Guide to Advanced Control Systems

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Contents

Page

Contents

Page

Guide to Advanced Control Systems

1 General

1.1 Introduction

This Recommended Practice (RP) addresses the implementation and ownership of advanced control systems for petroleum processing facilities. The major sections of this RP are described in 1.2.2 through 1.2.7.

Figure 1 illustrates the major functions involved in the efficient and economic operation of a refinery and shows where advanced control fits into this scheme. Advanced control systems form a fundamental building block on which many of the other functions depend. Similar function charts would be applicable to other types of continuous processing facilities. Similar function charts would be applicable to other types of continuous processing facilities.

1.2 Scope

1.2.1 General

This RP describes commonly used practices for the opportunity identification, justification, project management, implementation, and maintenance of advanced control systems. This practice is not intended to specify the use or selection of any particular technique over another, nor is intended to describe specific applications. It may be used as the basis for defining the work processes and common functions required to define, implement, and maintain advanced control systems.

The practices described in this document are applicable to all advanced control systems applications. Users who are experienced in advanced control may have developed their own equivalent practices. This document is not intended to supersede user practices that have been found to be acceptable or to require that the practices described in this document be followed if they are not appropriate to the circumstance.

Selection of a specific hardware platform, software platform, or application software is not within the scope of this RP

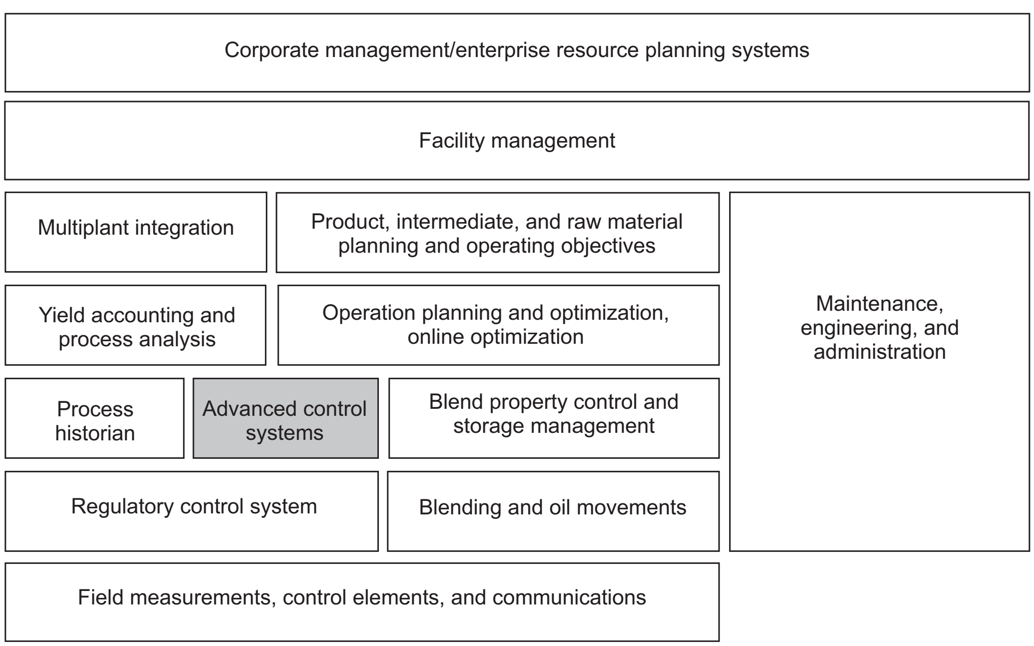

Figure 1—Refinery Operation Functions

1.2.2 Control Systems Functions and Types

The functions and characteristics of commonly used advanced control systems applications are described in Section 3.

1.2.3 Opportunity Identification and Justification

General procedures for identification of advanced control systems applications that may provide economic or operational benefit to a facility are described in Section 4.

1.2.4 Advanced Control Projects

General concepts for planning and management of an advanced control project are described in Section 5.

1.2.5 Technology Considerations

The technical issues that should be considered in selecting advanced control system hardware and software are described in Section 6.

1.2.6 Design Considerations

Application design features needed to support control functions, operator interfaces, and engineer interfaces are described in Section 7.

1.2.7 Application Maintenance

Ongoing maintenance recommended practices for advanced control systems are described in Section 8.

2 Terms and Definitions

For the purposes of this document, the following definitions apply. Also refer to API 554, (all parts) *Process Control Systems* for definitions of related terms.

2.1 Personnel

2.1.1
advanced control engineering specialist
An individual trained and experienced in the design and implementation of advanced control systems. This individual is knowledgeable in process engineering, process control theory and application, and computer applications. An advanced control engineering specialist may be an employee of a refining company, an employee of a control systems manufacturer or consultant, an independent consultant, or other contractor.

2.1.2
advanced control support specialist
An individual charged with monitoring and maintaining an existing advanced control application. This individual may be a unit process engineer, a plant control system engineer, or other individual who is knowledgeable in the specific application.

2.1.3
advanced control user
An individual who is the ultimate user of an advanced control system application. This individual may be a process operator or an engineer charged with operation of the advanced control system application.

2.1.4
operator
A person or persons that is responsible for day-to-day operation of a process unit and its advanced control applications.

2.1.5
project engineer
An individual responsible for the execution of an advanced control project. This individual may have a variety of responsibilities depending on the nature and scope of a particular project. Primary among these is management of the project resources, budget, and schedule. On smaller projects, an advanced control engineering specialist may also perform the duties of the project engineer.

2.1.6
unit engineer
An engineer (typically a process engineer) who is charged with engineering tasks directly associated with the day to day operation of a process unit or area. In some cases, this engineer may also be assigned the duties of an advanced control support specialist.

2.2 Controller Types

2.2.1
advanced control system
Any control system that has functions beyond those commonly associated with regulatory control systems. An advanced control system may be characterized by any of the following:

a) a control system that controls or manipulates multiple variables in order to maintain one or more operating objectives,

b) a control system that performs calculations beyond those that could normally be performed using standard algorithms available in process control systems,

c) a control system that may utilize a significant number of process control system standard algorithms connected together in a complex manner.

NOTE Advanced control system may be implemented in either a higher level computing resource such as a process control computer or implemented in a programming environment at lower control levels, irrespective of the complexity of the computations.

These types of applications are referred to by terms such as advanced process control, model-based predictive control, matrix control, and multivariable control.

2.2.2
controller
The collection of functions associated with either a regulatory control system or an advanced control system. In the context of this document, controller used without any other description is intended to mean an advanced control system.

2.2.3
multivariable control
A form of an advanced control system application in which several control variables (CVs) are maintained at desired values through a complex relationship. Several manipulated variables (MVs) may be adjusted simultaneously in order to maintain an economic or other operating objective. Multivariable controllers typically execute at a frequency of one to five minutes, although faster rates are also achievable.

2.2.4
optimization
A process control function that determines the operating conditions that maximize the economic benefit of an operation within a set of constraints. An optimization scheme may address any number of objectives such as

maximization of a particular product stream, minimization of operating cost, or maximization of an equipment item's operating life. Typically, optimization programs update operational targets at a frequency of hours to days and take into account the frequency of changes in the economic drivers at each site.

2.2.5
regulatory control
A control application in which generally one controlled variable is maintained at a desired value by adjusting one MV. Regulatory control may also include control applications that utilize common calculations or predictions. Examples are steam drum level controls, combustion controls, or mass flow calculations.

2.3 Controller Terminology

2.3.1
advanced control system
The combination of the hardware platform, software platform, and application software necessary to implement an advanced control system application.

2.3.2
automatic shedding
A function by which an advanced control system application fully or partially turns off and control is returned to the regulatory control scheme. This may be a result of invalid input values, inability to deliver controller outputs, or inability of the controller to meet its objectives.

2.3.3
constraints
Limits in the process or equipment that should not be exceeded. (Sometimes referred to as "limit variables.") Constraints may take the form of physical limits such as a design temperature or pressure or other predefined process limits such as a maximum feed rate, composition, or other value. Constraints may be either maximum values or minimum values such as flow pressure, temperature, or process stream qualities. Constraints should be consistent with the HAZOP and alert/alarm strategy for the area being controlled.

2.3.4
controlled variables
CVs
Process values that are maintained by the control system by making appropriate adjustments to MVs.

2.3.5
disturbance variables
DVs
Process input values associated with an advanced control system application that are measured but are not controlled by the application. An advanced control system application often takes control actions to maintain the control objectives when DVs change. Examples are ambient temperature, feed from another unit, etc.

2.3.6
linear program
LP
An algebraic computation optimization technique that uses two or more linear equations that relate process or economic variables. The LP solves the relationship to maximize or minimize the objective function that is usually an economic measure of operating efficiency.

2.3.7
manipulated variables
MVs
Process values that are adjusted by the advanced control system application to meet operating targets and desired values of controlled variables.

2.3.8
OPC server function
Refers to open data interchange functions that are based on standards developed and maintained by the OPC Foundation.

2.3.9
process variable
PV
An indication of process performance, which is directly measured using instrumentation sensors and transmitters, values that are computed from these variables or values obtained from laboratory testing or other techniques.

2.3.10
service factor
A measure of the effectiveness of an advanced control system application. It is more than a measure of whether the application is on or off. This usually is a complex calculation that is based on the numbers and types of subfunctions within an application, the percentage of time that the functions are operating and the relative economic weighting of each subfunction.

2.3.11
setpoint
SP
An input variable that sets the desired valued of the controlled variable; may be manually set, automatically set, or programmed. Its value is expressed in the same units as the controlled variable.

3 Control System Functions and Types

3.1 General

This section describes functions common to advanced control and related systems. Figure 2 illustrates basic control system functions and how they relate to this and other RPs.

3.2 Regulatory Control System Functions

Regulatory control systems provide fundamental control of process variables such as pressure, temperature, flow, and level by manipulating final control elements such as control valves or electric motors. The standard control algorithm used in these systems is proportional-integral-derivative, although alternate algorithms and calculations may also be used. The functions of regulatory control systems are covered in API 554, Part 1.

Complex regulatory control systems typically combine a number of functions used in regulatory control systems to meet a control objective. Typical applications include:

— cascade control,

— dynamic compensation (e.g. filtering or time-shifting of variables),

— variable gain adaptive controllers or other nonlinear algorithms,

— calculated variables such as pressure and temperature compensation of flow or other simple computations,

— override control using output selectors,

— ratio controllers.

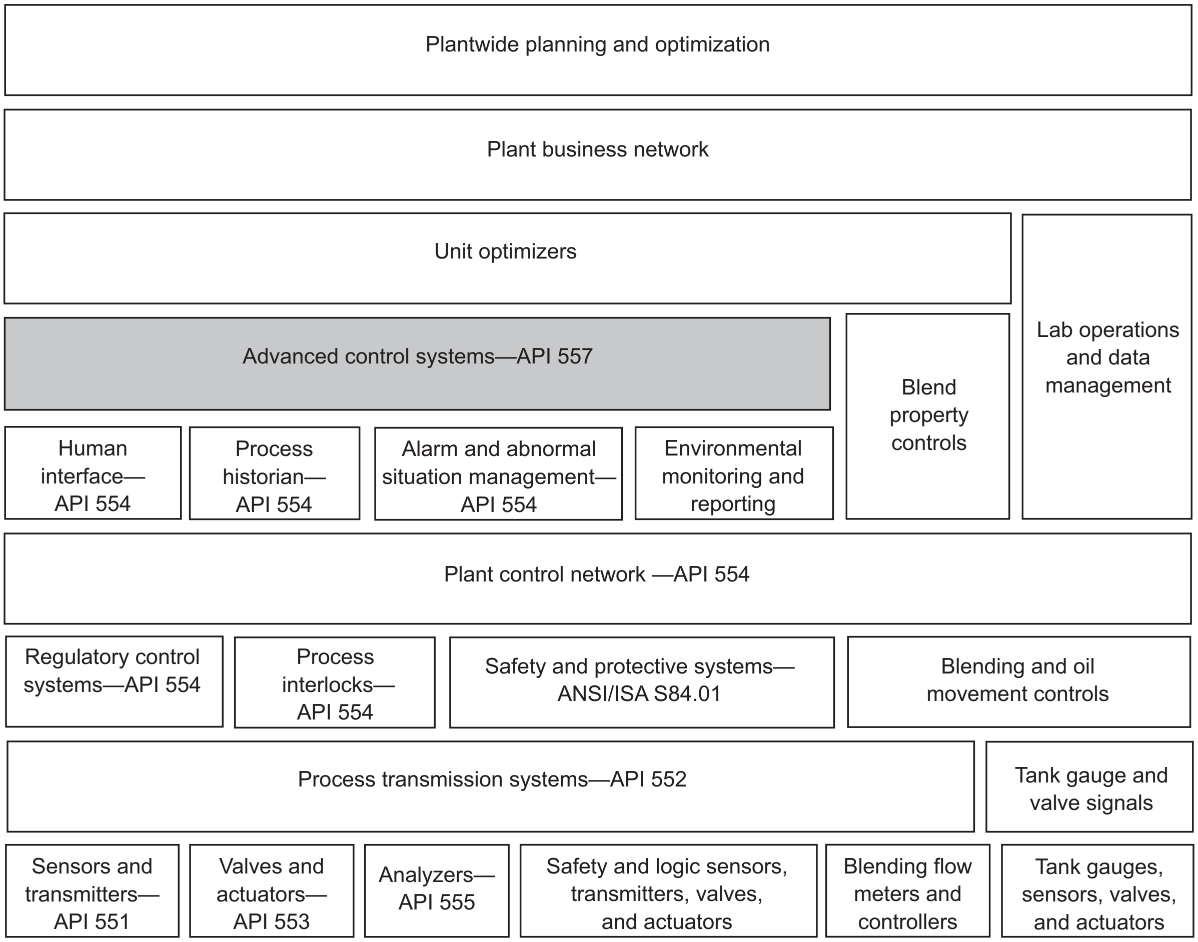

Figure 2—Control and Automation Functions

The regulatory control system should be configured to allow remote access to its setpoints so the advanced control system can write to them. It should also have a mechanism to automatically disable these remote setpoints or go to a predetermined status if the advanced control system has failed or is turned off. The reason for the failure or discontinued use should be captured at the time of occurrence.

3.3 Model-based Control Systems

3.3.1 General

Model-based control systems use a mathematical model of the process to improve process performance. The model may be based on process engineering principles or developed from empirical data collected from the process. These methods are described below.

3.3.2 First Principle Model-based Advanced Control Systems

First principle models are derived from the fundamental mass and energy balances and associated thermodynamics, equilibrium, and reaction kinetic relationships. These models can be used to improve control system accuracy or range when the characteristics of the process are well understood. Typical applications are:

— computation of heat and material balances or reactor yields and conversions,

— computation of inferred process variables that are not measured,

— improvement of control system operating range by including nonlinear effects.

First principle models typically are steady state relationships and become difficult to apply in processes that exhibit complex or variable dynamic behavior. One of the challenges with such models is the determination of the "values" to determine the relationships. Process unit meters are not meant to be custody transfer quality. Consideration should be given to "inferring flows and qualities."

3.3.3 System Response Based Advanced Control Systems

3.3.3.1 General

System response models are based on observations of actual system dynamic performance. They are usually applied when a process is too complex to use first principle models or when multiple interacting variables are to be controlled. Common characteristics are:

a) the control system is capable of performing multivariable control,

b) the model is generally used to predict the effects of control moves and determine the proper actions,

c) the controller handles constraints,

d) the controller can optimize performance within the definitions available in the process model.

The system model allows the controllers to relate multiple manipulated variables (MVs) that the controller adjusts and multiple disturbance variables (DVs) that the controller cannot adjust to multiple CVs. It simultaneously adjusts all MVs to drive all CVs to their "best" operating points.

The process models determine the "best" operating point based on user-defined constraints and process economic information. Typically, the best operating point is where the maximum number of system constraints possible is reached. Figure 3 shows the general relationships of operating points and constraints. This is a simplified presentation, as in most real applications, multiple operating values and constraints exist.

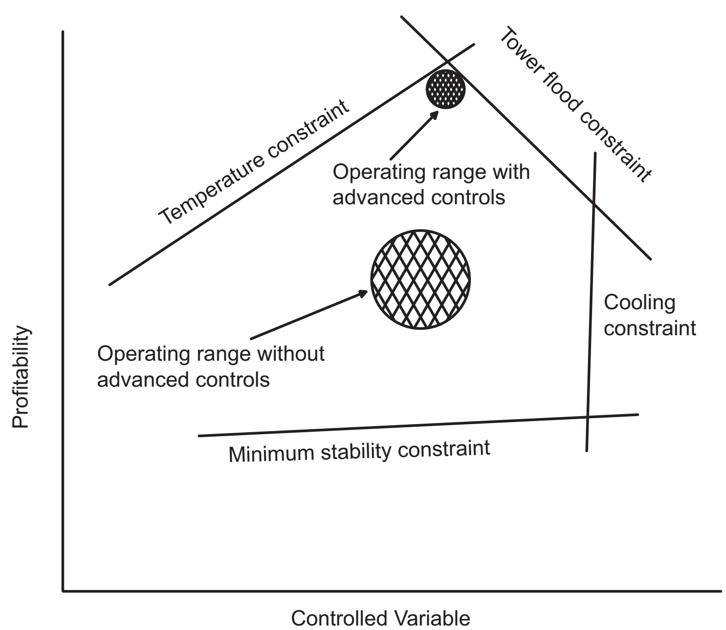

Figure 3—Operating Conditions vs Constraints

3.3.3.2 Multivariable, Matrix Based Systems

These systems use empirical models obtained by testing the process to identify its characteristics and interrelationships. Matrix controllers use linear models to relate MVs and DVs to CVs. They may also incorporate transformations of inputs and outputs to handle process nonlinearities. Some versions of these controllers have been extended to use nonlinear models. These controllers have been used in the industry for many years and have evolved considerably. In fact, they have improved to the point where the console operator's span of control has reached its horizontal limits.

3.3.3.3 Neural Net Systems

Neural networks are capable of providing similar functionality as matrix controllers. The fundamental difference between neural net and matrix controllers is a learning engine that develops the process model based on observations. The learning engine behaves somewhat like an optimizer that combines observations and user-supplied rules to generate a process model.

Neural net controllers require sufficient "good" process historical data to create a model. If such data is not available, a data acquisition period will be required.

Neural net controllers can produce nonlinear models and can adapt the model to process changes without requiring formal process testing. Typically, these adaptations are performed offline using parameters generated by the online neural net application.

3.4 Optimizers

3.4.1 General

Optimizers provide a computation method to determine the "best" operating point based on user-defined economic objectives and a model of the process. Typically, optimization programs update operational targets at a frequency of hours to days and take into account the frequency of changes in the economic drivers at each site. The outputs of optimizers are usually steady state objectives for other controllers such as multivariable controllers that handle dynamic control.

Optimizers may operate in an offline or online mode. In the offline mode the model is not receiving dynamic data from the process. In the online mode key real-time process data is connected to the model.

An online mode application may be online open loop or online closed loop. In online closed-loop mode, the outputs are automatically passed to the dynamic controls. In online open-loop mode, the optimizer outputs are presented to the operator, and the operator is responsible for passing changes to the dynamic control.

In online applications, significant data validation and reconciliation are necessary. It may also be necessary that steady operations exist when the optimizer is run. Some more powerful optimizers may not require this.

3.4.2 Imbedded Linear Programs (LPs)

Many multivariable controllers contain an imbedded LP to solve an optimization problem. The imbedded LPs are based on linear relationships between CVs, MVs, and the economic benefit or penalty associated with each variable expressed as a cost or benefit.

3.4.3 Unit Level Online Optimizers

Unit level optimizers may be used to compute operating targets for one or more unit multivariable controllers. These optimizers typically use a much larger number of variables and may have thermodynamic, equilibrium, or kinetic relationships built into them. They usually require functions for data validation, reconciliation, and parameter estimation. Unit level optimizers typically are able to access economic data from external sources. Unit optimizers may use more rigorous nonlinear models to identify optimum operating conditions for the overall unit.

3.4.4 Plantwide Optimizers

Linking several unit level optimizers allows the system to locate a global optimum for the entire plant. In practice this is an extremely complex undertaking. This type of optimization requires rigorous models to ensure accurate results. Data reconciliation with overall material balances and yield accounting systems is a critical requirement for plant level optimizers. For example, as the product slate from one unit is the feed to the next, a small error introduced due to a poor model or conflicting data will propagate throughout the entire optimizer, which can provide an inferior result.

Use of these optimizers has often been limited by the accuracy of the unit optimizers when applied to very large systems. The computing load for these optimizers and the volume of input data can be immense. Some success has been obtained using offline LP models of a number of plants.

3.5 Expert Systems

Rule based systems are used where predetermined events exist. They are well suited for providing detailed information to operations based on events that have occurred in the process. Typically, these systems are used in an advisory capacity and are not directly connected to a control system. Abnormal Situation Management is an emerging application of expert systems.

3.6 Fuzzy Logic Systems

Fuzzy logic is used when the rules followed are inexact. It is a technique that can transform graded or qualified rules, such as if a “temperature gets too hot then slowly increase the cooling water,” into specific actions. Fuzzy controllers are a developing technology in the process industries. Fuzzy controllers may be imbedded in equipment controllers provided with packages. Some process control systems provide fuzzy control blocks as part of their algorithm set.

3.7 Batch and Sequence Systems

These control strategies are used for operations that have finite steps executed in a predetermined order. Some examples include reformer regeneration, water treating, and coke handling. These operations are described in detail in ISA S88.01 and are not within the scope of this RP.

3.8 Blending Systems

Component blending is used in various fuel production complexes. These systems are comprised of blend ratio regulatory control elements, property estimators, and optimizers that adjust recipes to meet final property specifications. The control systems used include advanced strategies as described in this document, but blending practices are not within the scope of this RP.

3.9 Oil Movement Systems

Oil movement systems use heuristic rule-based systems and are not within the scope of this RP.

3.10 Manufacturing Execution System

An application that is directed towards management of manufacturing operations. This includes issues such as manufacturing scheduling, raw material management, and resource planning. The application typically resides at the business network level and is outside the scope of this document.

4 Opportunity Identification and Justification

4.1 Resource Requirements

The identification of improved control opportunities is a multidisciplinary task with incremental economics, statistical data reconciliation, operations planning (including scheduling and dispatching), operations, process, and control application knowledge and experience playing the most significant roles. Experience has demonstrated that the essential element of success in implementing advanced control projects is the engineers' knowledge, experience, and ability. While appropriate technology is an important factor, it cannot make up for lack of skill or experience in the personnel implementing, maintaining, and using the application.

A benefits feasibility study for a single process advanced control application can be handled by a suitably skilled individual relying on specialist support where required. However, as the scope of the study increases, particularly when studying a complete facility, a small mixed discipline team approach is recommended. The team should include representation from site process/planning, operations, and control system engineering.

Benefit identification requires both technical and interpersonal communication skills. Identification and realization of benefits requires:

a) understanding the economic driving forces for the processes (e.g. the incremental process and energy economics and the timing of the changes to those values);

b) understanding how the processes work and interact;

c) understanding the process's real limitations and constraints;

d) obtaining buy-in for the benefits and solutions from the advanced control users and business support specialists (e.g. budget planners, schedulers, and economists).

4.2 Economic Drivers

Long- and short-range business plans should be the basis for evaluating potential benefits. These plans should reflect the impact of a number of typical economic drivers. Not all of them will be applicable to a particular market or facility, but they are indicative of the forces that determine the economics. Examples of economic drivers that should be considered are as follows.

- Business management drivers:
  - financial objectives,
  - environmental and safety objectives,
  - process unit turnaround schedules.
- Local plant drivers:
  - feedstocks and finished product pricing;
  - volume and shipping methods for crude and other feedstock;
  - demand and shipping method of finished products;
  - product margins;

  — utility usage, prices, and contractual obligations (e.g. requirement to meet energy forecasts).

— Local economy issues:

  — seasonal variations in product demand, quality, and supply;

  — the economy in which the plant operates (e.g. open or closed market economic operation);

  — government influence and requirements.

4.3 Identification of Potential Applications

Most opportunities are identified during discussions with site personnel from the process, planning, and operations functions and a preliminary assessment of the process performance data. The following are useful guidelines for this preliminary assessment:

a) review actual plant performance against production/operating targets,

b) review plant performance against best of class or other benchmarks,

c) review the economic drivers added value potentials,

d) consider any anticipated process plant changes,

e) identify improvements that have been realized by existing advanced control system applications,

f) identify opportunities for control improvements using rigorous plant steady state models that have been tuned to correlate with statistically reconciled data.

A number of improvement areas that may be considered are listed in Table 1.

The outcome of this preliminary assessment is a list of potential applications and their benefits. This list should be reviewed with appropriate personnel to rank the potential benefits and identify those that appear to have high potential and that should be further studied.

4.4 Identification and Quantification of Benefits—Feasibility Study

4.4.1 General

Each of the top ranked items identified from examination of the potential benefits should be considered in detail. The overall methodology is outlined in Table 2. For existing plants, data can be obtained based on observed operation. For new plants, these data could be obtained from assessment of equivalent data from similar operations or process models.

4.4.2 Application Objectives

The first step in the feasibility study is to identify the objectives of the proposed control application. This can be achieved through a series of discussions with the site representatives from the planning, technical and operations functions. It is important that process constraints/limits and production targets/specifications are examined and challenged. Identified constraints should be considered for testing and data collection, as they may be perceived rather than real.

It is also important to identify the effects that proposed control improvements may have on other units or utilities. For example, an increase in an intermediate product stream rate may exceed the capabilities of downstream equipment. However, the benefits of selling any excess intermediate should be considered.

Table 1—Advanced Control Benefits

Improvement Area	Potential Benefits
Yield	— Product upgrading — Reduced variability — Reduced quality giveaway on intermediate or final product — Control closer to targets
Stability	— Reduced product downgrading — Reduced energy usage — Production closer to constraints for better control
Throughput	— Higher production by better operation against process equipment constraints and limits such as: — tray vapor/liquid loading — condenser/reboiler duty — pump/control valve capacity — heater/vessel temperatures — pressures/flows/levels — compressor parameters — minimization of unwanted material in feedstock (i.e. nC_4 in alkylation feed)
Reactors	— Improved reactor performance by better control of: — weighted average inlet temperature — weighted average bed temperature — hydrogen to feed/recycle — reactant and other key process variables
Energy usage	— Reduce total energy costs by better control of: — reflux ratios — pressure minimization — reduced stripping steam — pumparound heat recovery
Heaters	— Improved efficiency of heater operation through: — swing fuel firing control to maximize usage of lower value or variable fuel — injection steam ratio control where appropriate — multiuser control strategy (i.e. hot oil systems) — pass outlet temperature balance control (See API 556, *Instrumentation, Control, and Protective Systems for Gas Fired Heaters* for basic combustion control schemes, including excess O_2 and stack temperature)
Miscellaneous	— Enhanced understanding of the process for better management of all site functions — Improved equipment reliability due to more stable operation at intended conditions — Sharing of best practices from other applications

Table 2—Benefit Feasibility Study Steps

Step No.	Description
1)	Identify application objectives
2)	Identify representative period of operation
3)	Collect and validate process data
4)	Analyze data for performance against targets
5)	Identify control application improvement
6)	Analyze control infrastructure performance and requirements
7)	Apply appropriate economics
8)	Categorize benefits on a confidence basis
9)	Review and agree benefits analysis with site, including business support personnel
10)	Set up postapplication benefit audit basis

4.4.3 Data Collection and Validation

4.4.3.1 Data Requirements

The objective of this step is to identify all the necessary data and information that will quantify the actual performance of the process relative to its operating targets and the control objectives.

The following types of data should be collected in sufficient quantity to be statistically significant and consistent.

a) Operating targets—such as product qualities, rates, yields, and comparison to the LP vectors used to select raw material feedstocks (e.g. crude oil) and to optimize the facility.

b) Actual values achieved—feed and product rates, yields, and laboratory and online analyzer results that have been statistically reconciled.

c) Process operating constraints and limits, reasons, and values—this could include throughputs; pressure/flow/temperature limits; valve position and equipment capacity limits; limitations imposed by other processes; or planning restrictions, environmental restrictions, or safety restrictions.

d) Availability of process (stream days) and reasons for outages or restricted operation.

e) Measurement availability—analyzers, flows, inferred flows, qualities, etc., including accuracy, repeatability, and reliability.

f) Discrete events such as coke drum sequencing, dryer switches, etc.

g) Control system performance indicators such as poorly performing control loops, control valves, etc.

h) Future plans and timing for process modifications and their potential impact.

i) Production operating target changes that may be planned.

j) Future operational flexibility requirements.

k) Economic driver data and long-term plan (see 4.2).

Assumptions will have to be made where necessary data and information are unavailable. Assumptions relative to missing data and the impact on the confidence of economic predictions should be discussed with and accepted by site personnel (including business support personnel) in advance of moving the project beyond the preliminary stage.

4.4.3.2 Representative Period of Operation

It is important that one or more representative periods of operation be selected and agreed on as the basis for benefit identification. These should reflect “normal” operation of the process—no shutdowns, processing deficiencies, nor unusual planning/production requirements. Any variation due to weather or day/night operation should be included. One month minimum is recommended, particularly when infrequent (once per day) laboratory data will be used in the analysis. The data analyzed should be statistically significant and consistent, including consistency with the overall site material balance for the period.

Data from several periods during the operational run of a unit may be required. This will account for effects such as seasonal changes to plans and targets, ambient conditions, or start-of-run to end-of-run conditions that may have a significant impact on potential benefits.

The representative period(s) will be used for prorating the potential benefit to an annual basis using an agreed on stream days per year. Stream days vary between processes and sites. Three-hundred-and-fifty stream days per year are often used as a default when no specific information is available.

Failure to identify and agree on realistic representative periods can lead to misleading and erroneous benefit predictions. For example, the actual and audited benefits of a particular process unit application were $900,000 for the summer months and only $100,000 for the winter months. The original feasibility study had been based on summer operation only ($1.8 MM/year). Benefits were therefore overpredicted by $800,000 per year.

4.4.3.3 Performance Data Validation

Collected data should be validated before it is used in benefits computations. Typical steps taken to validate the data include:

a) filter out any obvious bad process data, including data from identified “non-normal” operation in the representative period(s);

b) carry out a simple statistical mean and standard deviation analysis of the absolute actual values of targets and constraints as appropriate;

c) compare to site-wide data reconciliation and consider developing and using inference equations to predict flows and qualities, since trade-offs between streams and qualities matter.

NOTE Frequently, the statistics vary as a function of the targets set and often reflect the nonlinear response of the process. In these cases, it is more meaningful to perform the statistical average and standard deviation on the difference between the target and actual values and to calculate a time weighted average for the actual value.

4.4.4 Control Improvement Prediction

4.4.4.1 Analysis Techniques

An important method in analyzing potential control improvement benefits is statistical analysis. Reducing the standard deviation of controlled variables (targets, setpoints) and moving operation closer to constraints is well accepted in practice as a basis for predicting the improvement achievable. Often a 50 % reduction is assumed, but the current value of the standard deviation should be considered and evaluated before assuming a reduction. Often, a 50 % reduction can be somewhat conservative as shown by actual audits of control applications.

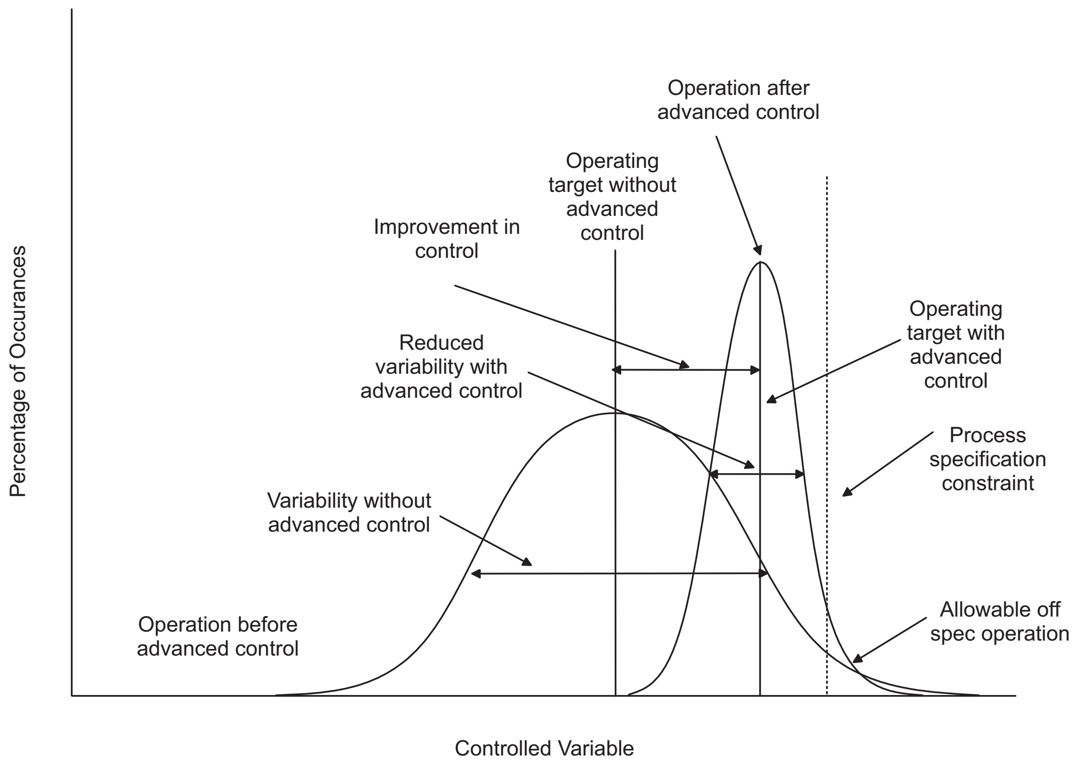

Figure 4—Improvements from Reduced Variability

It should also be noted that the improvement in stability of the controlled variables is often achieved by more frequent adjustments of the MVs. However, the net effect is a reduction in variability of the controlled variables. Figure 4 illustrates how reduction in variability results in the ability to operate closer to process constraints, which generally translates into tangible benefits related to increased process rates, improved product quality, reduced giveaway, or similar economic benefits.

Another valuable analysis is to compare operations variability among operating crews. Often significant benefits can be quantified by comparing "best" operation versus average operation within the site.

Skill is required in selecting which prediction method to employ. Limitations in information or current capability may indicate one method when in fact another is more appropriate. As discussed above, it is also necessary to consider the time weighted average of control targets when those targets are changing.

The prediction of reduced variability may then affect the overall process yield, feed rate, or energy usage. Economic factors for these effects should be readily available from the site. The same data can be obtained from a rigorous steady state process model and appropriate pricing information. Such a model can also be used to assess the impact of the predicted change(s) on other process parameters to confirm that the change is realistic and viable with respect to known process operating limits/constraints.

Where no acceptable analysis technique exists, it may be possible to infer benefit information from similar applications. However, this will impact on the confidence of the prediction.

4.4.4.2 Practical Considerations

One hundred percent of an identified benefit is rarely achievable in practice. Perfect control is not possible, and some small, but positive, giveaway will generally be required to ensure that market product specifications are not exceeded.

The existing control performance affects both the benefits prediction and the ability to realize the benefit with the intended control application. Additional measurement and control capabilities may be required, and their availability and utilization affect the realizable benefit. The use of online analyzers, either physical or inferential, may be required to realize a significant part of the benefit. Analyzer availability should be prorated into the prediction.

Process constraints and plant limitations provide limits to a benefit. However, actual constraints or limits should be established on an objective basis as limits may be more perceived than real or could be relaxed by improved control or minor physical modification.

Significant net incremental economic improvements are often a result of these evaluations. However, the prediction should reflect the present and future market situation. Predicted benefits will have to show up in the bottom line of the site's operation.

4.4.4.3 Synergistic Effects

The realization of a predicted benefit can have synergistic effects. These can either increase or decrease the ultimate benefits. Such benefits or costs should be included in the overall project's economics. In all cases, a mitigation strategy should be developed and the project's economics consider the costs and benefits of the mitigation strategy.

Examples of effects that may increase benefits include the following.

a) Reductions in stripping steam usage by implementing ratio control results in a reduced sour water stripper process load.

b) The reduction in the furfural wash ratio in a lube oil plant to minimize quality giveaway and improve raffinate yield also produces a throughput increase for some feeds and furfural recovery section heat demand reductions for all feeds.

Examples of effects that may decrease benefits include the following.

a) Increase in a product recovery that cannot be handled by a downstream unit or sold at a profit.

b) Improved controls on an upstream unit reduce potential of a downstream unit compared to a stand-alone look at the downstream unit. For example, stabilizing an upstream unit may reduce variability in a downstream unit, thus shifting potential benefits for the downstream unit to the upstream unit.

c) An existing control infrastructure may not be able to support the proposed control application fully. Examples include low online analyzer availability and poor basic control performance. In such cases, consideration should be given to using inferred qualities as a mitigation strategy.

d) Changes in the yield of upstream units may adversely affect the performance of downstream units. For example, the recovery of additional butane/butene components for alkylation feed can add unwanted n-butane and n-pentane, which in turn adversely affect yield, quality, and heat requirements in the alkylation unit.

e) Some predictions can only be taken for part of the time. As an example, the control objective of butane recovery in a debutanizer is a function of seasonal changes in demand, operational constraints, and quality specifications. For example, summer-to-winter change in gasoline specifications limit the amount of butane that gasoline can contain, plus summertime demand for LPG components is generally low. Therefore, summer pricing of butane may not justify additional recovery.

4.4.4.4 Existing Control Performance

The performance of an advanced control system application can be limited by the performance of the basic regulatory controls and infrastructure with which it interfaces. It is imperative to review this infrastructure and make the improvements required to support the advanced control system application.

Online instrument diagnostics and asset management systems can help to identify many infrastructure problem areas that need to be addressed. The ability to accomplish this is dependent on having qualified, responsive resources to properly evaluate the diagnostic information. Diagnostic data may also be useful in the design of the advanced controls, for example, to revert to appropriate level of control upon detection of degrading measurement quality.

The review should be undertaken with the knowledge of the objectives and requirements of the proposed advanced control system applications. Examples of the areas that should be addressed include the following.

a) Online analyzers—current performance and availability. Is improvement required? What additional analyzers or analyzer modifications are required? Can inferential models (e.g. neural networks) be used to predict product qualities in this application?

b) Regulatory controls—current performance. Are modifications or loop tuning required? Is a major upgrade prerequisite to implementation of the advanced control applications? Are periodic checks made to ensure that control loops have not been left in manual mode?

c) Control facilities maintenance. Is field equipment reliability high enough to support an advanced control system application?

d) Control valve performance problems. Are valves appropriate to the service or are improvements in valve dynamics or precision required? If valves are equipped with smart positioners, are valve signatures periodically evaluated to identify valve performance issues?

e) Additional required measurements. Are additional flow, column differential pressures, levels, etc. measurements needed to support the advanced control applications?

f) Are inferential models required because analyzers are not reliable or because the cycle time is long or results are not frequent enough for the control?

g) New or upgraded control facilities. Often existing regulatory control schemes need to be improved or modified. Occasionally, equipment cannot be operated in the manner intended and the control objectives must be modified. Examples are as follows.

   — *Heaters*—A control objective may be to improve efficiency by air trim control, but the basic requirements of box pressure and emissions compliance must also be met.

   — *Local Controllers*—Many older facilities may still have local pneumatic level controllers with perhaps an indication in the control room. In some cases, the level control valve position may be identified as a constraint. This requires relocating the controller to the process control system or making the control valve position available to the advanced control system.

   — *Measurements/Control Loops*—Stability improvement may require upgrade of existing regulatory controls. For example, existing level and temperature control loops may need to be modified to include cascade flow control. New measurements may be necessary for identified constraints. Often, side streams are not flow controlled, but the advanced control scheme may require it. In this instance, a flow measurement element and flow controller may need to be added.

   — *Precontrol Project Improvements*—The feasibility study invariably results in identification of any number of improvements. For example, loop tuning, control valve sizing and performance, improved sensors, etc. can be made without implementing the advanced control application. The benefits of these improvements may reduce the incremental benefits attributable to the advanced control application.

4.4.5 Economic Prediction

The final economic benefits predictions require combining the identified control improvements and operating economics discussed above.

Where possible, the predicted benefits should be confirmed against production performance monitoring. For example, performance monitoring should indicate similar magnitudes from assessment of product giveaway or loss. Where available, plantwide LP models can also help back check predicted benefits.

4.4.6 Benefits Assessment

Predicted benefits should be assessed to identify probabilities of realizing the benefits. Identifying benefits in terms of confidence can be very helpful in supporting financial cases for applications and quantifying of economic risk. A sensitivity analysis may be included to better summarize the economic response. Generally, benefits fall into the following four areas.

a) Benefits that can be rigorously quantified.

b) Benefits that can be positively identified in a qualitative sense but less rigorously quantified.

c) Benefits that are less tangible. These benefits cannot be readily quantified but are generally recognized in the industry. The quantification of these benefits may be somewhat subjective. These benefits tend to be those derived from the improved knowledge of the process, better operator interfaces, improved efficiencies such as better operator utilization, reduced maintenance, and faster troubleshooting.

d) Benefits resulting from the ability to meet regulatory requirements.

4.4.7 Feasibility Report

An advanced control feasibility report should be prepared. This document should address the following items:

a) an overview of the process;

b) current and future operating objectives;

c) economics used for the benefits prediction;

d) clear definition of the key performance indicators (KPIs) and the mechanisms that will be used to monitor them;

e) benefits prediction analysis, including assumptions made and references to all data sources;

f) functional specification and scope definition of application:

  — description of control objectives;

  — list of control I/O;

  — implementation platform requirements;

  — list control/measurement upgrades required;

  — control infrastructure upgrade requirements;

  — security for receiving functional and operating system updates and incremental economic updates, KPIs utilized and influenced;

g) feasibility of performing plant testing on MVs;

h) preliminary estimates of implementation costs, including the following:

  — application hardware and software, including license fees;

— engineering and project management;

— owners costs, support, training, documentation;

— measurement additions and upgrades;

— regulatory control upgrades;

— contract services;

— travel and living expenses;

i) preliminary schedule;

j) cash flow forecast of expenditures versus benefits with payback period and ROI calculations;

k) plans for postapplication audit.

4.4.8 Benefit Postapplication Audit Planning

Experience has demonstrated that postimplementation audits are only as good as the quality of the preimplementation (base case) information. The base case should be developed prior to implementation as this is the only time that the correct base data exists.

The information and data produced for a benefits prediction study provides a very sound basis (base case) for carrying out a subsequent postapplication audit. The application implementation will always be in the future. Hence, it is important that the impact of any intervening changes, both noncontrol (process modifications, catalyst/target changes, etc.) and control, are evaluated to check the validity of the base case.

5 Advanced Control Projects

5.1 General

This section addresses aspects of project management and execution that are unique to advanced control projects. This section is not intended to describe all general project execution issues such as budget, schedule, and contracting, but it is intended to address those issues unique to advanced control projects.

An advanced control project may consist of implementation of one or more applications. The scope may also include infrastructure scope items such as field instrumentation and measurements and regulatory control enhancements in addition to the applications and their associated hardware and software.

See API 554, Part 1 for additional guidance on project planning and execution.

5.2 Master Plan

Prior to embarking on any advanced control projects, the facility should have a defined automation master plan that includes advanced process control. This plan should have the full support of facility management and have considered the strategic business impacts. The content of an automation master plan will vary from facility to facility but should contain the following elements.

a) Definition of the long-term objective of the master plan and division of the work into phases.

b) Identification of benefits to be realized from each phase of the plan.

c) Identify the KPIs and how they will be quantified and monitored after the project is implemented.

d) Definition of the control and computing equipment and software platforms that the facility will use. This may include definition of allowed applications for various hardware and software alternatives.

e) Identification of existing and planned control networks and an expansion path or evolution plan for those networks.

f) Definition of process control implementation standards and practices for the facility.

g) Identification of critical timing issues with respect to unit turnarounds or other shutdowns that may be opportunities for control and instrumentation system modifications, upgrades, or improvements.

h) Milestones or schedule for review and update of the plan.

i) Identification of resources required to provide ongoing application maintenance after implementation is complete.

j) Statement of smart instrumentation strategy and utilization of its enhanced data and calculation capabilities.

k) Statement on techniques to ensure consistency of data across the site that does or does not recognize the inherent accuracy and current state of the instrumentation in determining flows and qualities. This should include the site's preferences on the use of inferred flows and qualities for various scenarios.

5.3 Project Execution Plan

Prior to commencement of an advanced control project, a project execution plan should be prepared as a guide to how the objectives of an advanced control project will be realized and maintained. The plan should build on the information in the feasibility report and master plan. It should address the following:

— timing of the project,

— functional specification,

— resource requirements,

— project benefits,

— benefit validation plan,

— use of dynamic simulators to validate the design and train personnel,

— training plan,

— design plant testing and implementation plan,

— commissioning plan,

— postcommissioning economic performance plan,

— ongoing application support and maintenance.

5.4 Implementation Issues

Advanced control projects have a number of implementation issues that are not normally associated with projects of other types. The project engineer should be fully cognizant of the requirements of the facility master plan and be prepared to execute the project within the guidelines of this plan.

Common issues associated with implementation of advanced control applications are as follows.

a) Advanced control projects often involve upgrades of existing control systems. This may range from wholesale upgrades of obsolete instrumentation systems with modern process control systems to incremental upgrades of existing systems.

b) Most advanced control projects will involve addition or upgrade of process measurements. Some of these measurement points may not be accessible for upgrade during normal operation, and design of the advanced control system may have to recognize delayed availability of certain measurements. Some of these measurements may involve the use of online analyzers. Typically, analyzers should be installed and have a demonstrated performance history before the advanced control application can use the measurement. The project budget and schedule should recognize the costs and timing associated with new or upgraded measurements.

c) In some applications, the use of inferred values may be an alternative to the use of online analyzers. Additional instrumentation may be required to support determination of the inferred values.

d) New construction projects often involve implementation of an advanced control system. Usually this implementation cannot proceed to any extent until after the construction has been completed and operating data are available.

e) New construction projects may also involve modification of existing units, which may also have existing advanced control systems. The scope of new construction may be such that the process equipment, operating conditions, or operating characteristics will be different than those on which the existing advanced control system was based. This may require that the existing advanced control system be redesigned or modified before it can be recommissioned.

f) Many advanced control projects are dependent on having a unit shutdown to install measurements that may not be accessible during operation. Until these measurements are available, it may not be possible to completely perform process testing or control system implementation tasks. This shutdown may also be required to implement control system replacements or upgrades. Many times the turnaround or shutdown schedule will determine the overall advanced control project schedule.

g) Process safety management regulations usually require that process hazard analysis be performed on the advanced control system. This may require implementation of a management of change (MOC) procedure to assure that developments in system design are properly reviewed before they are implemented.

h) An advanced control system's design may be based on a number of different techniques. Among these are steady state and dynamic process modeling to identify relationships among key operating variables and on stream testing of existing systems to derive empirical relationships. If significant process modifications are being made in parallel with the advanced control project, some of this work may not be completed until the modifications have been completed.

i) An advanced control system project may require integration of multiple software packages, possibly from more than one supplier. An integration plan, including identification of the organization and individuals responsible for ensuring that all software works as intended. The use of a single "suite" of software versus several applications from different sources should be evaluated. Not all applications in a suite of software may be the best fit for a project, but this should be weighed against the cost of implementing and maintaining software integration among several vendor's offerings. In any case, the full system should be tested in a virtual duplicate of the real environment.

5.5 Personnel Commitments

5.5.1 General

Successful execution of an advanced control project requires commitment of an appropriate number of personnel with the appropriate skill sets. As mentioned above, availability of personnel with the knowledge, experience, and ability to undertake advanced control projects is critical to the success of the project. Attempting to implement a project without adequately skilled personnel will likely result in failure.

As compared to many other types of design/construction projects, advanced control projects require that a substantially higher percentage of total project costs be devoted to engineering. Advanced control applications also require continued maintenance if a continuous benefit stream is to be realized. Process facility management should recognize the personnel commitments required and consider them with respect to benefits when making staffing decisions.

5.5.2 General Skill Set

Personnel assigned to advanced control projects should be familiar with the specific practices and techniques associated with such projects. This includes knowledge and experience in process control engineering, control system hardware and software, and general process engineering.

Appropriate training should be planned and budgeted to ensure necessary skill set capabilities. See 5.6.4 for additional guidance with regard to training.

5.5.3 Project Management Skills

Project management skills are an important factor in advanced control project execution. However, the management methodology needs to recognize the unique characteristics of advanced control projects. This includes issues such as critical path schedule items often being unit shutdown driven, extended periods where little or no apparent progress is made due to these restrictions, and the often extended implementation, testing, and validation periods associated with such projects.

5.5.4 Specialist Support

Participation of specialists skilled in such areas as process engineering, computer implementation, or analytical methods is a critical component of an advanced control project. IT specialists, with extensive communication and data MOC capabilities, are needed to support the virtual and collaborative environments. These individuals may be on the owner's staff or may be contract or manufacturer/vendor employees. In any case, these individuals may need to devote a significant amount of time to the effort.

5.5.5 Vendor or Consultant Support

In many cases, an owner may not have sufficient staff with the requisite skills available. In these cases, use of manufacturer, vendor, or consultant personnel can be applied to leverage existing staff and realize the benefits of the applications. Should use of such personnel be necessary, the owner should ensure that the personnel have the requisite skills and training.

5.5.6 Plant Operations and Maintenance Support

A key component of any successful advanced control project is the support and participation of plant operations and maintenance personnel. Operations input is a key factor in defining advanced control objectives and strategies and in implementation, execution, and maintenance of the control scheme, operator interfaces, and backup and fallback strategies. It is highly recommended that a skilled operator be assigned to the project team as well as a unit engineer who has detailed knowledge of the process and systems.

Maintenance input is necessary to identify requirements for the advanced control system to handle routine or unscheduled maintenance of sensors, transmitters, control elements and control equipment, and engineering oriented changes such as loop tuning, configuration changes, etc. These issues need to be addressed as an integral part of the advanced control system design.

MOC processes should be followed for all facility modifications necessary to support the project.

5.6 Schedule

5.6.1 General

Advanced control projects have scheduling characteristics that are unique to these types of projects. These characteristics often result in high activity periods separated by substantial periods of little or no apparent activity.

Prior to starting an advanced control project, all significant tasks and their expected duration need to be defined. All schedule constraints imposed by resource availability and operations should be identified. Table 3 shows a list of typical tasks associated with an advanced control project. The actual tasks, duration, and lead time may vary substantially depending on the scope of the application, plant operations, and the prior experience of the engineering, operations, and maintenance staff.

5.6.2 Resource Availability

Personnel with the skills required for implementation of an advanced control project are in limited supply. As part of the scheduling process, the types of skills and number of personnel required should be defined. The availability of such personnel may determine the project schedule.

5.6.3 Impact of Ongoing Operations

Implementation of advanced control projects is often dependent on ongoing operations. Shutdowns or turnarounds may be required to add or modify process measurements or final control elements.

Process testing to develop process models or other relationships is usually required for any advanced control system. This testing often can consume several weeks and may be interrupted by unstable operations or operations at conditions different than those contemplated by the advanced control system. It is also not unusual that after initial process testing is completed, changes in operating conditions or objectives require additional testing.

5.6.4 Training

5.6.4.1 General

Training programs for operations, engineering, and maintenance personnel should be developed. Depending on the responsibilities and prior knowledge of the personnel to be trained, the content and timing of this training will vary. Table 4 shows an example of an overall training program.

The training program needs to address initial training, refresher training for existing personnel, training for new personnel, and training in operations without the advanced control application in service. The training program should have provisions for tracking an individual's training history. Based on local regulations, it may be necessary that operators be certified to operate the process and its control systems.

5.6.4.2 Training Tools

At a minimum, training manuals shall be prepared for operator and maintenance technician training. The manual should describe the following.

a) The application and its implementation.

b) All operator interfaces and reports.

c) A list of inputs and outputs associated with the application and any requirements for their maintenance. Specialty sensors and online analyzers necessary to support the application are of particular importance.

Table 3—Typical Advanced Control Project Tasks

Task	Typical Timing
Facility master automation plan	12 to 60 months prior to project initiation
Feasibility study and project identification	6 to 18 months prior to project initiation
Project implementation plan	At initiation of project
Functional specification	Start of project scope definition
Regulatory control and measurement design	6 to 12 months prior to commissioning
Design specification	With regulatory control and measurement design
Advanced control software purchase	6 to 12 months prior to commissioning
Hardware platform purchase	6 to 12 months prior to commissioning
Implementation and testing on a dynamic simulator	In conjunction with design development
Model identification testing	3 to 6 months prior to commissioning
Model identification and implementation	2 to 4 months prior to commissioning
Engineer training	Initial at software purchase. General training 4 to 6 months prior to commissioning
Operator and engineering graphics implementation	2 to 4 months prior to commissioning
Advanced control hardware and software installation	2 to 4 months prior to commissioning
Regulatory control and measurement installation	As allowed by operation and scope of design. Minimum 2 to 4 months prior to commissioning
Install, test, and simulate advanced control applications	2 to 4 months prior to commissioning
Operator and maintenance training	1 month prior to commissioning and during commissioning
Commissioning	1 to 2 months—subject to operations schedule—reference point for other tasks
Initial advanced control system operation	Commissioning and 2 to 4 months after commissioning
Full time advanced control system operation	2 to 4 months after commissioning
Close-out documentation	1 to 4 months after commissioning
Postcommissioning economics audit	3 to 6 months after commissioning
Advanced control system adjustments and modifications	2 to 6 months after commissioning
Life cycle support	Ongoing

NOTE These tasks are generalized and not all tasks may be applicable to all types of control technologies. Depending on the technology used, additional or modified tasks may be necessary.

d) Instructions on how to put the application on control and take it off of control.

e) Instructions on how to respond to alarms and alerts that may be generated.

f) Operations in degraded control modes (e.g. partial shedding, operation with substituted values, etc.).

g) Application maintenance requirements and procedures.

Initial classroom training can familiarize the operators with the general application. This formal training should be supplemented with on-console training and support by the advanced control application engineers during initial testing and commissioning. This training may occur over several weeks. Console operators should be formally tested

Table 4—Advanced Control System Training Program

Organization	Personnel	Content	Location	Timing	Method
Operations	Console operator/ liaison with advanced process control project	Detailed commissioning, operation with and without controls	Vendor facility or plant training facility	At functional design with continuation during implementation and at commissioning	Classroom, detailed simulators, on process
	Other operators	Operation with and without controls	On site	Prior to commissioning and continuation during commissioning	Classroom, on console, and simulator
	Operation supervision	Overview of functions and objectives	Office	Prior to commissioning	Presentation
Engineering	Control engineer	Objectives, process, control technologies, and detailed application	Vendor facility and office	Prior to project and during functional design	Classroom, simulator
	Process engineer	Objectives, application details, commissioning, operation with and without controls	Vendor facility or plant training facility	Prior to commissioning	Presentation and classroom
	Project engineer	Objectives and scope	Office	At start of project	Presentation
Maintenance	Application support specialist	Control technologies and detailed application maintenance	Plant training facilities	During design	Classroom, simulator, actual system
	Instrument and process control system technicians	Maintenance procedures with and without controls	On site	Prior to commissioning and continuation during commissioning	Classroom, on process

through classroom and on-console training. The training plan should include plans for on-process training of shift operators and postcommissioning training to update personnel on changes that were made during commissioning.

In the event that the advanced controls are not operating, the unit operator should be able to assume safe control of the unit. The effectiveness and reliability of modern process control and advanced control systems has resulted in much more stable operation of process units. As a result, operators have far less exposure to upset operation or operation without the advanced control applications running. Additional training is required to assure that the operators are capable of handling upset and degraded control conditions.

Process simulators are an effective means to provide this training. The advances in computer technology have made implementation of high fidelity dynamic simulators an effective and economical tool for training. These simulators can accurately represent the behavior of a process, its control systems, and the operator interface. Routine refresher training of operators using dynamic simulators is becoming a viable and effective means of maintaining operator skills.

5.6.5 Testing and Commissioning

Relative to many other types of projects, the testing and commissioning processes for an advanced control system are extended activities. Advanced control systems are usually complex and require that a large number of variables and possibly several different operating conditions be tested and monitored.

Testing for an advanced control application consists of offline or simulated operation during which the performance of the application is checked for correct operation. Some of the test objectives are to:

a) verify input and output connections;

b) verify bad value behavior and control application shedding and degradation performance;

c) verify watchdog timer function for communication and application program failure;

d) verify that intermediate calculations produce expected results;

e) verify that application predictions and control outputs are as expected;

f) develop preliminary tuning constants;

g) exercise all operator, engineering, and maintenance interfaces.

Commissioning consists of placing the application on process and observing and adjusting its performance for a long enough period to demonstrate acceptable operation.

Often initial commissioning is done on a limited basis with the advanced control scheme being operated during day shifts or when a key operating crew is on shift. During this period, substantial specialist support is necessary to monitor the control system performance and identify any necessary modifications to the application. Larger applications, or applications that are difficult to turn on and off may require that the control application operate around the clock and that commissioning application support also be available around the clock.

5.6.6 Economic Performance Audit

Prior to close out of an advanced control project, an economic performance audit of the advanced control system should be performed. This audit serves to validate the benefits identified during project development and provides the baseline for use in monitoring ongoing performance. The methods used in performing this audit should be the same as those described above in 4.4.

5.7 Application Documentation

5.7.1 General

Each advanced control project shall produce a complete and accurate set of documentation for turnover to the plant operations, maintenance, and engineering groups. A documentation package should be produced for each application. This documentation package typically contains items described below.

In addition to these documents, there will be a number of project oriented documents that may be retained in historical files. Some of these items are records of feasibility studies, scope definitions and estimates, project execution records, and other records that are not identified as being required for turnover. Description of these files is not part of this scope.

5.7.2 Functional Specification

A functional specification for the advanced control application should be prepared and maintained during implementation. This specification will be an update of the specification developed for the feasibility study.

5.7.3 Design Specification

The design specification addresses detailed requirements to implement the application described in the functional specification. Examples of the items that this document addresses are:

a) description of the application objectives and functions;

b) definition of control technology and communications methods;

c) scope of regulatory control and measurement improvements;

d) security concepts;

e) expected results and KPIs;

f) business processes and workflows;

g) I/O requirements;

h) model details:

- — expected MVs, CVs, and DVs;
- — estimated response time for each controller;

i) application alarms and alerts;

j) operator, engineer, and maintenance interfaces;

k) requirements for turning the application on and off and shedding or control degradation behaviors;

l) database contents and structure;

m) maintenance requirements;

n) training requirements;

o) history collection.

Section 7 describes a number of issues that should be considered while developing this specification.

5.7.4 Ongoing Documentation

5.7.4.1 General

The following types of documents represent the actual installation in the field and shall be kept current.

5.7.4.2 Applications Configuration Database

A description of the contents and structure of the applications configuration database shall be maintained. Backup copies of the database shall be made at regular intervals. Methods for verifying its consistency with the official approved set should be included.

5.7.4.3 Custom Graphics and Reports

The primary documentation for graphics is a hard copy of each graphic in the system, preferably in color, and a listing of code or configuration associated with the behaviors of all active graphic elements. Similar information shall be documented for all configured reports. Electronic backups of all graphics and report files shall be made at regular intervals.

5.7.4.4 Program Listings

Up-to-date listings of all application programs should be kept in backed up electronic form and, if desired, in hard copy. It is also suggested that the listings be accompanied by descriptive material defining the purpose and function of all programs and the inputs and outputs used by the application. Program flow diagrams should be included where appropriate. Flow diagrams that include the operator's actions (e.g. business processes) are preferred over basic program flow charts.

5.7.4.5 Training Documents and Procedures

Copies of training procedures, records, and manuals shall be maintained.

5.7.4.6 Maintenance Procedures

Copies of maintenance procedures, records, and manuals shall be maintained.

6 Technology Considerations

6.1 Hardware Platform

The available hardware platform options should be evaluated, and a choice of platform should be made, as early in the implementation as practicable. Often, this may have been determined during development of the master plan. Control engineers and computer hardware systems specialists should be consulted when making this choice.

If the application software can run on multiple platforms, the relative advantages and disadvantages of each should be studied carefully. Typically, the choice will be between running the application on standard process control system equipment or on general-purpose computer hardware. If the application is run on general-purpose computer hardware, often the choice will be between a server and a personal computer (PC) type platform. As process control system equipment migrates toward using more general-purpose hardware, and as PCs and workstations evolve to have similar capabilities and pricing, the distinctions between hardware platforms are becoming increasingly difficult to discern. Corporate and site IT security policy may play a role in determining which platform to use.

There are trade-offs between locating applications on process control system platforms versus general-purpose computers. For example, running an application on process control system equipment may have the advantages of close coupling to the underlying regulatory controls, use of the familiar process control system operator interface console, and for many applications, may require no new hardware. Disadvantages may be lack of portability of the application to other systems, less "friendly" implementation and maintenance tools, and if required, hardware that is more expensive. Ease of application creation and maintenance need to be considered along with operator flexibility and usability.

System security and maintainability are major considerations. Any computer running an advanced control system should be dedicated to advanced control functions and not be shared with nonrelated functions. It generally is permissible to run advanced control applications on the same computer that is running a historian or providing an OPC server function but should not be shared with applications such as accounting, personal computing servers, or similar applications. It is good practice to segregate applications so that loss of a single computer will have limited impact. Consideration should also be given to computer loading so that applications will execute in the time required.

The recent history and likely future for a hardware platform should be analyzed carefully against the requirements for the application. The computer hardware and operating system environment is volatile and consideration should be given to migration paths available. The conditions and the hardware support infrastructure at the site should be evaluated carefully. This is especially true if the hardware platform will be completely new to the plant site requiring additional training or new support personnel. Contract hardware support with the hardware vendor may be an attractive alternative.

Involving knowledgeable specialists from diverse backgrounds often can prove beneficial in hardware selection. The capabilities of general-purpose computer hardware and process control systems are continuously changing. Proper selection of hardware requires the input of specialists who are aware of the existing and developing capabilities of various hardware platforms.

Often the advanced control application supplier, the underlying process control system hardware restrictions, or a previous choice of user company standard hardware may dictate the choice of hardware. Such a dictated choice should be evaluated to assure that the selection is appropriate.

6.2 Software Platform

6.2.1 General

The software platform consists of the operating system, the control application development package, and data collection/archiving packages with associated database systems. Issues that should be considered when selecting a software platform are discussed below.

6.2.2 Data Flow

Data flow requirements for control applications can have a major influence on the selection of a software (and hardware) platform. The data flow requirements of each control application should be analyzed when choosing the software platform. The real time aspects of control applications require that data flow in a deterministic manner at regular intervals and that this data come from or go to a permanently assigned location. Some software platforms can present a major problem for some control applications, for example:

a) the platform depends on exception-based data reporting,

b) the platform uses relational database structures,

c) the platform cannot process data frequently enough.

Control engineers familiar with the dynamic data requirements of the control application should be involved in data flow evaluations.

6.2.3 Application Separation

Individual control applications running on a common software platform shall be separate and distinct from each other. Any control application shall not depend on any part of any other unrelated control application for its proper functioning. Control applications shall be capable of being turned on and off and otherwise manipulated without causing disruption in any other unrelated application. This requirement shall be clearly specified and communicated to the people who will be doing the programming and configuration of the control applications.

6.2.4 Security

The software platform shall provide security from unauthorized access to the control applications and security from inadvertent and unauthorized changes to the process control system.

Security from unauthorized access usually is accomplished by some combination of password and keylock access. System administration and security procedures should be established as early in the project as practicable. A person knowledgeable in computer security administration and associated issues should be used when setting up the system.

Security from inadvertent changes shall be evaluated thoroughly when choosing the software platform. Any software platform used in process control should provide very robust, hard-to-bypass protection against accidental or unauthorized changes to the process control system. A computer specialist familiar with the software platform, how it communicates, and possible protections should be used when choosing the software platform.

Some plants adhere to strict security, such as using passwords, to limit process control system access to certain usage levels. For example, process operators are allowed access to all operating levels required to control the process, shift supervisors might have additional access to production schedules, and plant engineers would be able to access everything, including configuring the system. Access to controller tuning parameters is generally restricted to the plant engineers and instrument people. Otherwise, a troublesome control loop might be “retuned” by each shift.

6.2.5 Communications with Regulatory Control System

Communications with the regulatory control system are a fundamental requirement for any advanced control system application. The quantity and frequency of data communicated between the advanced control application and the process system should be determined as early in a project as practicable. Communication functions between the advanced control platform and the regulatory control system needs to be verified initially and periodically to confirm that nothing has changed.

Typically, process control systems provide a mechanism for restricting the ability for a remote application to write data to the system. The security setup of the system shall be evaluated to ensure that unauthorized data writes from a remote application do not occur. Often, the console operator or the control engineer has to verify and accept changes received from a remote application.

Communication limitations could have a major influence on the feasibility of a given advanced control application. Control engineers familiar with the quantity and frequency of data communication required by a given control application should be consulted when choosing a software/hardware platform.

6.2.6 Communications with Historian

The software platform should be capable of communicating with a historical database system. Usually the advanced control application is required to keep data on its past performance. The application may also require historical data to perform its functions.

Many control applications generate a set of future moves that the control system plans to make. It is desirable to be able to store the forecast moves and display them to the operator in either tabular or graphic format. Such capabilities should be included in either the historian or control application package. In any event, the future moves should be available for others for review. The length of time they should be available should be a matter of site policy.

Historical data requirements will have an influence on software (and hardware) platform choice. Frequency of historical data collection, retention time for this data, and where historical data will reside should be determined at the outset of an advanced control project. Any special uses of historical data, such as statistical calculations, can be heavily influenced by data archiving techniques.

6.2.7 Open Systems and Software Standards

Many of the open systems and software standards that are being developed for business information systems are being applied to process control applications. Methods for application of these standards to process control are evolving and are not yet mature. Use of these standards offers the potential for the following.

a) Significant reduction in the implementation and maintenance costs associated with advanced control applications.

b) Applications that are flexible, reusable, and portable. Application programs can be developed using the concepts of object oriented and modular programming. The applications may then be connected to many process control systems or hardware platforms through vendor-supplied open systems interface.

c) Significant improvement in the ability to support and monitor applications from remote locations, for example, through the use of control system firewalls, DMZ shadow servers, and virtual private networks.

These benefits need to be balanced with the significant security and reliability concerns associated with the use of open systems. Applications personnel should approach use of information systems standards with care. The security and reliability requirements of process control applications are much higher than those required of many business applications. Designs should recognize these requirements and provide for isolation of control system from other networks. The security system should also restrict access to the control systems to those computers and personnel who are authorized and ensure that actions and communications from other networks do not impact control system performance and security. Refer to API 554, Part 2 for information on network isolation practices.

7 Design Considerations

7.1 General Design Issues

7.1.1 Regulatory Control System

Performance of the underlying regulatory control loops is an essential part of advanced control success. Many advanced control performance problems can be tracked to poor regulatory control performance. Regulatory controller performance should be reviewed to verify that measurement accuracy and reliability, controller tuning, PV range selection, and control valve performance are adequate for advanced control functions. If regulatory control performance is unacceptable, upgrades of the regulatory controls will be required before the advanced controls can be commissioned. Use of standard tools to continuously evaluate the performance of regulatory control loops are encouraged.

The design of an advanced control application may also require that the basic regulatory scheme be reorganized. A key step in the overall design is determining which regulatory control loops should be connected to the advanced control system application. Since the purpose of the advanced control application is to help the console operator do a good job, the application needs to facilitate the console operator's activities. In other words, the application is really to serve the console operator.

7.1.2 Acceptance and Support

A successful advanced control application is one that is accepted and supported by the process facility operating and technical people. It stabilizes operations and is robust. It is easily operated and monitored.

Acceptance and support of the application requires the following.

a) Make process facility operations and maintenance personnel part of the project team.

b) Charge the process facility representatives with soliciting input from the rest of the process facility and representing their requirements to the project team.

c) Require that the project team conduct design reviews with the remaining process facility personnel. The design reviews should address the functions of the application, the status of work, and outstanding issues.

d) Involvement from the economics and planning personnel is critical to ensure that the application meets the overall requirements of the facility. It is also important that the changes in the operation of the plant (e.g. product yields and capacities) realized from the applications are communicated back to these groups. The methods and frequency for updating economic and planning parameters needs to be designed into the advanced process control system.

e) Involve all of the facility operations and maintenance people during the installation and testing phases.

An advanced control application that stabilizes operations and is robust will:

a) handle normal process disturbances with little or no operator attention;

b) handle major disturbances and bring the facility back into a normal operating range within an acceptable time frame. The magnitude and duration of disturbances that the control system should handle need to be developed with the facility personnel. This is often a trade-off between model complexity and willingness to accept some loss of the application on stream time;

c) incorporate techniques that allow the application to tolerate failures and degradation of control without upsetting the process (see 7.3.5.2);

d) run reliably without internal application program faults causing the application software to shut down.

An advanced control application that is easily operated and monitored will allow the operator to quickly and accurately determine the status of the application, determine the values of important measurements, and make appropriate changes when necessary. This is discussed in 7.3.

7.1.3 Focus and Simplicity

The project team should carefully examine the options available in the selected advanced control software and use only those functions required. Successful control applications are those that are only as complex as necessary to perform the required functions and do not include unneeded options and features. Direct, easy to understand implementations should be used even if they result in slightly less efficient program operation. Implementations that use tricks or complex functions make applications more difficult to maintain or modify and result in lower application usage.

7.2 Plant Data Collection for Application Design

7.2.1 General

Most advanced control applications require the collection of significant plant data in order to complete the design. The type of data needed, the quantity needed, and how it will be collected should be determined early in a project. The type of data required will vary based on the type of control application. For example, multivariable matrix controls require plant testing. Neural net controllers often require evaluation of historical data, while fuzzy logic or expert systems often require development of rules based on operating or process knowledge. Since the purpose is to optimize the process unit, the relationship between raw and "best estimate" yields and qualities need to be designed into the application.

7.2.2 Step Disturbance Testing

Often an advanced control application will require data collected during disturbances to the process facility steady state operations. If this is the case, involvement and consent of the operating personnel shall be sought well in advance. The extent and magnitude of the disturbances should be clearly understood and agreed to. Procedures for the testing should be in place and understood prior to the start of testing. Prior to commencement of testing, the calibration of all measuring instruments and review of the performance of all control valves shall be performed. A qualified and knowledgeable control engineer shall be present during all testing.

Disturbance testing may take the form of a series of step tests using either setpoint or control valve position step changes. Advances in analysis of test data have allowed use of other types of disturbance testing such as use of impulses. Disturbance testing may last over a period of days to weeks.

For some facilities, disturbances to normal operations could have major consequences; however, some advanced control applications require disturbance testing. In this case, compromises shall be explored with the relevant operations and technical people. If compromise is not possible, an alternative advanced control application may be required or the application may not be feasible at all. The feasibility of performing necessary plant testing shall be established during the scope definition of the project.

7.2.3 Plant Historian

Often, data collected from the plant historical database can be used in designing the advanced control application. This is especially applicable if neural net controllers are being implemented. If the application has special requirements for type, frequency, and time period of the data collected, these requirements should be communicated to those responsible for operating and maintaining the plant historian. If the requirements for the application data collection cannot be met, then alternatives and compromises should be explored and agreed to.

Historical data should be analyzed carefully to make sure that it is providing useful information for the control application. Often historical data collection schemes, such as averaging, compression, or exception reporting, can distort the dynamic or statistical behavior of the process to be controlled and make the historical data of limited value for controller design purposes.

If the process contains a regulatory controller that will not be present in the final advanced control application, the historical data may not be valid for the affected variables and additional testing or data analysis may be necessary. For example, the original control strategy may contain a temperature cascade that would not be used in the advanced control application. The behavior of this cascade can affect the validity of historical data for use in developing the model for the advanced control application.

7.2.4 Data Validation

Any data collected, massaged, and used to design the control application should be validated with the real operation and behavior of the process facility. During data collection, the reasonableness of the data should be evaluated. Criteria to evaluate data reasonableness are as follows.

a) Do flows add up to satisfy material balances?

b) Are energy balances correct? (For example, does a stream being heated have higher temperature leaving the exchanger than entering and does the heated stream absorb as much energy as the cooled stream gives up?)

c) The dynamic nature of the data should be analyzed carefully, especially where modeling is being done. (For example, is this truly a response to a process disturbance or is it noise?)

d) The state of the process facility at the time of data collection should be accounted for. (For example, was everything “normal,” or was the facility in the middle of a major transition?)

e) Any output resulting from the data should be analyzed carefully to make sure that it is reflective of actual conditions. (For example, does this dynamic model really show what happens?)

f) Has an unmeasured disturbance occurred during the data collection? If such a disturbance occurs during a test run, that data should be discarded.

Data analysis and reconciliation has a major influence on successful advanced control application design. Sufficient time to do a thorough job should be allowed for in the project schedule. This activity requires a well trained, thoroughly experienced control engineer.

In some cases, use of online data reconciliation may be necessary. This is a function of how much analysis or manipulation of test data is required. The need for online reconciliation should be identified early in a project, as this can require substantial amounts of planning and programming. Use of site-wide inference engines for all stream flows and qualities to ensure consistent optimization and provide the basis for each optimization package and projecting balanced score card for the end of the next several business days should be considered.

7.2.5 Data Collection for Fuzzy Logic or Expert Systems

Fuzzy logic and expert systems use a set of rules or knowledge about a system to generate their control decisions. Collection of data for these systems usually amounts to accumulating knowledge from personnel who are familiar with the operation of the process, from which rules that the controller should follow are generated.

7.3 Functional Considerations

7.3.1 General

Each control application is not an island unto its own. The overall site control strategy, automation philosophy, optimization concepts, security, etc. should provide the basis for each and every control package. The uniqueness of each new application should start with these concepts and constraints.

7.3.2 Control Design Criteria

Controller design is based to some extent on the experience of the control engineer and the features provided by commercial controller vendors. Packages available from various sources may have differing features and tools. Some may contain support for data input validation, operator interfaces, controller performance monitoring, or other accessories and tools.

In addition to technical decisions such as selecting controller type, control objectives, and design of the core control functions, controller design also consists of providing the support functions necessary for day-to-day operation. Some of the functions that need to be considered are as follows.

a) Input data validation and controller response to detection of bad data.

b) Operator interfaces, including simple methods to turn the controller on and off. Since success depends on the operator leaving it on, special attention needs to be given to the operator's needs.

c) Controller size and complexity versus issues of ease of operation reliability and ability to maintain good dynamic response.

d) Means to monitor controller performance and communicate it to the console operator and others, as needed.

e) Means to adjust controller operating parameters and tuning.

f) Use of inferential calculations in place of physical devices, such as temperature sensors and analyzers.

7.3.3 Application Maintenance

The application package should be designed to readily support modification of the advanced control application. These modifications can be of several different forms as follows.

a) Modifications due to normally anticipated changes in operating modes. Depending on the nature or frequency of these changes, it may be advisable to incorporate these capabilities directly in the base design. For example, an application may have to accommodate high/low severity, start or end of run conditions, or winter/summer operations.

b) Modifications due to changes in process requirements or process economics that were not anticipated at the time the application was designed. Examples here may be changes in equipment, changes in product slates, or substantial changes in economics.

c) Modifications that result from changes in control technology, platform technology changes, application package upgrades, etc. For example, a new controller algorithm may become available or a change in control platform or operating system may be necessary.

The evaluation of control packages should also consider the vendor's base structure and their technology migration philosophy. For example, does the vendor provide modular structure that allows for incremental upgrades and ease of change without having to do significant work to reimplement the users control applications.

7.3.4 Input Value Validation and Value Substitution

Any control system relies on the quality of the data received from sensors, transmitters, analyzers, or other input devices. In regulatory control applications, it is usually easy to assess the quality of the input, or an input failure generally has limited impact. In advanced control systems, numerous control outputs may be affected by failure of one input. Provisions shall be made to validate the input and to provide means of running with alternate data.

There are three general classes of input failure:

a) the input signal has failed;

b) a sensor or transmitter needs to be taken offline for maintenance, calibration, etc.;

c) the input signal appears to be good but is inaccurate, unstable, frozen, etc.;

d) modification that results from changes to the underlying process control system control strategy.

When an input signal goes bad while in service, the control application needs to recognize this event and take appropriate actions. Validation of input signals can be handled in a number of ways depending on the importance of the input and how it is used.

If an input is to a single regulatory controller, the controller may be placed in manual mode while the input is being repaired. Many process control system regulatory controllers have functions that automatically place the controller into a standby mode if its input is determined to be bad. If the input goes to a multivariable controller, it may be permissible to substitute a manual value, the last good value, or drop it from the multivariable controller calculations. If the value is a critical value, mechanisms may need to be in place to automatically shut down the multivariable controller.

The most common way of determining if an input is valid is to compare it with other process data. For example, a temperature may be compared with other temperatures or against a computed heat duty to determine if its value is reasonable. If the measured and computed variables do not agree within some limit, the variable can be declared bad.

Another method to validate input data is to use a statistical software package. The statistical package can monitor a large number of inputs of various types. It automatically and continually calculates online the mean, standard deviation, and median value for each monitored input. These values can be used to assess the quality of a given piece of data. This method tends to be quite computation intensive and normally is not used for advanced control applications. The more common application of this technique is for use in optimizer data reconciliation.

Analyzers are a good example of the kind of input where input validation and value substitution are needed. Analyzers often provide key inputs to an advanced control application but are the most complex and least reliable of inputs. For this reason, the inputs should be checked for absolute and relative accuracy. Analyzer results should be routinely checked against laboratory analysis. Analyzer status alarms and flags should be checked to verify that the analyzer is performing properly.

The above specifics should be detailed in the site automation strategy document.

Some techniques that are used to compensate for loss of an analyzer are as follows.

— Use of inferred value computations that can be used for short periods of time if the analyzer fails. These may be less accurate than an analyzer but suitable for short-term use. The inferred calculation can also be used to validate analyzer inputs.

— Use of inferred value computations that are corrected by the analyzer output but that may be used for short time periods without correction from the analyzer. This may allow the inferred value computation to be much simpler than a stand-alone algorithm but still allow for short-term operation without an analyzer. For example, this method will allow one analyzer to be used for several streams where normally cycle times would be unacceptable.

7.3.5 Application Controls

7.3.5.1 Initialization, Start-up, and Restart

For an advanced control application to be put into service, it is necessary for all underlying controls to be capable of accepting the application outputs and for all inputs used by the application to be available. Advanced control applications can be started up in a “cold start” or “warm start” mode. A “cold start” of an application is necessary when it is first implemented, has been totally shut down, the computer has been restarted, etc. A “warm restart” occurs after partial shedding or degradation as described below.

A cold start-up of an advanced control application requires that all underlying regulatory controllers be in the mode required by the advanced control application and that required inputs be available. Any inferred property calculations and process models used by the application should be functional. The advanced control application should track or initialize all appropriate internal values and setpoints so that the application start-up is bumpless. It may also be necessary for the advanced control application to initialize internal calculations, tables, and matrices or perform other calculations necessary to start the application.

A warm restart may not require that all of these actions be performed. Examples of what may be necessary for a warm restart are validation that a previously failed value is now good or placing a controller back into the proper mode in order to resume operation of the application.

An advanced control application is usually put online manually by the process operator. Advanced control applications should have start-up utilities that will either automatically perform all start-up steps when commanded or that step an operator through a commissioning procedure. A warm restart will likely have fewer operations that need to be performed. The operator interface should be designed so the start-up process can be initiated and monitored by a single operator.

Any and all changes need to be communicated to the console operator and logged. Current status of the entire application needs to be available to the console operator on demand.

7.3.5.2 Application Shutdown, Shedding, and Degradation

Advanced control applications require a means of both manual and automatic shedding of all or part of the application. This may be characterized by any of the following.

a) Total shutdown of the control application and return to regulatory control operation. This is defined as application shutdown or total shedding.

b) Shutdown of part of the application with some of the advanced control applications functioning but with other portions not operating. This is defined as partial shedding.

c) Continued operation of the advanced control application using last good values or substituted values for one or more input variables. This is defined as application degradation.

Automatic application shutdown may be the result of:

a) failure of a key input variable,

b) decision by the control application that it cannot maintain the control objectives,

c) operation outside of the valid control range,

d) the control application cannot write its outputs due to incorrect regulatory control modes.

Depending on the nature of a problem, automatic shutdown may shut down all or part of the application. The operator may initiate manual shutdown at any time.

Automatic or manual application shutdown should return control to the regulatory control system without disturbing the process or requiring additional intervention by the operator. All application shutdowns, sheds, or degradation should be alarmed or logged, depending on the severity or criticality of the event.

Any regulatory controllers having parameters adjusted by the advanced control application should be returned to automatic or cascade modes. The user will have to decide if automatic shutdown should establish cascade loops that are broken when the advanced control system application is operating. Any regulatory controllers that might have been placed in direct digital control by the advanced control application should be automatically placed back into operation.

7.3.5.3 Instrument Maintenance and Calibration

When a signal is being maintained or calibrated, it should be taken out of service as far as the advanced control application is concerned. This requires that facilities be provided to allow the operator to tell the application that a value should not be used or that a substituted value should be used. The operator interface should be designed to indicate the status of all values used by the application. Provisions should be made to detect bad values and shed control as described above.

A manual input may be used in place of the live signal if the signal is noncritical, typically stable, and is not the PV to a regulatory controller. If the value is a critical input, part or all of the application may need to be stopped during maintenance. It is recommended that field instruments associated with advanced control applications be identified as such by field labeling and maintenance of lists or displays of all inputs used by an advanced control application.

Maintenance of control valves usually require that an entire control loop be taken out of service, and it may require that all or part of an advanced control application also be taken out of service. This should be done manually before the loop is released for maintenance.

Maintenance practices should also address the effect on regulatory controls. This is beyond the scope of this document.

7.4 MV Functions

7.4.1 Setpoint Control

Setpoint control is a mode of control where an advanced control application's outputs are the setpoints of regulatory controllers. The regulatory controllers perform the task of maintaining an advanced control system's MVs at the values required. Figure 5 illustrates this relationship.

A well-designed, well-tuned regulatory control scheme is critical to the success of any advanced control system. If key regulatory controllers are in manual or cannot maintain their setpoints, the advanced control application may have to automatically shed.

Setpoint control requires that the advanced control system be aware of the operating mode for the controller and be able to read the regulatory controller setpoints. During operations when the advanced control system is not determining the setpoint of the regulatory controllers, the advanced control application should be able to adjust its internal values to track the current setpoints and be ready for bumpless transfer. If automatic application start-up is part of the system design, the advanced control system should also be able to command and verify mode changes in the target regulatory controllers.

It is possible to independently set regulatory control limits (e.g. setpoint minimum/maximum and setpoint rate of change) in both the advanced control application and the process control system. It is important to consider these issues and set standards for the implementation. The clear problem to avoid is having limits set in the process control

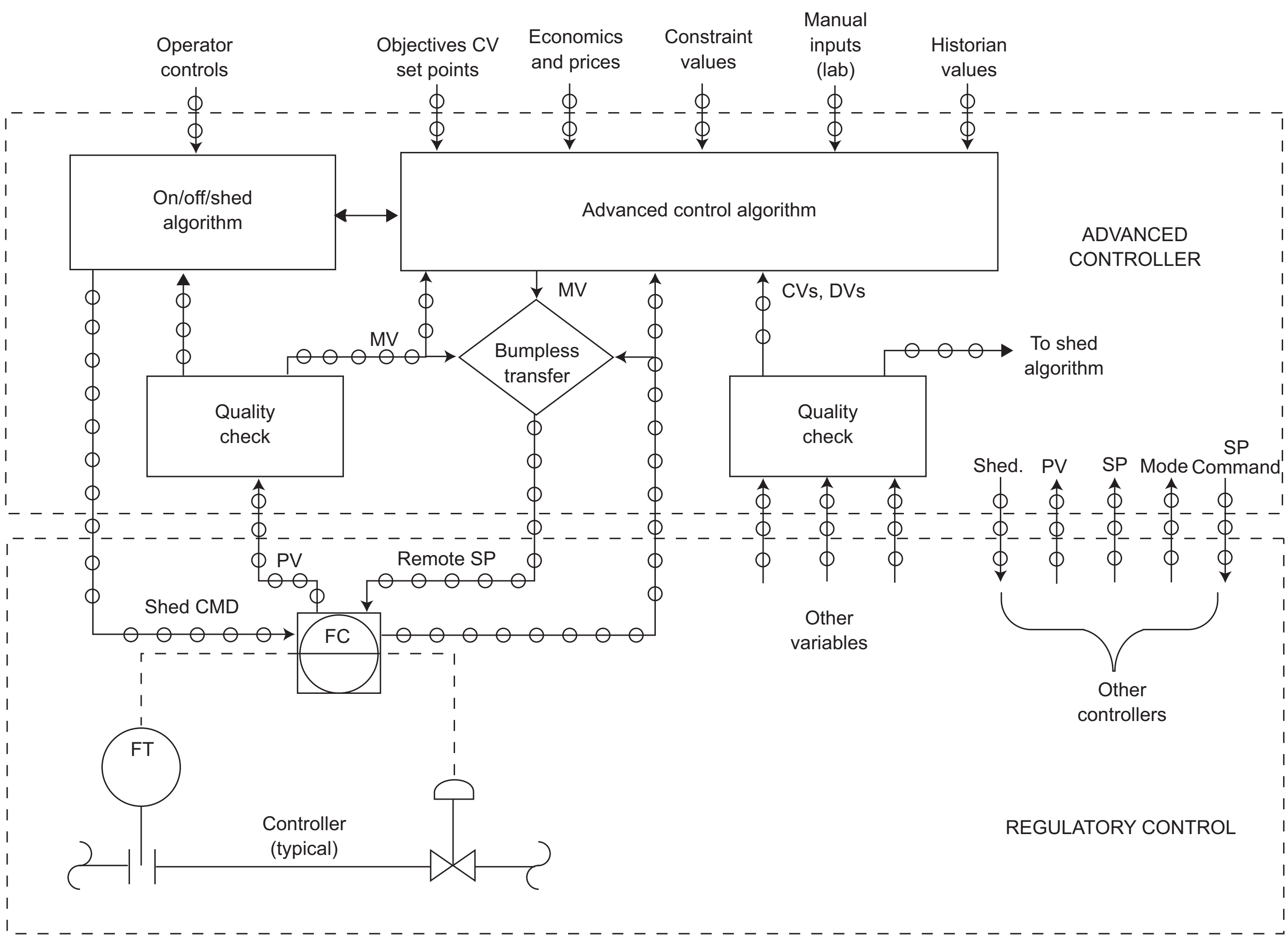

Figure 5—Advanced Control System/Regulatory Control System Interface

system that are unknown to the advanced control system (e.g. setpoint rate of change limits in the process control system). This can introduce model error when the advanced control system performs its control calculations.

The advanced control application should be made aware if there is any limitation in the regulatory control loop that would prevent the setpoint to the regulatory controller from being realized. Typical examples are controller windup or setpoint/valve clamping logic in the regulatory control system. This communication typically takes the form of a discrete flag informing the advanced control application that setpoint changes are only allowable in certain directions (up, down, or neither direction).

7.4.2 Direct Digital Control

Direct digital control is a form of control in which the output signal from an advanced control application goes directly to a valve rather than to a setpoint of a regulatory controller. In most implementations, direct digital control bypasses a regulatory controller. If the advanced control application is turned off or automatically sheds, the regulatory controller takes over control of the valve. This practice is no longer as common as it once was and is not recommended.

If direct digital control is used, the advanced control system should be able to read the current values of the regulatory controller setpoint and output and be able to track those values for bumpless transfer. The regulatory controller should also be configured to track the performance of the advanced control system and be able to bumplessly transfer control back to the regulatory controller when required.

7.5 Operator Interface

7.5.1 Operator Graphics

Operator graphics can range from tabular data to very sophisticated pictorial displays. Graphic fields can display fixed data and dynamic data whose attributes can change the color of process values, vessels, pipes, etc.

Advanced control applications should be provided with adequate graphic displays to allow operators to understand and control the operating state of the application. Generally, overview information and access to detail graphics are included on normal operating graphics. Detailed graphics display comprehensive data and provide the means for interfacing with the advanced control application. Detailed advanced control graphics provide the operator and engineer with sufficient information to allow for monitoring and manipulation of the application. Detailed graphics provide information such as the following:

a) the state of each control function within the advanced control system,

b) values and status of inputs and outputs,

c) predicted values for manipulated and controlled variables,

d) indication of active or predicted constraints,

e) interface for starting and stopping the application or portions of this application,

f) functions to command the bypass or substitution of input variables,

g) instructions on start-up and shutdown procedures.

Engineering detail graphics provide information on the function of the application, intermediate results, performance statistics, and tuning parameters. These are discussed below.

7.5.2 Online Instructions and Help

Online instructions and help should be provided with any advanced control application. Online instructions are used to instruct the operator how to perform a particular task when a certain process event occurs or to provide background information on the application. Online instructions/help may appear as tabular or written text on a graphic or they may appear as single line text in a dedicated field on the graphic. If available, online help should be context sensitive. If the computer or DCS system being used supports a multiwindow environment, help instructions may be contained in pop-up windows. More sophisticated systems may support online access to the application instruction manuals.

Operators should be able to record their comments in the online help system. Any revision to their comments should be first reviewed with the operator who made them.

7.5.3 Engineering Interface

An effective engineering interface is required to allow engineering personnel to develop and maintain applications, monitor performance, and tune and adjust the system. Depending on specific system design, the engineering interface may be integrated with the process control system or be implemented on a separate computer or PC platform.

Access to engineering functions should be restricted to authorized personnel by some type of security system.

7.6 Application Tools

The proprietary software package and the hardware platform used for a particular application define application tools. These engineering tools provide the following functions.

a) *Application Installation*—Software should be provided to install the application and tools on the application platform. This software should be designed such that the applications can be installed without interruption to any ongoing operations.

b) *Data Acquisition and Analysis*—These tools should perform or enable data acquisition for purposes of model or control engine identification. Depending on the application, data acquisition may be direct or utilize an existing plant data historian. The analysis tools should allow for designation of good and bad data. Tools should be available for evaluation of the data for purposes of validating the data collected (see 7.2.4). The analysis tools should also provide methods for evaluating the data and converting it to a control model.

c) *Application and Model Building and Editing*—The application and model building tools should provide the means to interface the plant model to the basic control system and to set up all parameters required for the controller and model.

d) *Model and Controller Simulation and Testing*—These tools allow the engineer to simulate, test, and debug the controller without having to operate the controller on the process. Simulators can also be used to provide training to engineering personnel.

   NOTE The simulator functions available as an engineering tool generally may not be sufficient for operator training.

e) *Application Performance Monitoring and Historization*—The application tool set should provide functions that allow for monitoring of the performance of the advanced control application. This tool should allow the user to monitor on-control time, time operating against constraints, controller errors, and degraded performance time and to define the economic performance of the controller. The monitoring tool should be able to historize the performance results of the controller for periods specified by the user, typically for two to five years. If alternate history tools are available, these may used to satisfy this function.

f) *Application Tuning*—The tuning tools should provide a means for the engineer to adjust the tuning parameters associated with the advanced controller to provide the desired dynamic response.

g) *Engineering Displays*—An application's software set may provide a number of standard displays and graphics that facilitate all of the above functions. These graphics may be fixed or may be customizable by the user depending on the specific control technology and supplier. They may reside on a PC, a workstation, or on the process control system (see 7.7).

The ultimate application tool is the control system architecture itself. When deciding on a new process control system, several systems may be considered. In many cases, existing plant infrastructure may dictate the system to be used.

An important consideration in assessing application tools is to identify the means by which the advanced control system will interface with the underlying regulatory control system. Additional hardware and software may be required (see Section 6).

7.7 Engineering Graphics

Engineering graphics are those displays used by the engineer to install, start up, monitor, and adjust the application. This information is normally viewed by technical personnel. Examples include:

a) intermediate calculations,

b) special tuning parameters,

c) unit performance calculations,

d) cost and profitability data,

e) production schedule.

These displays should be comprehensive, easy to use, and under tight security (see 6.2.4). Engineering data that is of relevance to an operator should be replicated on the operator's graphics (see 7.5.1).

7.8 Performance Monitoring

7.8.1 General

Monitoring is necessary to quantify the effectiveness and economic performance of an advanced control application. There are two kinds of performance monitoring. The first is the functioning of the control model and algorithms as compared to their design intent. The second is monitoring of the economic performance of the process with the control application in service. Such economic performance needs to be rated by the economics group.

Some vendors offer proprietary packages that provide monitoring of advanced process control applications and benefits. These packages provide automatic reporting of benefits and functionality.

7.8.2 Control Function Performance

The application monitoring system should be able to quantify the following information relative to the function of the control model and algorithms.

a) The percentage of time that each controlled variable was in service.

b) The percentage of time that the advanced control system was online and controlling the process.

c) The percentage of time that each MV (regulatory control loop) was in cascade mode and receiving its setpoint from the advanced control application.

d) The percentage of time that the controller was operating against constraints and what those constraints were.

e) The number of moves, sizes of moves, and direction of moves made by the control application.

f) The times when the control system had to shed due to input or output errors and the cause of the errors.

g) The times when the control system was turned off or on by the operator.

h) A measure of the controller model prediction compared with actual process response. This is a measure of the process/model mismatch.

i) A measure of the dynamic behavior of the controller (underdamped, overdamped, oscillatory). This is a measure of the controller tuning.

7.8.3 Economic Performance

The primary measure of success of any advanced control application is its economic performance. Economic performance metrics should be as simple as possible and directly indicate the economic performance of the unit relative to appropriate benchmarks. Examples of performance metrics that are commonly used include:

a) measurement of the cost of production per unit of feed or product,

b) measurement of energy use per unit of feed or product,

c) total throughput,

d) product yields,

e) product quality and variability relative to specifications.

Economic performance metrics should be evaluated at multiple points during the life of an advanced control application. A baseline operation should be determined for preproject operation. A second evaluation is determined during a postproject audit. This second value normally becomes the baseline for values that are calculated at regular intervals as a measure of continuous improvement.

The baseline performance metrics may require reevaluation as modifications are made to plant equipment or operating objectives.

Performance analysis information should be shown on a daily, weekly, or monthly basis, as appropriate.

7.8.4 Performance Information for the Operator

The advanced control application should have functions that compute and display key monitoring factors. Notification to alert the operator that the control application is not performing as expected should be provided. This may consist of alarms, messages, or flags. Examples include the following.

a) Indication that the advanced control application is on and functioning normally. Notification should be provided to warn that the application or parts of it have been turned off either manually or automatically.

b) Indication that the status of inputs and the underlying regulatory control is normal. Alarms should be provided to warn that the advanced control application function has been degraded due to loss of connection to the regulatory controls or due to bad inputs.

c) The advanced control service factor.

d) Computed economic metrics and the current delta from the baseline.

e) When control against constraints is a control objective, the status of which constraints are active and the percentage of time at which the application has operated against constraints should be indicated. In larger applications, prioritization of constraints may be necessary.

8 Application Maintenance

8.1 General

Advanced control systems support requirements do not end with completion of the implementation project, but continue for the life cycle of the application. Advanced control applications typically are designed around a very specific set of operating conditions and economics. Changes in business requirements, operating objectives, operating conditions or plant physical design (as described in 7.3.3) can adversely affect the benefits that can be obtained from a specific design.

8.2 Personnel Requirements

Life cycle support requirements should also address personnel issues such as turnover, changing work assignments, and promotions. Personnel involved in the original design may be working on new applications and may be unavailable for existing application maintenance.

Industry experience has shown that the long-term success of advanced control applications is directly related to the quality of ongoing application support. Dedicated staff will be necessary to perform maintenance activities. Usually this takes the form of advanced control support engineers and technicians directly available to operations, preferably located in close proximity to the operating areas.

Depending on the size of the applications, it may be desirable to outsource application support to a control vendor or local specialized engineering house. Many control vendors also offer remote maintenance and diagnostic services via a secure remote network connection.

8.3 Continuing Training

8.3.1 General

Training is a key activity during implementation of an advanced control application, and it is also a key ongoing activity during the life of the application. Refresher courses and new personnel training should parallel the training program developed for the original application training.

8.3.2 Operations Training

Experience has shown that well-designed advanced control applications result in substantial improvements in the stability of unit operations. This has also reduced the amount of operator intervention required on a day-to-day basis. Ongoing operations training is necessary to maintain the skill set required to operate the unit with and without the advanced control system in service. This training should include:

a) refresher training in the application for experienced operators,

b) application training for new operators,

c) training and drills to retain the skills required to operate the unit without the advanced control application in service and during abnormal situations.

8.3.3 Maintenance Training

Ongoing application maintenance training parallels operations training. Existing personnel need refresher training on the application and new personnel require new user training. This training should address training for all aspects of application maintenance, including:

a) maintenance of field instrumentation associated with the application;

b) application maintenance, including backups of program files and data and modification of application performance parameters and tuning;

c) system platform maintenance, including computer hardware and operating systems.

The affordability and availability of virtual systems with I/O simulation provides the possibility of maintaining a complete system for console operator training and that can also be used for final checkout, before modifying the actual production system.

8.4 Change Control

8.4.1 General

Change control refers to procedures to ensure that modifications are made in an approved manner and are properly executed, tested and documented. Typically, processing facility management establishes overall MOC policies and procedures. Change control functions for advanced control applications should adhere to those policies. These MOC policies usually deal with equipment issues, so specific advanced control change procedures will need to be defined. Areas that should be addressed by MOC for advanced control applications are discussed below.

8.4.2 Tuning and Parameters

Changes to tuning constants or operational parameters, such as input ranges, constraints, targets, and alarm limits, should be restricted to authorized personnel. A list of parameters that should have controlled access shall be prepared for each application.

Any changes to restricted parameters should be logged or historized. Any advanced control applications that automatically change parameters need to be clearly documented and a means for tracking the changes shall be available.

8.4.3 Control Objective Modifications

Sometimes a control application needs to be modified to accommodate a change in the control objective. Changes of this type should go through the facility's MOC process. Depending on the type and magnitude of change, additional engineering and validation testing may be necessary.

8.4.4 Process Modifications

Changes in processes usually affect advanced control applications associated with them. Any modifications required to the advanced control applications as a result of process changes should be handled under the MOC for the process change.

The control engineer should be consulted early in the process design phase so that he/she can analyze the impact on existing control hardware and applications. Additional control hardware required, control system processor capacity, and the impact on existing applications should be considered and defined. Careful planning and scheduling is required for the installation, testing, and commissioning of any new hardware and applications. Some process modifications may require that work be done during a plant shutdown. Control system scheduling considerations should be integrated into the master project schedule.

8.4.5 Infrastructure Modifications

Modification or upgrade (e.g. a new version) of existing software or hardware or addition of new software or hardware requires administration under MOC procedures. Procedures shall be established for testing and validation of the modification and records shall be maintained.

8.4.6 Control Technology Advances

Advances in control or computer technologies may make reimplementation of an existing application using a new technology or platform desirable. The magnitude of the reimplementation scope usually will require that the work be managed under a project structure. The project organization will still be required to follow MOC procedures.

8.5 Performance Monitoring

8.5.1 General

Performance monitoring of the advanced control application is necessary to track the benefits realized by the application and the control function performance. Procedures and standards for applications performance monitoring should be established and followed. A log of system deficiencies should be maintained.

8.5.2 Data Collection and Archiving

Advanced control system applications typically have a significant amount of performance data collected by the plant or application historian. The data captured by the historian should be reviewed periodically to verify that the data is being collected, archived, and backed up properly.

8.5.3 Performance Evaluation

Performance monitoring functions were described earlier in this document. The performance of an advanced control application is monitored by the operators and advanced control support specialists. The following are common performance problems and examples of corrective measures.

a) Online time is unacceptable. This may be due to input variables that are not reliable, the controller may need tuning, the model may need reidentification, the objectives may need correction, or additional operator training may be necessary.

b) Benefits may not be as expected or may be declining. This may be due to a low online time factor, inappropriate objectives, changes in the process, or unreliable input data.

c) The controller may be operating against a constraint that limits potential benefits. Values assigned to constraints should be evaluated periodically to determine if they can be relaxed.

d) The controller may be operating against an unexpected process limitation. If this is the case, the control objectives may need adjustment, the model may need to be updated, or constraints may need to be reidentified.

e) The controller may be making too many or too large of moves or be cycling. This may be indicative of a need for retuning or reidentification of the model.

f) Inputs may not be valid or substituted values are being used. This is indicative that maintenance of field instrumentation or analyzers may be required.

g) Controller functions may be limited by underlying regulatory control loops not being in cascade, or they are not performing acceptably. Tuning or maintenance of those loops may be required.

8.6 Documentation Maintenance

Several types of supporting documentation for an advanced control application need to be maintained and kept up to date. In addition to hard copies of these documents, regular backups of software and databases should be made and kept in a secure location. All documentation should be available and searchable online.

a) Functional and detailed design specifications.

b) Application configuration database and source code listings.

c) Graphics and reports.

d) Operations instruction and training manuals.

e) Training and certification records.

f) MOC change control records.

g) Engineering documentation: intermediate calculations, controller tuning and special tuning parameters, unit performance calculations, process control system control connections.

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