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Computational Pipeline Monitoring for Liquid Pipelines

Pipeline Segment

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American
Petroleum
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FOREWORD

Suggested revisions are invited and should be submitted to the standardization manager, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

CONTENTS

Computational Pipeline Monitoring for Liquid Pipelines

0 Background Information

0.1 INTRODUCTION

This is the second edition of API 1130. The first edition of API 1130 was published in 1995. Since that time, the users of this information (e.g., pipeline operators, system developers, system integrators and the regulators) have had an opportunity to employ the information provided and to evaluate the publication. They have offered suggestions for changes to improve the document.

Since publication, API 1130 has also been referenced in the federal pipeline safety regulations (see 0.2 below). In addition, API requires that API publications and standards be reconfirmed on a regular basis. Therefore, this second edition of API 1130 has been modified to include suggested improvements and rectify inconsistencies and errors.

Computational Pipeline Monitoring (CPM) is a term that was developed to refer to algorithmic monitoring tools that are used to enhance the abilities of a pipeline controller to recognize hydraulic anomalies that may be indicative of a pipeline leak or commodity release. In the past, these CPM systems have been generally 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. Consequently, the term CPM was developed to specifically cover leak detection using algorithmic tools.

The original edition of API 1130 (1995) was written by the API Computational Pipeline Monitoring Task Force which was formed in April 1994. The purpose of the group was to develop an API publication for CPM as it is used in the liquids pipeline industry. This update of API 1130 (2002) has been written by a Task Force of the API Cybernetics Sub-Committee and includes input from all committee members as well as a broad community of CPM system developers and system integrators.

0.2 REGULATORY CONSIDERATIONS

Users of API 1130 must 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 Department of Transportation's Office of Pipeline Safety has included a reference to API 1130 in 49 *CFR* Part 195. Those regulations will likely be subject to updating within the life of this second edition of API 1130, so the exact references are not included in this document.

In regulations, a reference may be directly to CPM or may use the words "leak detection" or aspects of "integrity management." A CPM or "leak detection" system may be mandated by future regulations or by operating restrictions. 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 requirements state:

a. A pipeline operator must have a means to detect leaks on its pipeline system.

b. 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 proximity 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 does not claim to be all inclusive in that regard. The pipeline operator will need to understand the regulations and work with the regulators and their agents to satisfy all requirements.

1 Scope

1.1 PURPOSE

This publication 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 operational upset or commodity release

The purpose of this publication is to assist the pipeline operator in identifying issues relevant to the selection, implementation, testing, and operation of a CPM system. This document be used in conjunction with other API publications and applicable regulations.

1.2 CONTENTS

This publication 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, record 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 publication is limited in scope to single-phase, liquid pipelines. It is recognized that no one particular 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. Figure B-1 (along with the discussion in Appendix B) provides a starting point for understanding where the practical detection limit of commodity releases starts. This publication is not all inclusive. The reader must have an intimate knowledge of the pipeline and may have to refer to other publications for background or additional information.

CPM is intended usually as a tool to be used by the pipeline controller in the safe operation of the pipeline. Effective operation of a pipeline requires that the pipeline controller be familiar with the pipeline and the tools at their disposal. CPM is not currently intended to replace human judgement and intervention in the shutdown of the affected pipeline segment(s) and the closure of remote control valves or directing field staff to close hand operated valves on the pipeline.

This publication 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 publication 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) 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 applicability range.

Note: This publication is in keeping with standard industry practice and commonly used technology; however, it is not intended to exclude other effective commodity release detection methods.

1.4 TRANSPORTATION SYSTEMS

This publication 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, viscosity, density, sonic velocity, bulk modulus, vapor pressure, pressure, temperature, and heat transfer. The CPM methodology selected must be evaluated against what characteristics of the pipeline are known and what is required by the methodology to provide acceptable results. Most CPM technologies have not thus far proven themselves capable of providing satisfactory CPM operation during periodic or permanent slack line conditions. If this condition exists in a particular pipeline, then the CPM selection criteria for that pipeline will need to consider that operating condition.

2 References

2.1 REFERENCES CITED HEREIN

The following standards, codes, and specifications are cited herein:

API

RP 1149	*Pipeline Variable Uncertainties and Their Effects on Leak Detectability*
RP 1155	*Evaluation Methodology for Software Based Leak Detection Systems*
RP 1161	*Guidance Document for Qualification of Liquid Pipeline Personnel,* August 2000

2.2 OTHER APPLICABLE REFERENCES

API

RP 1113	*Developing a Pipeline Supervisory Control Center*

Manual of Petroleum Measurement Standards (instruments and trends)

CSA[1]

CSA-Z662-M99	*Oil and Gas Pipeline Systems*, Appendix E, "Recommended Practice for Leak Detection"

DOT[2]

49	*Code of Federal Regulations* Part 195

ISO[3]

ISO 9000	*Quality Management Family of Standards and Guidelines*

3 Definitions

Definitions for all the important words or phrases used in this publication are listed and described in the glossary, Appendix A of the document.

4 Technical Overview

4.1 METHODOLOGIES

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

The SCADA and 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:

a. Compensate for pipeline operational and/or configuration uncertainties.
b. Reach an acceptable compromise between accuracy and speed of solution.

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

Methods that use sensors directly or indirectly to detect commodity releases can be classified as EXTERNALLY BASED or INTERNALLY BASED (respectively).

4.1.1 Externally Based Leak Detection Systems

This publication does not consider externally based pipeline leak detection systems 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 methods are excluded from the discussion of CPM because they do not meet the requirement of performing computation on field parameters for inferring a commodity release.

The following are common types of externally based systems or devices:

a. Fiber optic hydrocarbon sensing cables.
b. Dielectric hydrocarbon sensing cables.
c. Acoustic emissions detectors.
d. Hydrocarbon vapor (gas) sensors (including those with vapor pick-up tubes).

4.1.2 Internally Based CPM Systems

CPM systems that are internally based utilize field sensor outputs that monitor internal pipeline parameter(s). The particular methodology 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 manual or electronic computation.

A brief description of each of the common CPM methods is included in Appendix C. The following describes the types of CPM internally based methodologies:

a. Line balance.
b. Volume balance.
c. Modified volume balance.
d. Compensated mass balance.
e. Real time transient model.
f. Pressure/flow monitoring.
g. Acoustic/negative pressure wave.
h. Statistical analysis.

Each CPM method 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 has been proven suitable for all pipeline applications. Multiple CPM systems may be employed to provide a CPM that can more broadly cover the pipeline operating conditions.

4.2 SELECTION CRITERIA

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

[1]Canadian Standards Association, 5060 Spectrum Way, Suite 100, Mississauga, ON L4W 5N6, Canada.
[2]U.S. Department of Transportation, 400 7th Street, S.W. Washington D.C. 20590, www.dot.gov.
[3]International Standards Organization, 11 West 42nd Street, New York, New York 10036, www.iso.ch.

allows for independent validation or redundancy. The following is a list of desirable CPM features and functionality.

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. A CPM system must have at least one of these features.

The CPM system may:

a. Possess accurate commodity release alarming.

b. Possess high sensitivity to commodity release.

c. Allow for timely detection of commodity release.

d. Require minimal software configuration and tuning.

e. Perform its CPM functions with existing sensors and instruments (or does not have special or additional requirements for instrumentation).

f. Be minimally impacted by communication outages or by data failures.

g. Accommodate complex operating conditions.

h. Be available during transients.

i. Be configurable to complex pipeline networks.

j. Perform an imbalance calculation on meters at one instant in time.

k. Possess dynamic alarm thresholds.

l. Possess dynamic liquid pack constant.

m. Accommodate commodity blending.

n. Account for heat transfer.

o. Provide the pipeline system's real-time pressure profile.

p. Accommodate intermittent or permanent slack line conditions (avoiding alarms and not totally disabling all segments of the pipeline during the event).

q. Accommodate all types of liquids.

r. Identify leak location with appropriate mile post locations or the nearest station.

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

t. Provide for automatic and manual data substitution during periods of data non-availability (e.g., communication outage, measurement failure, maintenance, etc.).

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

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

w. Identify the leak rate.

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

y. Provide batch tracking with interface location, be able to compute bulk modulus, and perform inventory compensation.

z. Perform calculations quickly using data immediately as it becomes available.

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

ab. Accommodate pump start-ups/shutdowns, valves opening/closing, and other normal operational functions without generating alarms.

ac. Account for effects of drag reducing additive.

ad. Offer efficient field and Control Center support.

ae. Contain a leak probability analyzer to weigh all of the components of a leak (linepack loss, pressure/flow deviation, meter shortage) to assist a pipeline controller in making a leak declaration.

af. Possess ability to allow alarms to be integrated into the pipeline controller's alarm processing.

ag. Possess audit trails of CPM actions taken by pipeline controllers and allow saving of historical data.

ah. Have the ability to return to normal detectability limits rapidly after data or computer service is restored or after an unscheduled interruption.

ai. Have the ability to provide various types of warnings and alarms for example warnings or alarms on data failure or unusual operating conditions that indicate the cause is not a commodity release.

aj. Provide an alarm under all operating conditions and will not be disabled or turned off automatically regardless of circumstances.

ak. Have the ability to automatically self test without affecting performance while the test is underway.

API Publ 1155 can be consulted for additional details on CPM performance criteria.

4.3 COMMODITY PROPERTIES

Commodity properties must be considered when the CPM methodologies that consider fluid properties are employed. For these methodologies 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 in a transient-composition mixed phase situation, 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. HVL liquids are more compressible than crude oils, thereby making it more difficult for some CPM approaches to discern hydraulic anomalies from normal pipeline operations.

5 Technical Details

5.1 FIELD INSTRUMENTATION

Aspects of field hardware are discussed in this section. Sensor and instrument data must be sent from the field sites to the CPM system for computation or other usage.

This portion of the publication defines good operating practice in the design and maintenance of the field instrumentation necessary to adequately support a CPM system.

API Publ 1149 *Pipeline Variable Uncertainties and Their Effects on Leak Detectability* discusses the importance of instrumentation to CPM performance. The software developers or providers may also advise an operator on what instruments influence the capabilities of the CPM methodology and what effects additional or upgraded instrumentation will have on their system. The calculations of API Publ 1149 can demonstrate that inadequate and inaccurate instrumentation reduces 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.

Note: Different CPM methodologies require varying levels and types of instrumentation. Instrumentation costs may vary significantly for each method. Some methodologies may have specialized instrumentation needs. A operator may want to consider CPM instrument best practices (equipment and installations methods—for example, using buried temperature probes to avoid ambient factors), installation of density and/or viscosity monitors at injection points where fluid properties are variable and installation of additional pressure sensors at intermediate locations.

5.1.1 Selection of Instrumentation

Ranges and specifications should be carefully matched to pipeline operating design, pressure, flow, temperature, density, etc. to make best use of the instrument manufacturer's stated accuracy and linearity. Because instrument 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 overspecification of instrumentation accuracy if CPM performance will be limited by the instrumentation loop accuracy, or repeatability and resolution of the SCADA system. One such limitation may be imposed by the resolution, measured in bits, of the analog-to-digital (A/D) conversion hardware, as shown in the following table.

A/D Bits	% Resolution
8	0.4
10	0.1
12	0.025
16	0.0015

5.1.2 Installation of Instrumentation

The quality of instrument data can affect the CPM system. Instruments should be installed in accordance with API RP 550, manufacturer's recommendations and applicable industry codes and standards. The placement of instrumentation in relation to the process equipment is important, and should be carefully designed with due consideration to variations in operating conditions. Pressure should be measured well away from pump discharge turbulence and with taps off the side of the line to avoid plugging from sediment. Flow should be measured in an area where it can accurately be measured; for example, for inferential meters—in a location where there is a well-developed flow profile. Temperature must be taken in a location representative of the majority of the product in the line or it will 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 *Manual of Petroleum Measurements Standards* for instrumentation).

5.1.3 Calibration and Maintenance of CPM Instrumentation

A CPM system that has adequate instrumentation to achieve the desired commodity release sensitivity may be limited in its effectiveness by instrument calibration drift. A system that receives inaccurate data will yield inaccurate results.

Instruments should be calibrated in accordance with manufacturer's recommendations and calibrations should be traceable to National Institute for Standards and Testing. Operating experience will provide the basis for determining an appropriate test and re-calibration fixed interval. The CPM system itself may in some cases be the best indication of the necessity to test and re-calibrate a particular instrument a random interval.

To maximize CPM performance, each pipeline company should prepare a test and calibration plan as part of CPM operating and maintenance procedure. This plan should recognize the importance of the CPM system to the safe operation of the pipeline and provide for the priority of CPM instrument repair.

Note: Such a plan could result in instrumentation calibration practices that may exceed the requirements of applicable regulations.

Test and re-calibration events should be documented, and such records shall, at a minimum, include the date of the test and initials of the person performing the test. Test and re-calibration records should be retained in accordance with the each company's written procedures. The operator should consider the storage location for records so that they are protected for the life of their required retention.

When developing a maintenance history for field instrumentation, consideration should be given to recording "as found" and "as left" calibrations in accordance with ISO 9000 conventions.

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 performance of the system.

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. For example, instrument mounts and process piping should be designed to minimize resonance. Electrical noise in sensor wiring often can be reduced through the use of shielded signal cables and proper grounding.

When attempts to eliminate noise are unsuccessful, signal conditioning techniques may be used with some types of CPM systems to limit bandwidth and thus attenuate noise. API RP 1149 describes a digital low pass filter that was effective in reducing noise and thus improving the leak sensitivity under test conditions. These filters may be contra-indicated for particular types of CPM systems and that excessive signal conditioning may remove desired information. Signal conditioning techniques also introduce time lags in changing data and may reduce the effectiveness of the CPM system.

5.2 SCADA/COMMUNICATIONS

The Supervisory Control And Data Acquisition (SCADA) system is a computer-based communications system that gathers, processes, displays and controls data from field instrumentation. This section focuses on the design of the data gathering sub-system and its effect on CPM.

CPM systems will generally use data gathered by the pipeline 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 is available from the SCADA system or other sources (e.g., scheduling computer) particularly when needed.

The following paragraphs describe several SCADA system design factors that can affect the quality and timeliness of the data required by a CPM system.

5.2.1 Communications Media and Error Detection

Any data communications medium can be used for SCADA, but the most common media in the liquid pipeline industry are dedicated telephone circuits, fiber optic cable, and various forms of terrestrial radio, microwave and satellite-based systems. These media vary in quality, but all are subject to noise and interference causing data corruption. Virtually all SCADA systems are designed to detect and reject corrupted messages. Data Quality Bits (sometime called data attributes) are often available in the SCADA system to indicate lost messages and other information about the data (e.g., off scan, alarm inhibited, manually entered, etc.) and should be used by the CPM system to identify missing, suspect or conditional data.

5.2.2 Communications Message Structure

SCADA systems gather data from field instrumentation via Data Acquisition Devices (DADs) such as a Remote Terminal Unit (RTU), Programmable Logic Controller (PLC), Field Data Acquisition Server (FDA), or Flow Computer (FC) located at the field site. Each of these devices may be interchanged for specific applications. Data collection designs may include any combination of DAD devices interrogating other DAD devices for information. Data is then collected in one or more computers associated with the pipeline operations Control Center. The specifications of the messages between the DAD's and the Control Center computers are collectively referred to as the communications protocol.

The protocol is said to be "polled" when the Control Center computer requests data from each field location in turn. Typically, when the last field location has been polled, the communications polling will return to the first, repeating the cycle endlessly. The time interval required to poll all field locations and return to the first is referred to as "poll time" or "scan time." If the DAD always reports all its data in response to a poll, the system is said to be "strictly polled." On some SCADA systems, other polling algorithms are also used to compensate for media speeds and loading (e.g., interleaved scans, demand scans, etc.).

A DAD may fail to report when polled due to equipment failure or noise in the communications channel. This fault condition, sometimes called "no reply" is often indicated by SCADA system quality bits.

To improve the update rate 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 has changed since the previous poll. Such protocols are referred to as "Report-by-Exception." Scan time in a Report-by-Exception protocol may vary depending on system design and operating condition of the pipeline.

SCADA communications may also be non-polled. "Quiescent" or "Unsolicited" operation refers to DADs that report without being polled, either on a time scheduled basis or when field data changes. Refer to 6.2.4 "Analog Deadband" for a description of analog data change. The design of quiescent and Report-by-Exception systems may include provision for the Control Center computer to poll for all field location data. Such a poll is used to verify the validity of the data image in the Control Center computer and is called an "Integrity Scan."

5.2.3 Communications Timing

In polled systems the variation in reporting times from one field location to another is called "time skew." Designers of CPM systems may also consider the impact of time skew in the data.

Quiescent systems that report on data change and Report-by-Exception protocols 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 DADs 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.

5.2.4 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 in the analog signal will appear to be a valid change in data in Quiescent and Report-by-Exception systems. Deadbands, however, introduce a noise level that may be counterproductive for particular CPM methodologies that analyze the Flicker for pattern changes.

When the precision of the SCADA system's analog-to-digital conversion hardware exceeds the repeatability of the sensor, it is appropriate to reduce the precision through the use of an analog deadband. Care must be taken not to use an excessively large analog deadband as this technique effectively reduces the precision of the analog value (see 5.1.1).

5.2.5 The Impact of Data Collection

CPM systems must be implemented with an understanding of the underlying communications protocol. It is possible to have variation in communications protocol within one SCADA system. It is not unusual to find that multiple protocols may be used in layers or sequentially to complete the transmission of one field message to the SCADA System. The use of multiple protocols may have no effect on update time.

5.2.6 Data Processing

Field data received by the SCADA system is generally coded in the most compact manner possible to maximize efficiency on the communications link. Such data is said to be "raw." 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. Recent designs may perform this formatting in the DAD. This section describes data processing features that enable or improve CPM functionality.

5.2.6.1 Time Tagging

Time tags record when a particular data point was last updated. Some systems generate the time tags in the DAD, but it is more common for the SCADA Control Center computer to create the time tag at the time the data is either acquired or processed. Time tags, preferably originating at the DAD, 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.

5.2.6.2 Data Quality

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

a. "Non-updated" or "old data" caused by a DAD that is not responsive.

b. "Off-scan," when an DAD has been taken off-line.

c. "Manual data," when manually entered data overrides interrogated values.

d. "Range error," when an analog value falls outside specified hardware limits.

e. "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. On some SCADA systems, data quality bits are also used to reflect the results of calculations or operator action (e.g., data is currently in a specific type of alarm, pipeline controller has not acknowledged an alarm condition, the field point is currently part of a control sequence, etc.).

5.2.6.3 Analog Processing

Analog values typically represent measured variables such as pressure or flow rate, but can also represent items such as tank levels. Raw analog values are scaled into engineering units such as pounds per square inch (psi), or barrels per hour (bph), or feet by the analog processor. Some variables used in particular CPM systems will also require a secondary conversion to obtain the final desired value (e.g., specific to API gravity, level to volume, etc.). The scaled or final 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 SCADA system, 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.

5.2.6.4 Status Processing

Status data records 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. Some SCADA systems permit the configuration of status into 2-bit (4-state) or higher combinations.

Changes in equipment state are generally logged to a printer or other permanent recording device by the status processor. Such a set of records is usually referred to as an "event log."

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

5.2.6.5 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 system. The accumulator values may either represent "gross," "net," or partially netted values depending on the particular type of DAD used (e.g., RTU, PLC, flow computer).

5.2.6.6 Alarm Processing

Alarms are a special case of events that indicate a transition into an unexpected or abnormal state. The return transition to the normal state is generally referred to as "return to normal." Alarms can either be transitory or continuous in nature. For example, a field status bit going into the alarm state or an analog exceeding a high limit would be examples of continuous alarms that have a complementary return to normal state. Transitory alarms have no return to normal state and are simply an indication that something has occurred (e.g., two minute warning prior to a batch arrival, "pig signal" that a scraper has passed a station, etc.).

Alarms can be configured to trigger an audible signal, which can be acknowledged or and silenced by the pipeline controller. The pipeline controller may also be required to acknowledge each alarm as it is displayed. Many SCADA systems have special summary lists related to alarms:

a. Chronological alarm logs/files.
b. Unacknowledged alarm summaries.
c. Summaries of points in an unusual state.

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. By maintaining a familiar method of data presentation, this approach will facilitate interpretation of the data by the pipeline controller. It is also a preferred configuration because it allows the pipeline controllers to view and analyze CPM data and alarms in conjunction with SCADA activities and events.

5.2.6.7 Data Historian Archiving

CPM systems may store data values to a historical database. The SCADA system or other applications such as CPM systems may access historical data.

Playback is a method for capturing field data for recall at a later time. The ability to playback SCADA data in a test mode can be useful in analysis and tuning of the CPM system for training and maintenance

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

5.3 DATA PRESENTATION

Interpretation of results from manual CPM systems are based on pipeline controller training. Therefore, this section is primarily concerned with the presentation of data from an automated CPM system.

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 will enable the pipeline controller to more easily identify and interpret hydraulic anomalies.

5.3.1 Display Ergonomics

The CPM integrator should carefully consider the aspect of display of the CPM system and alarms to the users. Considerations should include the following:

a. Displays need to be simple, easy to read, and presented in an uncomplicated screen arrangement.

b. If possible, the CPM displays should be have the same format and functionality as the SCADA displays so the usage is familiar to the pipeline controller but the displays should also be clearly differentiated so the pipeline controller will know if a SCADA or CPM display is viewed.

c. When a simulation trainer is used for pipeline controller training, the simulation system displays should be the same as the on-line Control Center displays so the pipeline controller are familiar with the format.

d. The CRTs should be positioned in a manner to avoid causing body and eye strain.

e. It is important to consult the user during the design of the CPM system, so that the pipeline controller is satisfied with the layout and design.

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

g. The CPM integrator should consider use of industry standards, standards of other industries that make use of control displays or research that suggests approaches to make control displays appropriate for the level of urgency of information displayed.

h. The display should limit the number of colors.

i. The display should be designed to work well with the particular CPM methodology; for example, uppercase letters may be more readable on some screens and applications. Also the information displayed should be easy to read on the specific display equipment that the controller is using.

j. Screen savers should not be used.

k. If other tasks are on the same CRT, care should be taken to prevent interference with the monitoring of the CPM system.

5.3.2 Trending

Trending operating parameters (e.g., flow rate, pressure, viscosity, density, over/short and temperature) from the SCADA system may help determine what caused a CPM alarm. If trending is employed, the trend needs to cover a long enough duration to see values prior to when 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.

5.3.3 Alarm Display

CPM alarms should be consistent with SCADA system alarms and should have an appropriate priority. The alarm should have an audible tone, and can be varied for different categories of alarms. Alarms should have different colors if there are 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.

Alarms should be presented as both audible and visual. 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.

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.

5.3.4 Integration of CPM and SCADA

The display of alarms from the CPM system and SCADA system should preferably be integrated and put on the same alarm display. 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.

6 Operation, Maintenance and Testing

6.1 CPM OPERATIONS

CPM systems employ an inference engine and an alert algorithm that are defined for a given pipeline and its instrument 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 will issue an alarm if a limit is exceeded, e.g., a mass conservation algorithm's 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 unusual 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 unusual 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 company procedures should require that all CPM alarms be evaluated. Simply understanding the cause of the alarm condition on a monitored pipeline may not be the end of the alarm evaluation.

6.1.1 Alarm Credibility

Alarm credibility may be enhanced by occurrence of a certain number of non leak alarms so the pipeline controllers know that the CPM system is functioning. An excessive number of alarms will detract from credibility and may create complacency.

A CPM system design goal is to maximize the system sensitivity to leaks (or to find all leaks within the system threshold) 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.

6.1.2 Types of CPM Alarms

In this publication, CPM alarms are subdivided into three classes: DATA FAILURE; UNUSUAL OPERATING CONDITION; and POSSIBLE COMMODITY RELEASE. Ideally the categorization of the alarm into one of these three causes will be made by the CPM system. Many CPM systems provide just one type of alarm. In this case, the determination of cause will be made by the person who evaluates the alarm (the pipeline controller, 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.

Operational response to a CPM system alarm would normally include the following:

a. Investigation of the cause and initiation of action likely following a procedure.
b. Shutdown of the pipeline based on a pipeline controller decision or automatic shutdown of the pipeline in a closed-loop control system.

DATA FAILURE. This class of alarm would occur when critical CPM input data is missing or is determined as incorrect. These may also be called system-impaired alarms. Also included in this alarm type 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 alarms could be automatically generated by the SCADA or CPM software or as manual entries in a pipeline controller's shift log. Some CPM systems would indicate the effect the data failure has on continued CPM operation. The effect of this alarm class could range from minimal or no effect to the severe degradation of the CPM commodity release detection threshold. In the case of CPM system failure, the effect would be total loss of this leak detection type. 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.

These and other CPM alarms need to be presented to the pipeline controller in a way that clearly identifies the alarm as distinct from a SCADA alarm.

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

UNUSUAL OPERATING CONDITION. 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. If the alert algorithm subsection of the CPM system cannot determine to a set certainty level that a commodity release situation does exist, then some CPM systems may declare an unusual operating condition alarm. The purpose of this alarm class is to minimize incorrect leak declarations. The unusual 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 that seldom experiences this condition; or during unstable/severe transient hydraulic conditions created by an emergency shutdown.

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

These and other CPM alarms need to be presented to the pipeline controller in a way that clearly identifies the alarm as distinct from a SCADA alarm.

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

POSSIBLE COMMODITY RELEASE. If 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 will be made by a pipeline controller who will use CPM output (and possibly other information sources such as the SCADA system). In the case of closed-loop control (which may be possible on some pipeline systems), the CPM system will automatically initiate action to shut down 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.)

The operational responses to a possible commodity release alarm need to consider these factors:

a. All CPM alarms have a cause.

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

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

6.2 SYSTEM TESTING

Testing of CPM systems evaluates actual system performance and provides a baseline of achieved performance. The CPM baseline may be established by testing, operating experience, off-line modelling, or an API RP 1149, API RP 1155 or other theoretical analysis of the CPM/pipeline fit. This section outlines testing methods and intervals.

The primary purpose of testing is to determine that the CPM will alarm if a commodity release occurs. The purpose of tests could also to be make sure that data failure alarms and unusual operating condition alarms function as expected. The text that follows will not discuss CPM testing for other than commodity release alarms. The testing may also continue after the occurrence of the alarm to see also the transition from alarm state back to normal state.

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 representative of line operating conditions.

Possible methods of testing include, but are not limited to the following:

a. Removal of test quantities of commodity from the line.

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

c. Altering an instrument output, e.g., a meter factor, to simulate a volume imbalance, or a pressure output to simulate a hydraulic anomaly that represents a leak.

d. Other means that are capable of testing the performance of the CPM system.

The method used should be specific to the particular CPM application and pipeline system. CPM tests may be "announced" or "unannounced." An announced test begins with the awareness of the pipeline controller and tests only the CPM system. An unannounced test begins 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. When a series of tests are conducted, only the first test can be unannounced.

The location of the test may vary 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. Also, the test may be performed at more than one withdrawal or simulated withdrawal rate so the time and leak rate response of the CPM can be evaluated over a range of possible leaks.

6.2.2 Initial Tests During CPM Commissioning

A new CPM system must be tested to verify that it has achieved the design or expected performance and to establish a baseline of performance. The reasons for testing a new CPM application are different than for retesting (which is outlined below). Throughout the installation and commissioning procedure, there may be a number and variety of tests. These would test 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 prior to acceptance will establish the baseline.

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

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

6.2.3 Retesting

CPM retesting of applications will be necessary on a periodic basis to meet regulations, to confirm the continued effectiveness of the CPM, or to re-establish CPM performance after significant changes have been made to an existing CPM application or to the pipeline configuration. Retesting will be documented in test records.

CPM applications should be tested on a 5-year interval (or more frequently if significant changes have been made to the CPM or the pipeline segment or if there is a change in regulations that require retesting) to confirm the CPM's continued effectiveness. It may be unnecessary 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. The retest may use the same method employed in the initial tests or may use another test method.

Operational use of a CPM system, e.g., 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 of the CPM during the retest interval, the retest will be a confirmation test only.

6.2.4 Maintenance Testing

Maintenance testing is a type of CPM retesting but for a different purpose than outlined above. Maintenance testing may be performed on a much more frequent basis than retesting. There could be many reasons to perform maintenance testing on an operating CPM system. For example, throughout the life of the CPM system, it may be necessary to reconfigure and retest the CPM software when the pipeline system, SCADA system, CPM software or configuration changes; instrumentation changes; or any other changes occur to a degree that there may be a concern that the change will affect the CPM system performance. Among those may be testing following minor tuning changes, installation of a new software release, event re-run testing to examine CPM response to an unusual operating condition. The decision to perform maintenance testing will be based on individual analysis of possible effect on performance and on a line-by-line basis. Maintenance testing may be included as a part of change management.

Maintenance testing may employ an actual commodity release data-set, a data-set from a leak test; or a test simulation. The persons responsible for the CPM will determine that method is best suited to maintenance test the CPM system.

The results of maintenance testing may not be recorded in test records. However, when the maintenance test is documented in accordance with 6.2.6, such maintenance tests may be considered a 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 retesting or maintenance 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:

a. Date, time and duration of the test.

b. 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.

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

d. Operating conditions at the time of the test.

e. Details of any alarms generated during the test.

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

g. 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

Provisions should be made to limit operations and maintenance access for changes to the SCADA/CPM system, logic solver (i.e., PLC, RTU, etc.), alarm limits, and to deactivation of sensors. The access protection may be in the form of passwords, locked cabinets, "read only" or "write protected" data and administrative procedures. Access protection may have varying levels of accessibility for different users, e.g., systems designers, technicians, pipeline controllers.

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

Access control and security may be provided by a combination of application logic and passwords for any CPM user interface device, parameter, alarm inhibit, and or limit which could interfere with or degrade the performance of the CPM function.

System changes can be made through several ways. These changes should be coordinated or otherwise managed, for example, by segregating the degree of changes by multiple levels of accessibility. Any changes should 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; instead, it 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 alarms and operator 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 operating company should develop and implement a revision and release policy for software and firmware used in a CPM system.

6.3.2 Parameter Changes

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 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 the 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. These indicators show 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 capabilities performance integrity of the CPM during periods of hardware, software and field equipment maintenance and system upgrades.

System maintenance should be performed under the control of maintenance procedures that 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, legal requirements, 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 sorts of data and information may be useful or helpful in the future; for example, a data-set from a leak or leak test that can be used to verify CPM performance after changes have been made to the system.

In any case, all occurrences of a leak declaration should be historically documented as to cause, assessment and pipeline controller response.

6.5 PIPELINE CONTROLLER TRAINING & 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 *Recommended Practice for Controller Training* that considers many important related training issues outside the scope of this publication.

The training plans may include periodic reviews of pipeline controller training material to make sure it is up-to-date, retraining of the controllers and possibly knowledge testing. Retraining may be aided by review of known cases where the unusual operating condition alarms and possible commodity release alarms have been generated. Documentation of these alarms will assist with this activity.

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

Hydraulics. A pipeline controller must be trained in the basic concepts of pipeline steady state hydraulics as they relate to the CPM system. The gradual change of the line hydraulics due to movement of different fluid batches or temperature change, for example, may be part of a controller's education.

A pipeline controller must be trained to recognize the effects of pump start-ups/shutdowns, a valve operation switch, and other everyday activities that case transient conditions. Any of these will cause a system flow or pressure transient to appear and will, therefore, potentially be a problem for the CPM alarm notification system. Everyday pipeline transients may cause upsets in a CPM system that cannot accommodate transients. The upsets may cause operating alarms that are well within the realm of normal system behavior.

Alarming/Performance. The pipeline controller should be able to recognize and react to all types of CPM-related SCADA alarms, such as "Communication Outage." Some SCADA alarms affect CPM system performance.

The pipeline controller should be able to qualitatively identify the effect 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 would 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 unusual operating conditions and to take appropriate action. The training may be directed towards following procedures or calling on and working with external resources for alarm evaluation.

Inventory Control (Online). A pipeline controller should be trained to recognize CPM hydraulic changes due to varying line pack. A fundamental element of the spectrum of inventory control is the calculation of mass, or the comparison of net barrels in versus net barrels out. This training would include the ability to recognize the packing behavior of the pipeline(s) that they operate.

A pipeline controller should be knowledgeable about sections of the pipeline that are susceptible to intermittent "slack line flow." The controller should be knowledgeable about how that condition affects the CPM performance.

Trending. A pipeline controller should be able to recognize that trending and analysis of certain pipeline variables provides a simple form of CPM system. 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 correlation CPM output with SCADA output wherever possible to have independent confirming data for CPM alarm evaluation.

CPM System Operation. The pipeline controller must be trained to understand the CPM system, and the concepts of its operation. A portion of pipeline controller training may include periodic review of the use of the CPM system in a training environment, and the 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 must 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.

Data Presentation. A pipeline controller must be trained in the recognition of the CPM notification or alarm and may be trained to research the cause of the alarm (data failure, unusual 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.

Abnormal Functions. The pipeline controller must be trained to react to the abnormal function of a CPM system in the same way as being trained to react to the abnormal function of the SCADA system. The loss of either must elicit certain predefined actions intended to preserve pipeline integrity. Targeted response actions should be thoroughly analyzed and scripted for prompt, efficient action.

Other Leak Detection Methods. The pipeline controller should be trained in how to employ the results of other methods of detecting leaks such as third-party reports so that a CPM system is not considered to be the only means of detecting leaks. The controller should know what procedures to follow for these other methods.

6.6 CPM DOCUMENTATION

Each CPM system employed on a pipeline segment 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. It is recommended that the following information be available:

a. General Information (this information is usually available as a part of normal Control Center information).

b. A system map, profile and detailed physical description for each pipeline segment.

c. A summary of the characteristics of each product transported.

CPM Specific Information:

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

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

c. A list of special considerations or step-by-step procedures to be used in evaluating CPM results and for requesting assistance with alarm evaluation, e.g., on-call support phone numbers where this systems is implemented.

d. Details of the expected performance of the leak detection system under normal and line upset conditions; and the effects of system degradation on the leak detection results.

e. CPM pipeline controller training manuals or information.

f. CPM alarm thresholds for the various applications.

APPENDIX A—GLOSSARY

A.1 accumulator data: A SCADA data value that represents an accumulated quantity, usually volume in liquid pipeline service.

A.2 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.

A.3 alarm: A notification to the pipeline controller that an 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.

A.4 alarm acknowledgement: An action by the pipeline controller, signifying that the alarm event is recognized.

A.5 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.

A.6 analog data: A SCADA data value that represents some measured quantity, for example, temperature or pressure.

A.7 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.

A.8 commodity release: A loss of fluid from the pipeline. Within the context of this publication, 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.

A.9 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.

A.10 communications messaging protocol: The specific format of the data communicated amongst the Control Center computers and RTUs PLCs and Flow Computers in a SCADA system.

A.11 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.

A.12 data acquisition device: A field device used to acquire data from field sensors and transmit the data to the Control Center computers. Some Data Acquisition Devices also contain intelligence to perform local field logic and operations.

A.13 data archiving: A SCADA system feature that records data in an historical database under some pre-defined data management process.

A.14 data quality: A SCADA system feature that creates status bits that are attached to the message to reflect the validity of process data.

A.15 drag reduction agent: An additive used on liquid pipelines to reduce the amount of friction loss. Also referred to as "DRA."

A.16 event log: A SCADA system feature that creates a permanent record of changes to the pipeline and the system's state in chronological order.

A.17 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.

A.18 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 unusual operating condition.

A.19 filter: A device or algorithm to remove unwanted components from a process signal. Also called signal conditioning.

A.20 fluid properties: The characteristics of the fluid that describe its hydraulic behavior, including: density, viscosity, compressibility (or bulk modulus); coefficient of expansion; thermal capacity. Many CPM techniques also need to consider the effects of Pipeline Drag Reducers on fluid properties.

A.21 historical data: Data that has been retained for later retrieval. Typically maintained by a SCADA system's data archival subsystem.

A.22 hydraulic anomaly: An unusual condition on the pipeline or abnormal operating condition that is explainable through the systems hydraulics.

A.23 inference engine: A part of the CPM system that accumulates data, performs calculation (e.g., line hydraulics) and provides outputs to the alert algorithm.

A.24 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 is 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.

A.25 leak declaration: The declaration that is made if a pipeline controller has reasons to suspect that a commodity release is occurring on the pipeline.

A.26 manual data override: When manual entries are input in lieu of actual field data values.

A.27 manual system: A CPM system that is based on non-software algorithmic calculations.

A.28 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.

A.29 material balance: A mathematical procedure based on the laws of conservation of mass and fluid mechanics and is used to determine if a commodity release has occurred on a pipeline system. May also be called mass balance.

A.30 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.

A.31 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.

A.32 noise: An unwanted component in a process signal. Noise may be reduced by filtering.

A.33 over/short: A manual, computer-based or automatic calculation of volumes of fluid injected from which the volumes delivered are subtracted. Volumes may be corrected for temperature. The calculation indicates if the injections equal the deliveries. Over/short may be positive or negative. Also may be called loss/gain.

A.34 pipeline controller: A person who is responsible for the monitoring and direct control of a pipeline. This is the accepted industry term for this position (as outlined in API Publ 1118). Other industry terms used are operator, operations coordinator or dispatcher.

A.35 pipeline rupture: In the context of Computational Pipeline Monitoring (CPM), a rupture is a pipeline leak that releases a large quantity of the pipe's contents. 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. It may also be characterized by registering a differential far larger than system noise in some measured/trended values on the SCADA system, and the rupture will cause an immediate impairment to the operation of the pipeline. The size of a pipeline rupture is difficult to define as indicated in the explanation that is provided in Appendix B of this publication.

A.36 PLC (programmable logic controller): An intelligent field device that collects various instrument data, provides interim sequence control, and packages station information for transmission to a SCADA system.

A.37 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.

A.38 protocol: The specifications of the message structure between RTU or PLC and Control Center computer are collectively referred to as the communications protocol.

A.39 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.

A.40 rate of change: A calculated value that reflects the change in an analog data value per unit time.

A.41 reliability: A measure of the ability of a CPM system to render accurate decisions about the possible existence of a commodity release on a pipeline, while operating within an envelope established by the CPM system design. This term is fully defined and discussed in API Publ 1155.

A.42 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.

A.43 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.

A.44 return to normal: The transition from alarm to normal state that signifies that an alarm condition has ended.

A.45 SCADA: An acronym for Supervisory Control and Data Acquisition, the technology that makes it possible to remotely monitor and control pipeline facilities.

A.46 scan time: The time interval between two consecutive polls to Data Acquisition Devices on a SCADA communication channel. Also called Polling Time.

A.47 segments: A segment typically refers to a shorter section of pipeline. A segment is bounded by defined by instrumentation (e.g., meter) or other physical features of the pipeline (e.g., valves).

A.48 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 API Publ 1155.

A.49 shut-in: A pipeline that is shut-in 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.

A.50 single phase: A fluid state, either liquid or gaseous, based upon commodity, vapor pressure, pipeline pressure and temperature.

A.51 slack line: The condition where a pipeline segment is not entirely filled with liquid or is partly void. May also be called column separation.

A.52 status data: A SCADA data value that represents the operational state of an item of field equipment.

A.53 steady state conditions: The pipeline hydraulic condition that exists when all the pipeline operating parameters remain nearly constant over a period of time.

A.54 system: A system refers to a entire entity such as a complete pipeline. Segments (see above) are subset of a system.

A.55 threshold: A threshold is 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).

A.56 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.

A.57 time tag: A SCADA system feature that records the time that a measurement or event occurs along with the data.

A.58 time tag error: The difference between the time the actual measurement was made and the time tag associated with the measurement.

A.59 transient operating conditions: The pipeline hydraulic condition that exists when any pipeline parameter is changing in time.

A.60 unusual operation condition: A pipeline operating condition which is not displayed during the normal operation of the pipeline. For example, a slack line condition or column separation that occurs infrequently on the pipeline.

APPENDIX B—DISCUSSION OF PIPELINE RUPTURE DEFINITION

The size of a commodity release or leak and rupture is defined in this appendix in the context of how it relates to CPM. Figure B-1 shows a representation of commodity release sizes. The relationship of rupture size to other leak sizes is important because regulations may call for a CPM that is able to detect pipeline "ruptures."

A rupture cannot be considered to be at a fixed value of commodity release relative to the line flow rate or volume of the pipeline. The following factors characterize a rupture:

The volume of product loss that occurs in a rupture will be different for each individual pipeline. The volume released in a rupture on a small pipeline will be much less than on a large pipeline.

Operating conditions of the pipeline (steady state or transient) will influence the minimum size of commodity release above which a leak can be called a rupture. CPM detection limits are not fixed. API Publ 1149, for example, provides methods to calculate theoretical detection limits while the pipeline is in steady state operation and when hydraulic conditions are transient. During transients the detectable limit is significantly higher.

The time interval may be considered in defining a pipeline rupture. A specific volume of a commodity release that escapes over a short period of time could be classified as a rupture whereas the same volume over a far longer period of time may not be designated as a rupture.

If a requirement exists to recognize a commodity release size above which a rupture is defined, it may be done by the pipeline operator. In defining a rupture on an individual pipeline, the pipeline operating company may need to consider the following:

a. if slack line flow exists at the time of the commodity release.

b. The line pressure at the rupture site.

c. The operating state of the pipeline (steady state, or transient and the severity of the transient).

d. The CPM methodology which is used to detect the commodity release. Some methods are optimized to detect small leaks over a longer period of time.

e. The SCADA scan time. Long scans time will not provide field data as quickly.

f. The flow rate of the line at the time of commodity release occurrence. At a lower than normal rate the CPM system may be less sensitive.

g. The temperature gradient may affect the calculation of pipe inventory.

h. The CPM pipeline segmentation. Longer sections of CPM monitoring will have a greater uncertainty to overcome before a leak declaration can be made.

i. The pipe volume and length will affect the detectable limit.

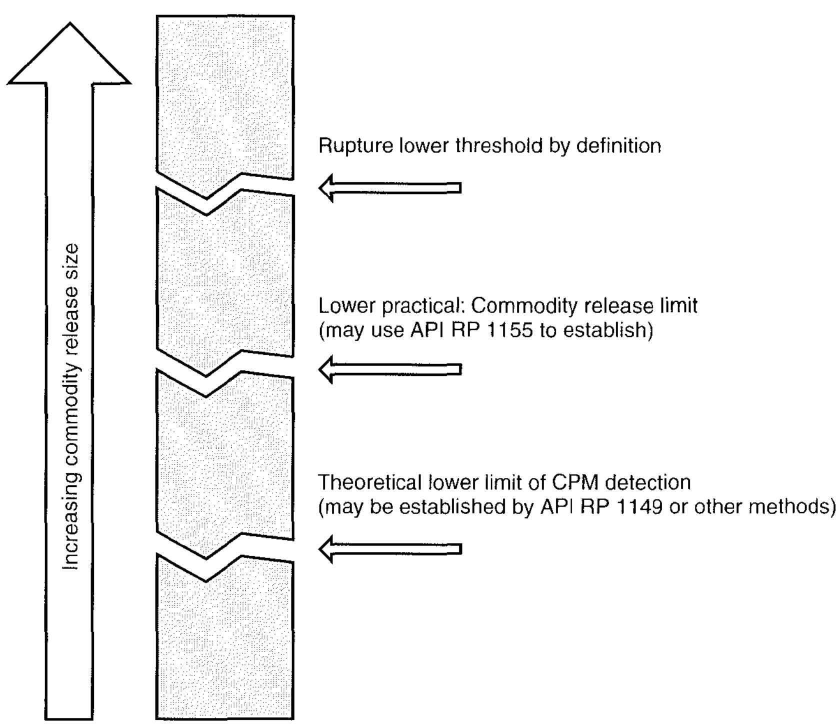

Figure B-1—Graphic of Leak/Rupture Definition

APPENDIX C—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. Figure C-1 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 formula 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.

C.1 Line Balance (LB)

This meter-based method determines 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). There is no compensation for the change in pipeline inventory due to pressure, temperature or composition. Imbalance calculations are typically performed from the receipt and delivery meters, but less timely and less accurate volumes can be determined from tank gauging. Line balancing can be accomplished manually because of its simplicity.

C.2 Volume Balance (VB)

This method is an enhanced line balance technique with limited compensation for changes in pipeline inventory due to temperature and/or pressure. Pipeline inventory correction is accomplished by taking into account the volume increase or decrease in the pipeline inventory due to changes in the system's average pressure and/or temperature. It is difficult to manually compensate for changes in pipeline inventory because of the complexity of the imbalance computation. There is usually no correction for the varying inventory density. A representative bulk modulus is used for line pack calculation.

C.3 Modified Volume Balance (MVB)

This meter-based method is an enhanced volume balance technique. Line pack correction is accomplished by taking into account the volume change in the pipeline inventory utilizing a dynamic bulk modulus. This modulus is derived from the bulk moduli of the various commodities as a function of their percentage of line fill volume.

C.4 Compensated Mass Balance (CMB)

As a further enhancement to the MVB method, this volume balance technique models pipeline conditions between measurement points to more accurately determine pressure and temperature profiles as input for the line pack calculation. The pipeline is sub-divided into a pre-defined number of segments based on available instrumentation, elevation characteristics, and the desired level of sensitivity. In addition, inventory locations are determined through batch/DRA/hydraulic anomaly tracking. Volume imbalance is typically monitored over a number of time periods (e.g., 15 minutes to 24 hours, also weekly and monthly) to detect commodity releases of different sizes.

C.5 Real Time Transient Model (RTTM)

The fundamental difference that a RTTM provides over the CMB method 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.

C.6 Pressure/Flow Monitoring

Pressure/flow values that exceed a predetermined alarm threshold are classified as excursion alarms. Initially, excursion thresholds are set out of range of the system operating fluctuations. After the system has reached a steady-state condition, it may be appropriate to set thresholds close to operating values for early hydraulic anomaly recognition.

Pressure/flow trending is the representation of current and recent historical pressure and/or flow rate. These trends may be represented in a tabular or graphical format on the Control Center monitor to enable a pipeline controller to be cognizant of these parameter fluctuations. This method can be used to display operating changes from which a pipeline controller can infer commodity releases.

Rate-of-change (ROC) calculates the variation in a process variable over a defined time interval. The rate at which line pressure and/or flow changes over to time are the two most common forms of ROC for pipeline operation. The intent of this approach is to identify rates of change in pressure and/or flow aside from normal operating conditions, thereby inferring a moderate to large commodity release if operating hydraulic anomalies cannot be explained.

In general, there are four types of pressure/flow monitoring techniques used on liquid pipelines to indicated unusual operating conditions and potential leak conditions:

1. Pressure/Flow Limit Monitoring—Ensures that measurements stay within predefined operating conditions and emergency limits.
2. Pressure/Flow Deviation Monitoring—Ensures that measurements stay within a predefined tolerance of an expected operating value. Often, separate deviation limits are established for active and inactive conditions and for positive and negative deviations.
3. Pressure/Flow ROC Monitoring—Ensures that any rapid measurement change, above a predefined value per defined time period, is annunciated. Often, separate ROC limits are established for the positive and negative directions.
4. Pressure/Flow ROC Deviation—Modified version of the Pressure/Flow ROC Monitoring, that projects expected ROC values during transient conditions. Often, separate ROC deviation limits are established for the positive and negative directions.

C.7 Acoustic/Negative Pressure Wave

The acoustic/negative pressure wave technique takes advantage of the rarefaction waves produced when the commodity breaches the pipe wall. The leak produces a sudden drop in pressure in the pipe at the leak site that generates two negative pressure or rarefaction waves, travelling upstream and downstream. High response rate/moderate accuracy pressure transmitters at select locations on the pipeline 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.

C.8 Statistical Analysis

The degree of statistical involvement varies widely with the different methods in this classification. In a simple approach, statistical limits may be applied to a single parameter to indicate an operating hydraulic anomaly. Conversely, 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, it can correlate the changes in one parameter with those in other parameters over short and long time intervals to identify a hydraulic anomaly.

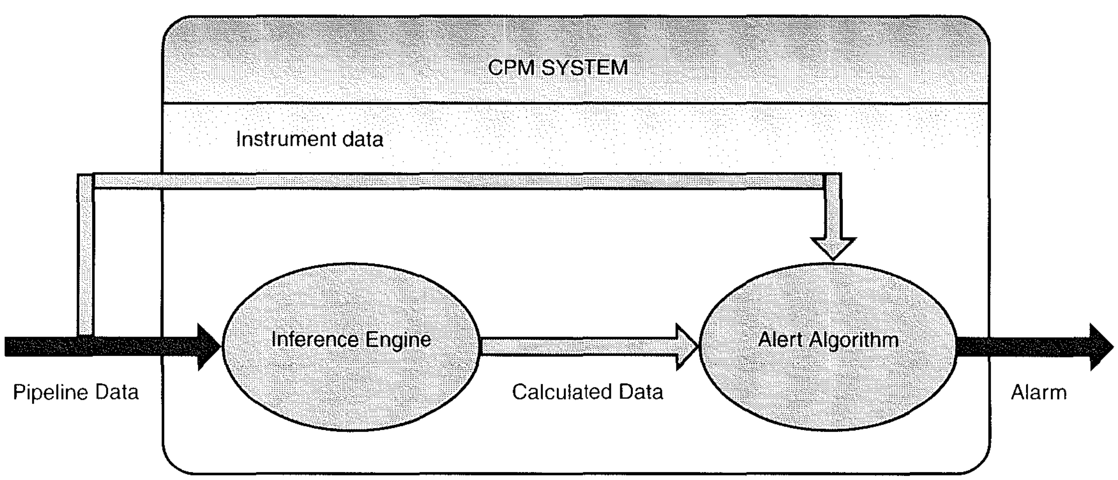

Figure C-1—CPM System

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