

— *Alarming/Performance*. The Pipeline Controller should be able to recognize and react to all CPM alarming, cognizant to indicators of CPM system performance.

— *Data Presentation*. A Pipeline Controller should be trained in the recognition of the CPM notification or alarm and may be trained to research the cause of the alarm (data failure, irregular operating condition or possible commodity release), or in methods of correlation of the alarm to independent data so the Controller will pursue the appropriate response. The presentation of CPM alarm data is a crucial component, such as the trend of the probability of a leak, or the description of the location for which the leak declaration has occurred. Other specifics to Data Presentation can be referred to in API RP 1165.

— *Instrument Failure*. The Pipeline Controller should be able to qualitatively identify the impact of an instrument failure on the CPM system. The Pipeline Controller should be trained to link the alarm event with the concept that the CPM system could be impaired.

— *Validating CPM Alarms*. An evaluation of the CPM system and operating conditions is necessary for validating or explaining the cause of a CPM alarm. The Pipeline Controller should be trained to recognize and react to abnormal operating conditions and to take appropriate action. The training may be directed towards following procedures or calling upon and working with external resources for alarm evaluation.

— *Line-pack Change (Online)*. A Pipeline Controller should be trained to recognize CPM hydraulic pressure changes due to varying line-pack. A fundamental element in the spectrum of inventory control is the calculation of mass, or the comparison of barrels in versus barrels out. This training would include the ability to recognize the compressibility behavior of the liquid hydrocarbons that are transported.

  A Pipeline Controller should be knowledgeable about sections of the pipeline that are susceptible to intermittent “slack line conditions.” The Controller should be knowledgeable about how this condition affects the CPM performance.

— *Trending*. A Pipeline Controller should be able to recognize benefits provided by trending analysis of pipeline variables from SCADA and CPM. Trending data can be presented graphically or may be presented as a tabular display of historical data. A graphical output may provide the best visual history of CPM parameters. The Controller should be able to cross correlate CPM output with SCADA output wherever possible confirming CPM alarm evaluation.

— *CPM System Operation*. The Pipeline Controller should be trained to understand the CPM system, and the concept/theory of its operation. A portion of Pipeline Controller training may include periodic review of the use of the CPM system in a training environment. Training may cover all the various CPM systems in use within the Control Center and unique aspects of each application as they apply to individual pipeline segments.

  The Pipeline Controller should be trained to interpret alarms correctly and in a timely manner or work with internal or external resources to evaluate the alarm. The CPM system should be implemented so the alarms are readily recognizable.

— *Abnormal Functions*. The Pipeline Controller should be trained to recognize and react to the abnormal function of a CPM system as well as the abnormal function of the SCADA system. The loss of either should elicit certain predefined actions intended to preserve pipeline integrity. Targeted response actions should be thoroughly analyzed and scripted for prompt, efficient action.

For example, if the CPM system becomes non-functional or severely degraded due to field equipment or SCADA failure, the Pipeline Controller should be trained to employ other leak detection methods to compensate for the inadequacies of CPM. Alternatively, the Control Center may need to define what interval of time the CPM can be non-functional and what action needs to be taken. Short term solutions may consider manual line balance and over-short and Pressure/Flow Monitoring. Actions might include tightening of pressure and flow alarm parameters.

— *Other Leak Detection Techniques*. The Pipeline Controller should be trained in how to employ the results of other leak detection technique such as third party reports, SCADA deviation alarms, etc. so that a CPM system is not considered to be the only means of detecting leaks. The Controller should know what procedures to follow and reactions to make for other methods.

6.6 CPM Documentation

Each CPM system employed on a pipeline system should be fully described and the documentation should be readily available for reference by the users and by those employees responsible for the maintenance and support of the CPM system. Consider the following information;

— A tabulation of the inputs used in the CPM procedure for each pipeline segment.

— A summary of the characteristics of each product transported.

— A general description of the CPM outlining its principles of operation.

— An elevation profile.

— A list of special considerations or step-by-step procedures to be used in evaluating CPM results and for requesting assistance with alarm evaluation.

— Details of the expected performance of the leak detection system under normal and abnormal conditions; and the effects of system degradation on the leak detection results.

— CPM Pipeline Controller training manuals or information.

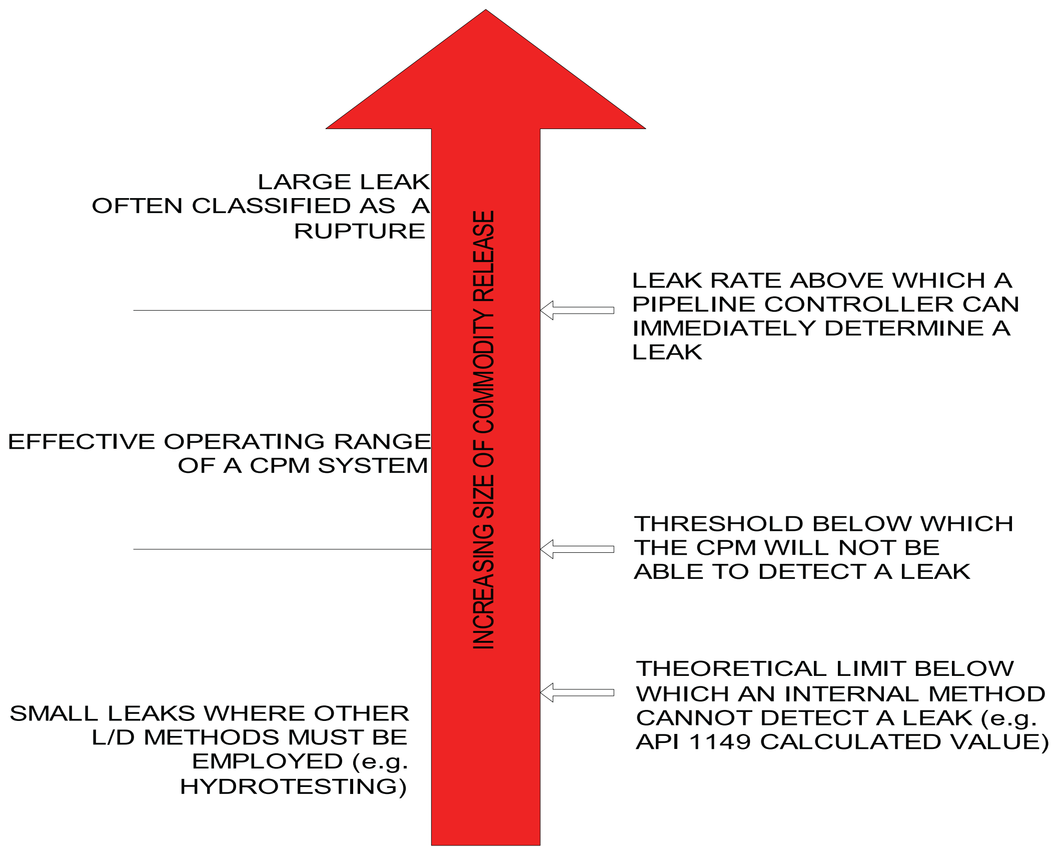
— CPM alarm thresholds for the various applications.

Annex A

Discussion of CPM Thresholds

This annex discusses and illustrates that CPM is a pipeline tool designed to detect leaks within its capabilities. It will detect commodity releases or hydraulic anomalies that look like releases. Similar to any other tool, the CPM system is useful for a specific purpose and has its limitations. Limitations can be due to many reasons, which are discussed below.

This diagram shows increasing sizes of commodity release and what sorts of techniques find leaks in the leak ranges:



Important concepts:

— The volume of product loss that occurs in any leak will be different for each individual pipeline. Therefore, it is impossible to specify an absolute leak volume number.

— Operating conditions of the pipeline (steady state or transient) will influence the minimum size of commodity release that can be detected so, CPM detection limits are not fixed. API Publ 1149, for example, provides a method to calculate theoretical detection limits while the pipeline is in steady state operation and to some extent when hydraulic conditions are transient. During transients the detectable limit is higher.

— Performance of Conservation of Mass CPM systems (the most common applications of a CPM) are influenced by the time over which the leak occurs and the magnitude of the leak. A commodity release at a high rate may exceed the CPM threshold quickly whereas a leak at a smaller rate will take longer to exceed the CPM threshold. Other factors that need to be considered for Conservation of Mass system:

  — Slack line flow affects the volume in/out relationship.

  — The line pressure at the leak site affects the leak rate.

  — The operating state of the pipeline: transient operation increases packing/unpacking uncertainties.

  — CPM technique and tuning: some applications are optimized to finding small leaks over a long time window.

  — SCADA scan rate: a slower scan will provide CPM data more slowly and may increase time skew.

  — Flow rate: at a lower rate the CPM may be less sensitive.

  — Temperature gradient: pipe inventory is greatly influenced by fluid temperature.

  — Length of the balance section: longer sections have a greater uncertainty in the pipe inventory and take longer to react to operational changes.

— Performance of a CPM is governed by uncertainties in instruments, by knowledge of the physical details of the pipeline, and by the noise of the data used by the CPM. For example, less accurate data or instruments may affect threshold and/or detection time.

— Although a CPM system will alarm on a large rupture size leak, the line hydraulics will deteriorate to such an extent that the Pipeline Controller will be able to determine a leak immediately.

— There will be a small leak size limit below which the CPM is not capable of declaring a leak.

— Different CPM methods will find different sizes of leaks. Use of multiple CPM methods, each with its own capability, are suggested.

— The CPM sensitivity may be affected by the flow rate of the line at the time of the commodity release. At a lower than normal rate the CPM system may be less sensitive.

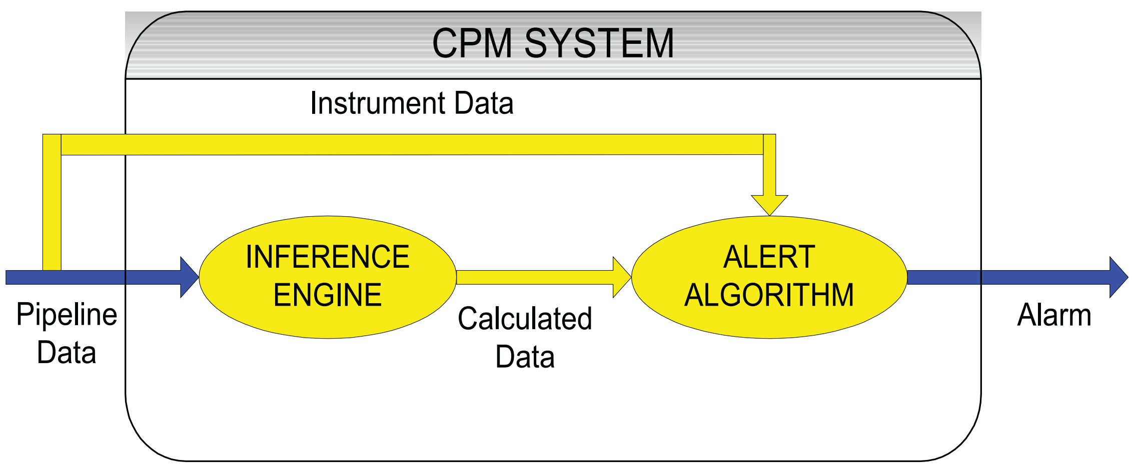
Annex B

Description of Types of Internal Based CPM Systems

A CPM system is comprised of two parts, which can be called an Inference Engine and an Alert Algorithm. The figure below shows the two parts, and these two parts are defined above.

The inference engine accepts data from instruments on the pipeline. For CPM systems the most common being: flow meters, pressure sensors, temperature sensors, densitometers, and status's (valves, pumps). The data may be used in calculations to produce new values, for example flow may be corrected to standard conditions; the calculations may use hydraulic formulae to calculate fluid flow; or pressure may be averaged. The values are then passed to the alert algorithm.

The alert algorithm accepts values from the inference engine and/or data for field instruments and compares the values to thresholds. If the values exceed the threshold the algorithm determines if an alarm and what type of alarm should be generated.



There are two primary technologies used in CPM systems: Conservation of Mass or Mass Balance methods; and Signature Recognition methods. Conservation of Mass methods work on the principle that whatever enters the pipeline must be equal to whatever exits the pipeline adjusted for change in inventory of the pipeline. Signature Recognition methods consider the relationships of system pressure and/or flow or recognize anomalies in sensor outputs on the pipeline.

Common names and types of CPM techniques are described below. These are included here to provide more vocabulary for the reader of this document and were outlined in the previous versions of this document.

B.1 Line Balance CPM Techniques

These meter-based methods determine the measurement imbalance between the incoming (receipt) and outgoing (delivery) volumes. The imbalance is compared against a predefined alarm threshold for a select time interval (time window). The imbalance is typically monitored over a number of time periods or windows (e.g. 15 minutes to 24 hours, also weekly and monthly) to detect commodity releases of different sizes.

The capabilities of the basic technique (i.e. simple meter in/meter out comparison) can be enhanced by applying correcting the meter readings to standard conditions and by compensation for changes in pipeline inventory (line-pack) due to temperature and/or pressure and/or commodity characteristics. Good engineering practice should be applied to determine the CPM's requirement for line-pack correction.

Names that are used for enhanced line balance techniques are: Volume Balance; Modified Volume Balance, and Compensated Mass Balance.

All of these systems use Conservation of Mass CPM techniques.

B.2 Real Time Transient Model (RTTM) CPM

The fundamental enhancement that a RTTM provides over the enhanced Line Balance methods is that it compares the model directly against measured data (i.e. primarily pressure and flow) rather than use the calculated values as inputs to volume balance. Extensive configuration of physical pipeline parameters (length, diameter, thickness, pipe composition, route topology, internal roughness, pumps, valves, equipment location, etc.) commodity characteristics (accurate bulk modulus value, viscosity, etc., and local station logic (e.g. pressure/flow controllers) are required to design a pipeline specific RTTM. The application software generates a real-time transient hydraulic model by this configuration with field inputs from meters, pressures, temperatures, densities at strategic receipt and delivery locations, referred to as software boundary conditions. Fluid dynamic characteristic values will be modeled throughout the pipeline, even during system transients. The RTTM software compares the measured data for a segment of pipeline with its corresponding modeled conditions.

A RTTM uses a Conservation of Mass CPM technique although it is possible to utilize Signature Recognition in a RTTM.

B.3 Statistical Analysis CPM

The degree of statistical involvement varies widely with the different methods in this classification. A more sophisticated statistical approach may calculate the probability of commodity release against the probability of no-commodity release. Pressure and flow inputs that define the perimeter of the pipeline are statistically evaluated in real-time for the presence of patterns associated with a leak. A probability value is assigned to whether the event is a commodity release. The analysis can, with suitable instrumentation, provide intelligent alarm processing which reduces the number of alarms requiring Operator analysis. This type of CPM methodology does not require an extensive data base describing the pipeline. The Statistical Process Control (SPC) approach includes statistical analysis on pressure and/or flow. SPC techniques can be applied to generate sensitive CPM alarm thresholds from empirical data for a select time window. A particular method of SPC may use line balance data from normal operations to establish historical mean and standard deviation. If the mean value of the volume imbalance for the evaluated time window increases statistically, the CPM system will give a warning. An alarm is generated if the statistical changes persist for a certain time period. Also can correlate the changes in one parameter with those in other parameters over short and long time intervals in order to identify a hydraulic anomaly.

Statistical analysis CPM systems can utilize either Conservation of Mass techniques or Signature Recognition techniques or both techniques.

B.4 Pressure/Flow Monitoring CPM

Pressure/Flow Monitoring CPM examines the relationship between various sensors outputs and applies an algorithm to determine if they indicate an anomaly.

Generally, more simplistic Pressure/Flow Monitoring techniques that alarm a single variable such as pressure/flow-rate deviation and pressure/flow-rate limit monitoring, although providing valuable information to the Controller, *are not considered CPM systems.*

CPM Pressure/Flow Monitoring techniques should make use of an inference engine and generally use multiple variables to alert the Controller of a possible leak.

Pressure/Flow Monitoring CPM usually utilizes Signature Recognition techniques.

B.5 Acoustic/Negative Pressure Wave

The Acoustic/Negative Pressure Wave technique takes advantage of the rarefaction waves produced when the integrity of the pipe is compromised and a leak occurs. The leak produces a sudden drop in pressure in the pipe at the leak site. The leak generates two negative pressure or rarefaction waves, one traveling upstream and the other downstream. For this CPM, high response rate/moderate accuracy pressure transmitters at installed a selected locations on the pipeline. The transmitters continuously measure the fluctuation of the line pressure. A rapid pressure drop and recovery will be reported to the central facility. At the central facility, the data from all monitored sites will be used to determine whether to initiate a CPM alarm.

Acoustic/Negative Pressure Wave CPM utilizes Signature Recognition techniques.

Annex C

Metrics and Other Pertinent Text from API Publ 1155

Explanation of this annex. API Publication 1155, *Evaluation Methodology for Software Based Leak Detection Systems* is being withdrawn by API. The Task Force charged with the development of this document decided to include the valuable definitions and discussion into an annex so it is still available. The sections which were thought to be most pertinent are included below. A few minor modifications to the text have been made to make it consistent with the body of this document.

API 1155 Overview of Pipeline Leak Detection

Pipeline leak detection is treated herein as a classical problem in parameter estimation. In other words, the software-based leak detection system estimates parameters based upon measurement data. The leak parameter estimates are then examined to decide if they warrant the issuance of an alarm to indicate the likely presence of an actual leak. Note that the estimated parameters depend upon the nature of the leak detection system. These might include the leak flow-rate, amount of fluid lost, magnitude of pressure or flow disturbance at the leak site, most probable location of the leak, and so forth. Virtually all systems that make a statistical decision based upon a set of measurement data can be discussed within the framework of this model.

As represented in Figure 1, the detection problem is a step-wise process that logically separates each of the system's components in terms of their relationship to the desired result. The software-based leak detection system relies on data values acquired from some reliable source, usually the real-time SCADA system, to provide a series of data sets representative of actual conditions at any given point in time. Once data for a given time period have been acquired, they are subjected to some pre-determined mathematical or statistical analysis process that generates additional data based on an assumed model of the pipeline and its associated parameters. Results from the analysis process are produced in the form of parameter estimates. These parameter estimates are in turn subjected to some probability law or decision criteria to determine if a leak does indeed exist. In the simplest case, a given set of data can represent one of two possible outcomes; the existence of a leak or the absence of one. Typically, the process requires an examination of many complex data interrelationships in order to provide acceptable results. Depending upon the nature of the leak detection system, this examination might be done over a small window in time or it could involve periods of several minutes or even hours. In some cases, the time required to make a decision might also depend upon the size of the leak, if one should occur.

The phrase “model of the pipeline” is used in the most general sense. Some vendors and client companies tend to group software-based leak detection systems into the two categories “model-based” and “not model-based,” depending upon whether or not the system involves a fluid dynamics model. In fact, this is an incomplete characterization. Fluid dynamics models employ one or more of the basic equations of fluid mechanics, which include the equations of continuity, momentum, and energy. However, there are a number of software-based leak detection methods, all of which are based upon some set of rules or “model” describing the pipeline operation. It is this set of rules that determines how such systems use the measurement data to make decisions.

Leak Detection Performance

Determination of the presence or absence of a leak requires that the software-based leak detection system has prior knowledge of the problem to be solved and some pre-determined criteria upon which to base its decision. In the most general sense, there are four possible outcomes each time the leak hypothesis is tested:

1) The system correctly indicates that there is no leak,
2) The system correctly indicates that there is a leak,
3) The system incorrectly indicates that there is a leak, and
4) The system incorrectly indicates that there is no leak (failure to detect).

Outcomes 1 and 2 constitute proper operation of the leak detection system whereas outcomes 3 and 4 constitute failure of the system. In the ideal system outcomes 3 and 4 never occur.

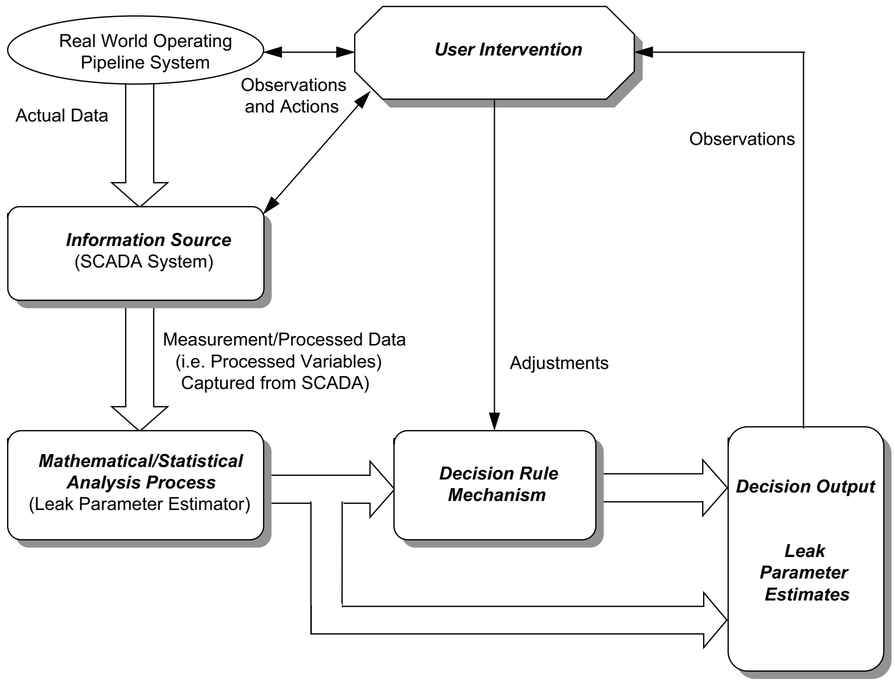


Figure 1—Generalized Example of the Software-based Leak Detection Process

To further characterize an ideal leak detection system, one should recognize the importance of an accurate and timely response in the event that a leak occurs. With this in mind, the characteristics of an “ideal leak detection system” are easily stated. Such an ideal system would always and immediately detect any leak that might occur and it would never incorrectly declare a leak. Furthermore, it would always and immediately provide an accurate estimate of the location and size of any leak. Of course, there are no known software-based leak detection systems that currently provide this ideal level of performance. Furthermore, certain characteristics of the “ideal leak detection system” impose conflicting requirements upon practical leak detection systems. For that reason, it is not likely that such an ideal system can ever be achieved in practice. Thus the task of determining the best leak detection solution for a given pipeline always involves performance tradeoffs. In many cases these tradeoffs should be judged before the leak detection system is actually installed on the pipeline. In some cases, the leak detection system may be selected before the pipeline itself is placed into operation. Once installed, periodic adjustments of leak detection system parameters might be necessary to account for operational experience, configuration changes, and so forth.

Appraisal of Leak Detection System Performance

Determining the level of performance that can be expected from a software-based leak detection system is a process that involves several factors, some of which may not be within the control of the pipeline company or the leak detection vendor. Many implementations assume that a certain degree of error will exist within the specification of the pipeline and with the measurements taken during operation, and provide algorithms to compensate for such inconsistencies. Additionally, some vendors require that the system be subjected to a tuning period during the installation process, so that adjustments to the configuration and the corresponding compensation algorithms can be made using real-time pipeline measurement information. Although this can sometimes be a tedious and time consuming process, it is generally accepted in the case of the more complex solutions, in that the ultimate outcome produces more accurate and reliable results.

Ideally, a vendor, given accurate information, could state exactly how their software-based leak detection system would perform on a given pipeline configuration, prior to its installation. In practice, this is sometimes difficult due to unavailable or incomplete information regarding the physical pipeline and its operation.

Output Data and Performance Metrics

Selection of a software-based leak detection system for a given application involves evaluation of the expected (or estimated) performance of the system, as well as operational features and functions that might add to the utility of the system but do not directly improve leak detection performance. The selection process for a specific pipeline system might also include commercial and economic criteria such as system cost, support, ease of maintenance, and so forth.

Any appraisal of leak detection system performance involves an assessment of the various tradeoffs that should be made when the system is installed. In order to establish appropriate performance criteria, the client pipeline company must perform their own assessment and understand the implications of that assessment with respect to the various categories of leak detection performance. In practice, real and potential costs are incurred for each incorrect alarm, missed alarm, late alarm, and/or any other deviation from ideal leak detection system performance. Any evaluation of costs and liabilities associated with improper alarming is beyond the scope of this annex.

Performance of a software-based leak detection system is tantamount to its ability to recognize leak conditions rapidly and without failure, so as to minimize fluid loss, property damage and the risk of personal injury. However, this definition of performance is too broad to be useful to determine projected performance of a leak detection system on a given pipeline or set of pipelines and needs to be defined more specifically by its components. With that goal in mind, a wide range of criteria used by pipeline companies and vendors in the specification of leak detection system performance has been examined. These performance criteria could be grouped into four categories, or metrics, that determine a system's reliability, sensitivity, accuracy, and robustness. A definition and discussion of each of these performance metrics follows.

Reliability

Reliability is defined as a measure of the ability of a leak detection system to render accurate decisions about the possible existence of a leak on the pipeline, while operating within an envelope established by the leak detection system design. It follows that reliability is directly related to the probability of detecting a leak, given that a leak does in fact exist, and the probability of incorrectly declaring a leak, given that no leak has occurred. A system is considered to be more reliable if it consistently detects actual leaks without generating incorrect declarations. Conversely, a system which tends to incorrectly declare leaks is often considered to be less reliable. This is particularly true in cases where it is difficult for the Pipeline Controller to distinguish between actual leaks and incorrect declarations. On the other hand, a high rate of incorrect leak declarations might be considered less significant if the Pipeline Operators have access to additional information that can be used to verify or disqualify a leak alarm.

Systems that limit or inhibit alarm generation in response to certain conditions of pipeline operation are not necessarily less reliable. Reliability pertains only to the functionality of the leak detection software without regard to SCADA system performance, availability of the pipeline instrumentation and communication equipment, or any other factor beyond the control of the leak detection system vendor. Such factors involve a separate category of performance, namely robustness.

The reliability of a leak detection system usually depends upon a number of parameter settings (e.g. decision thresholds, filter characteristics, and so forth) as well as all of the suitable leak detection techniques employed for the operational characteristics of the target pipeline system. In some cases, a Pipeline Operator should decide whether to use settings that cause frequent alarms during normal pipeline operations, or to use other settings that are less likely to cause alarms, but might delay or even fail to alarm when a leak is present. Many systems also make automatic adjustments to decision thresholds and other parameters in order to reduce the likelihood of generating alarms during defined operating conditions. When such adjustments are made, a corresponding penalty is normally incurred in some other aspect of performance. For example, decisions based on longer observation intervals might make a particular system less susceptible to random instrumentation errors or disturbances caused by normal pipeline operations, but this performance gain is achieved at the expense of longer response time and the risk of greater fluid loss if a leak should occur.

Reliability can be managed through the use of Pipeline Operator's response criteria and procedures. Such procedural methods, unless embodied within the leak detection software itself and performed automatically by the system, do not serve to discriminate between leak detection systems with regard to performance. On the other hand, if additional information is available from the leak detection, SCADA, or other systems, then reliability may be better managed.

Sensitivity

Sensitivity is defined as a composite measure of the size of leak that a system is capable of detecting, and the time required for the system to issue an alarm in the event that a leak of that size should occur. The relation between leak size and response time is dependent upon the nature of the leak detection system. In some cases, as illustrated in Figure 2, there is a wide variation in response time as a function of leak size. In other cases the response time is relatively independent of leak size, as depicted in Figure 3. However, there are no known systems that tend to detect small leaks more quickly than large leaks.

To further illustrate this definition of sensitivity, consider a hypothetical case involving four different leak detection systems (W, X, Y, Z) with the following projected levels of sensitivity on a given pipeline:

System W: This system is capable of detecting a small leak within 5 minutes of the start of the leak.

System X: This system is capable of detecting a small leak within 15 minutes of the start of the leak.

System Y: This system is capable of detecting a large leak within 5 minutes of the start of the leak.

System Z: This system is capable of detecting a large leak within 15 minutes of the start of the leak.

On the basis of these performance projections it is obvious that System W is the most sensitive and that the System Z is the least sensitive. However, comparison of the Systems X and Y is less apparent. It is possible that for one pipeline System X might be more appropriate, whereas for another pipeline System Y is more applicable. Since some leak detection systems manifest a strong correlation between leak size and response time, it is also possible that the two levels of sensitivity shown for the Systems X and Y could be manifested by the same leak detection system.

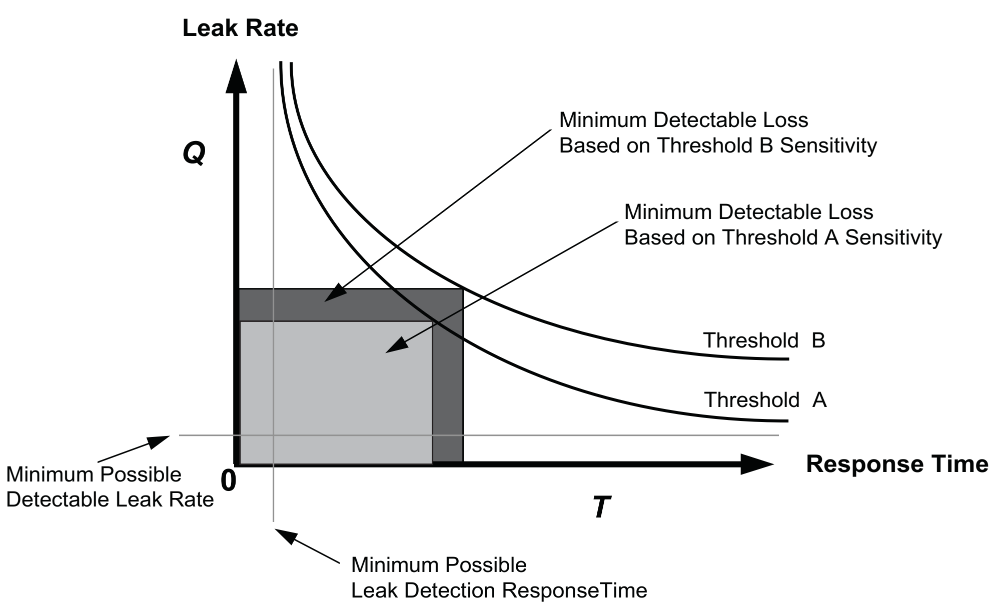


Figure 2—Examples of Sensitivity Curves Based on DIfferent Operating Thresholds. These Examples are Typical of Systems that Operate on Accumulated Parameter Errors (e.g. Volume Balance).

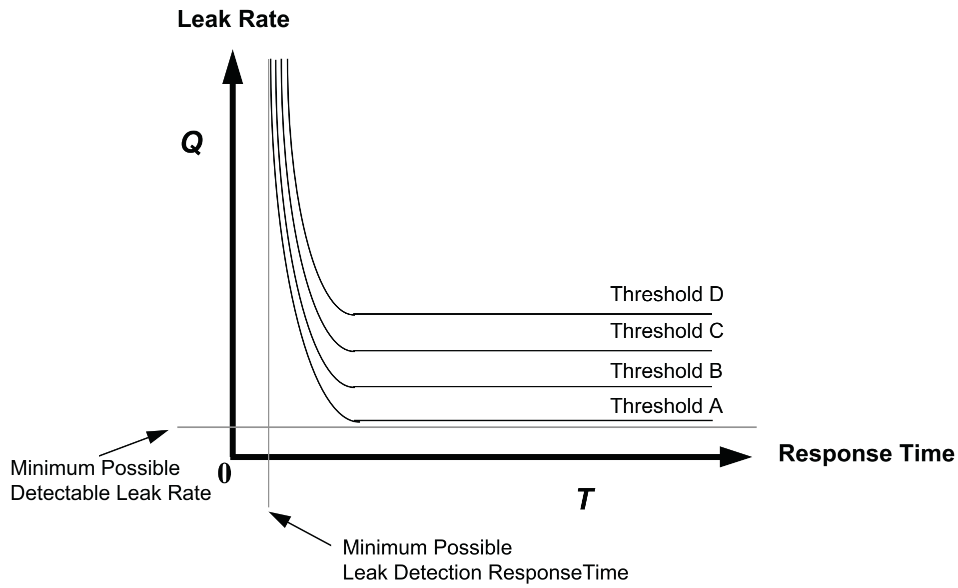


Figure 3—Examples of Sensitivity Curves Typical of Event Oriented Systems. Such Systems Might Employ Pattern Recognition Techniques to Identify the Onset of a Leak.

Frequently during the specification process, users attempt to define leak detection performance in terms of detecting a particular leak flow-rate within a specified minimum period of time. Although sensitivity expressed in such terms certainly represents one aspect of performance, its importance can vary depending on the nature of the leak detection system and the operating characteristics of the target pipeline system. As shown in Figures 2 and 3, the correlation between leak size and response time can be highly dependent upon the leak detection techniques employed. It is also important to recognize that adjustments made in the interest of improving sensitivity can have a corresponding and not necessarily beneficial effect on other aspects of performance.

The examples shown in Figures 2 and 3 also serve to illustrate the concept of *minimum detectable leak size* and *minimum attainable response time* on any given pipeline. In practice, most systems can be set up to achieve various levels of sensitivity, provided the minimum detectable leak size and minimum attainable response time are not violated. The leak detection system vendor, and possibly the Pipeline Operator, can affect these characteristics by adjusting leak detection thresholds, filter characteristics or other parameters. Appropriate settings for these thresholds are usually dependent upon factors such as the SCADA system's scan time, instrument placement, fluid types, and so forth.

Accuracy

To this point, the focus has been upon the philosophy of detecting and announcing a leak, but has not considered the additional information that might accompany a leak alarm. With reference to Figure 1, this additional information is derived by the leak parameter estimation process, and is made available to the user as ancillary data output from the software-based leak detection system. Although the amount and nature of such information varies between vendors, it typically includes estimates of leak parameters such as *leak flow-rate, total volume lost, type of fluid lost,* and *leak location* within the pipeline network at certain pipeline conditions. The validity of these leak parameter estimates constitutes a third measure of performance referred to as accuracy.

From a strictly mechanical point of view, leak rate depends upon the magnitude and shape of the perforation, pipe environment, fluid characteristics and pressure at the leak site. If the location of a leak is known, the leak flow-rate can be used to determine resultant disturbances in pressure, flow rate, and temperature at other points on the pipeline. Software-based leak detection systems, on the other hand, deal with quite the opposite situation. Although these systems approach their task in a wide variety of ways, the one thing they all have in common is that they should operate with no prior knowledge of the size or location of a leak, should one occur. Thus, a particular system might calculate a leak flow rate to compensate for a difference between observed and expected values of pressure or flow at certain points on the pipeline. This effective leak flow rate might then be used to estimate the location of the leak and/or the volume loss related to the leak. Another system, operating on the same pipeline, might estimate total fluid volume lost on the basis of metered volumes and calculated changes in line-pack, without ever attempting to directly estimate leak flow rate or location.

Robustness

Robustness is defined herein as a measure of the leak detection system's ability to continue to function and provide useful information, even under changing conditions of pipeline operation, or in conditions where data is lost or suspect. A system is considered to be robust if it continues to function under such less than ideal conditions. On the other hand, if the system disables certain functions, it might then achieve better reliability, but would be considered less robust.

The distinction between reliability and robustness is significant. Reliability is a measure of performance within a specified operational envelope. Robustness is a measure of the effective size of the operational envelope. For example, consider the following hypothetical leak detection systems:

System I: This system employs a sensitive leak detection algorithm. The system is normally very reliable, but will frequently generate alarms during certain normal pipeline operations.

System II: This system employs an alternative algorithm which is somewhat less sensitive than that of System I, but generates only a fraction of the alarms.

System III: This system employs the same sensitive leak detection algorithm as System I, but inhibits leak detection during pipeline operations that can cause it to generate alarms.

System IV: This system normally employs the same sensitive leak detection algorithm as System I, but switches to the less sensitive algorithm of System II when it senses conditions that generate alarms.

In this example, the designers of System I have sacrificed a degree of reliability in order to maintain a high level of sensitivity, whereas the designers of System II have chosen to sacrifice a degree of sensitivity in order to achieve a high level of reliability. By simply disabling the leak detection function under certain conditions, the designers of System III have sacrificed a degree of robustness in order to achieve higher levels of reliability and sensitivity. The example of System IV represents an attempt to selectively trade sensitivity and/or reliability in order to achieve a more robust system.

Although techniques vary between different software-based leak detection methodologies, most attempt to achieve an acceptable tradeoff between reliability, sensitivity, accuracy, and robustness by sensing conditions of pipeline operation that cause alarms and making temporary parameter adjustments or disabling certain functions as required. Prior to the selection of a methodology for a given pipeline system, it is important that the pipeline company understand the way all operating conditions are handled by that methodology. This understanding will help the pipeline company to determine if a particular solution is consistent with the target pipeline's operational characteristics, as well as the company's expectations.

The reliability of a pipeline's communication, SCADA, and instrumentation systems can also have a dramatic effect on the utility of a software-based leak detection system. A more robust system is one that is less likely to exhibit loss of functionality during periods of partial data outages caused by instrument failures, communication anomalies, routine maintenance, and so forth. Systems that continue to operate during outage periods or transient conditions on the pipeline might employ different settings for thresholds, filter characteristics, and other parameters. This usually results in some degradation of the system's sensitivity, accuracy, and/or reliability. In such cases, robustness is enhanced at the expense of other aspects of performance.

Consistent and reliable SCADA system performance is of critical importance to a software-based leak detection system, regardless of the methodology employed. If the quality of the data is bad, or if the data acquisition frequency is inadequate, the ability of the software to recognize a potential or actual leak condition is compromised. In addition to the physical description of the pipeline system, definition of the pipeline company's SCADA system, and its performance characteristics, are of critical importance to the leak detection vendor. This definition provides the vendor with background information necessary to determine if an existing SCADA system will be adequate to support the needs of their software. SCADA performance characteristics that can have a negative affect on leak detection include slow or irregular update rates, time skew in acquired data from opposite ends of the pipeline, and communication system reliability. These, like many of the other factors, have different effects depending on the leak detection method under consideration, and therefore, should be discussed with each vendor to determine their impact on that method's functionality.

Specification and Prioritization of Performance Metrics

Within the framework of the proposed leak detection system evaluation methodology, each performance metric is evaluated in terms of a system's ability to satisfy a set of related criteria. Vendors should assist in the development of performance criteria that are relevant to their particular leak detection systems, but ultimately, it is the pipeline company that should establish specific criteria for a particular pipeline. In so doing, the company should first define their leak detection goals for the pipeline and then specify corresponding criteria relative to the performance metrics of reliability, sensitivity, accuracy and robustness. These performance criteria constitute one set of information that the company would then provide to a potential vendor in order to determine if that vendor's system is an acceptable leak detection solution.

There are three steps involved in determining the appropriate leak detection performance criteria for a particular pipeline. The pipeline company should first identify any *legal, contractual* or *regulatory requirements* relating to leak detection. A minimum set of performance criteria should be established to meet these obligations.

The next step is to *characterize the pipeline* in terms of its possible leak mechanisms and the likelihood that one of these will result in a leak. A number of diverse factors are involved in this characterization: see 49 *CFR* 195.452 (i)(3) and FAQ 9.5 for these factors.

The final step in developing performance criteria is to perform an assessment to definite potential costs associated with incorrectly declared leak alarms, missed alarms, late alarms, and any other deviation from ideal leak detection system performance. This assessment, when considered alongside the regulatory requirements and the leak potential characterization of the pipeline, could provide a basis from which the pipeline company could establish a set of leak detection objectives. The task of defining the appropriate leak detection performance criteria could then be reduced to a process of prioritizing each performance metric in terms of its level of importance, and further defining a set of specific performance criteria that illustrate the desired objectives.

As an example, the format for presenting performance metrics and the related specific performance criteria to software-based leak detection vendors is divided into two tables as presented in Figure 4. In the first table, each performance metric is ranked based on its level of importance to the pipeline company. Ranking of the four (4) performance metrics simply involves assignment of a numerical rank (1, 2, 3, or 4) to each, with the most important performance metric being assigned a rank of one (1).

The second table contains definitions of specific performance criteria related to each performance metric, and may be optionally left blank or deferred to the vendor to complete. In this table, each performance metric may be characterized by a set of performance criteria to be evaluated under certain operating conditions on the pipeline. This criterion may be specified in either qualitative or quantitative terms. Pipeline companies are encouraged to provide qualitative specifications for performance criteria and quantitative specifications where possible. Even though many of the performance criteria are difficult, or even impossible, to completely separate from others, this mechanism provides the pipeline company with a means to identify and rank the specific elements of performance important to them and relevant to their operational needs and leak detection goals.

It should be noted that the performance criteria identified in Figure 4 are specified in qualitative terms rather than quantitative terms, and are only a representative sample of criteria that might be established under a given set circumstances. This is not an all-inclusive list that would apply to every pipeline, nor is it a recommended list with application to any particular pipeline. Since the needs of each pipeline company differ, it is only necessary to specify those performance criteria that are representative of the pipeline's specific needs.

Performance Metric	Level of Importance (Rank 1 – 4)
Sensitivity	
Reliability	
Robustness	
Accuracy	

Performance Metric	Qualitative Performance Criteria Specification
Sensitivity	Minimum detectable leak rate
	Minimum detectable leak volume
	Maximum volume loss prior to alarm
	Response time for a large leak
	Response time for a small leak
Reliability	Incorrect leak alarm declaration rate (overall)
	Incorrect leak alarm declaration rate (steady state flow)
	Incorrect leak alarm declaration rate (transient conditions)
	Incorrect leak alarm declaration rate (static conditions)
Robustness	Loss of function due to pressure outage(s)
	Loss of function due to temperature outage(s)
	Loss of function due to flow measurement outage(s)
	Loss of function due to pump state changes
	Loss of function due to valve state changes
	Loss of sensitivity due to pump state changes
	Loss of sensitivity due to valve state changes
	Startup stabilization period
Accuracy	Leak location error
	Leak flow rate error
	Leak volume error

Figure 4—Tabular Format for the Ranking of the Level of Importance for Each Performance Metric, and an Optional Table for Qualitative or Quantitative Specification of Performance Criteria Related to Each Metric

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