INTERNATIONAL STANDARD

ISO 15746-1

First edition
2015-04-01

Automation systems and integration — Integration of advanced process control and optimization capabilities for manufacturing systems —

Part 1: Framework and functional model

Systèmes d'automatisation et intégration — Intégration de contrôles de processus avancés et capacités d'optimisation des systèmes de fabrication —

Partie 1: Cadre de travail et modèle fonctionnel

Reference number
ISO 15746-1:2015(E)

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Foreword

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The committee responsible for this document is Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 5, *Interoperability, integration and architectures of automation systems and applications*.

ISO 15746 consists of the following parts, under the general title *Automation systems and integration — Integration of advanced process control and optimization capabilities for manufacturing systems*:

— *Part 1: Framework and functional model*

The following parts are planned:

— *Part 2: Activity models and information exchange*

— *Part 3: Validation and verification*

Introduction

As a crucial part of manufacturing systems with increased complexity, the automation and control applications enabled by advanced process control and optimization (APC-O) methodology and solutions perform the operations directed by production planning and scheduling. ISO 15746 deals with the integration of APC-O with manufacturing operations management (MOM) and with automation and control of manufacturing process and equipment.

The following IEC 62264 functionalities related to manufacturing are hierarchically structured in a functional model, as shown in Figure 1.

a) Level 0 defines the actual physical processes.

b) Level 1 defines the activities involved in sensing and manipulating the physical processes. Level 1 typically operates on time frames of seconds and faster.

c) Level 2 defines the activities of monitoring and controlling the physical processes. Level 2 typically operates on time frames of hours, minutes, seconds and sub-seconds.

d) Level 3 defines the activities of the work flow to produce the desired end products. It includes the activities of maintaining records and coordinating the processes. Level 3 typically operates on time frames of days, shifts, hours, minutes and seconds.

e) Level 4 defines the business-related activities needed to manage a manufacturing organization. Manufacturing-related activities include establishing the basic plant schedule (such as material use, delivery and shipping), determining inventory levels and making sure that materials are delivered on time to the right place for production. Level 3 information is critical to Level 4 activities. Level 4 typically operates on time frames of months, weeks and days.

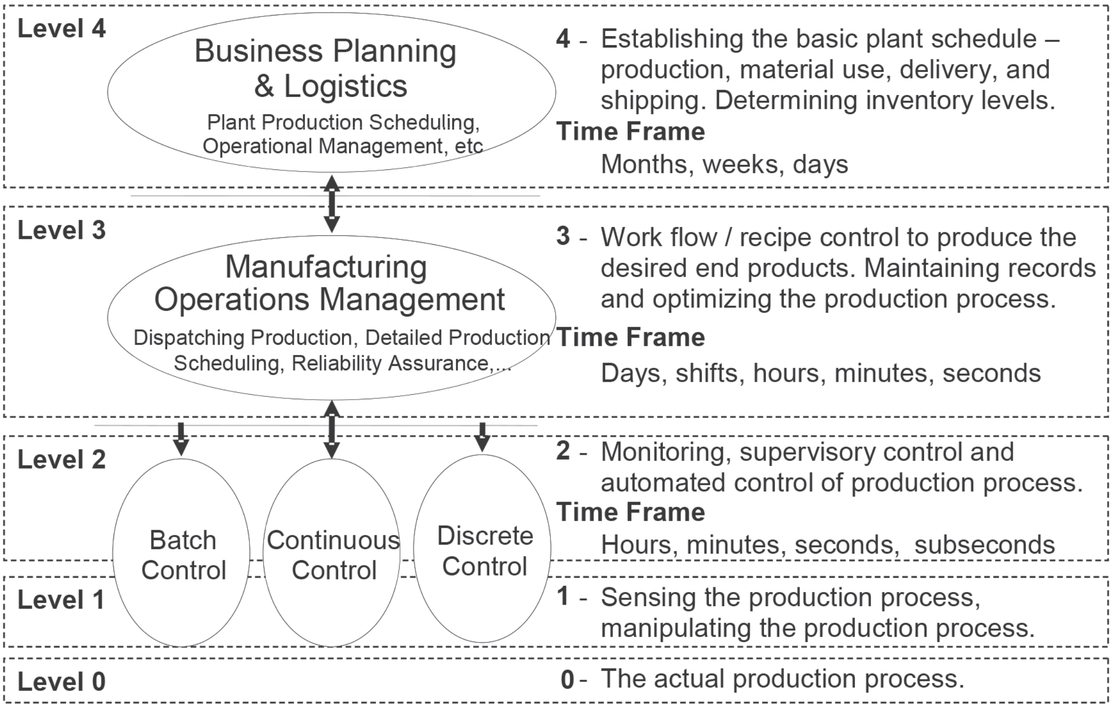


Figure 1 — Functional hierarchy

ISO 15746 mainly focuses on the integration of APC-O capabilities into control activities (Level 2) and MOM (Level 3), in Figure 1.

The APC-O system within Level 2 interacts with the MOM system of Level 3. It shall provide the information of the production processes to the MOM system, and in return accepts and executes the corresponding operational commands from the MOM system. The APC-O system within Level 3 samples measurement signals and monitors behaviour, and in return controls the operational systems within Level 2.

Automation solutions composed of software and hardware are provided by different suppliers to accomplish APC-O capabilities. Due to the diversity of development environments and the variety of demand focus, the automation solutions from various suppliers are isolated and relatively independent. These differences make the integration of automation solutions difficult. Consequently, the customers may purchase different automation solution components with redundant and duplicated functions, resulting in a waste of resources and limited interoperability. This part of ISO 15746 offers a reference interoperability framework for APC-O. It is intended to maximize the integration and interoperability of automation solutions.

This part of ISO 15746 is intended to help:

— identify an approach to assist the providers and system integrators of APC-O systems and related automation solutions components in verifying the interoperability of the components used to construct the automation solutions to meet application lifecycle requirements during designing, developing, implementing, testing, validating, installing and maintaining the automation solutions;

— identify the criteria to help users in choosing the appropriate automation solutions, such as APC-O modules, to meet their requirements;

— outline the concepts and conceptual framework elements that will be sufficient to address the identified problems and opportunities;

— reduce the time and cost in defining and describing the application requirements, as well as, in developing and implementing automation solutions based on APC-O systems.

The target users of this part of ISO 15746 include users and providers of the APC-O solutions, such as project solution suppliers, automation systems integrators, production departments of companies, process engineers, independent software testing organizations, implementation and consulting service organizations of APC-O software, and relevant governments and academic organizations.

Automation systems and integration — Integration of advanced process control and optimization capabilities for manufacturing systems —

Part 1:
Framework and functional model

1 Scope

This part of ISO 15746 establishes a framework and general functionality of a method for integration of advanced process control and optimization (APC-O) capabilities for manufacturing systems. The goal is to reduce the cost and risk associated with developing and implementing integrated APC-O capabilities.

The scope of this part of ISO 15746 is limited to specifying the set of concepts, terms, definitions and the associated rules for describing the required functional capabilities of APC-O units.

The following are outside the scope of this part of ISO 15746:

— definition and specification of an interface or communication protocol between APC-O capabilities;

— requirement and restriction of a specific technical specification when developing and implementing APC-O systems;

— strategy and method of a certain APC-O system.

2 Terms and definitions

2.1
advanced process control
APC
control strategy to cope with processes characterized by *large time delays* (2.18), non-minimum phase, non-linearity, loop instability and multi-variable coupling

Note 1 to entry: APC enhances basic process control by addressing particular performance or economic opportunities in the process.

EXAMPLE MPC, Adaptive control, Inferential control.

2.2
advanced process control and optimization
APC-O
collection of *advanced process control* (2.1) and *optimization* (2.13) strategies

2.3
controller
functional unit consisting of electronic devices or realized by computers (or digital systems), which is used to execute the specified control strategies

2.4
data driven model
model (2.11) developed through the use of data derived from tests or from the output of investigated process

2.5
expert control
control strategy based on rule set and reasoning process, which adopts the knowledge and ideas to the problem for control implementation

2.6
first principle model
model (2.11) reflecting physical and chemical laws, such as mass balance and energy balance

2.7
performance indicators
category of quantized and pre-authorized benchmarks that reflect the realization of the goals

2.8
physical sensor
physical equipment or converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument

Note 1 to entry: These days, instruments are mostly electronic.

EXAMPLE Flowmeter; pressure transmitter.

2.9
manipulated variable
input variable of the control system, which is used to manipulate the controlled variable

2.10
model predictive control
predictive control
comprehensive closed loop optimized control strategy which combines a dynamic *model* (2.11) for predicting future behaviour of the process, a continuous implementation of the control action based on on-line repeated *optimization* (2.13) and a feedback correction for the model error

EXAMPLE Model Algorithmic Control (MAC); Dynamic Matrix Control (DMC); Generalized Predictive Control (GPC).

2.11
model
abstract description of reality in any form (including mathematical, physical, symbolic, graphical or descriptive) that presents a certain aspect of that reality

[SOURCE: ISO 19439:2006, 3.47]

2.12
manufacturing operations management
MOM
activities within Level 3 of a manufacturing facility that coordinate the personnel, equipment and material in manufacturing

[SOURCE: IEC 62264-3:2007, 3.1.11, modified — Notes have been deleted; abbreviated term has been added.]

2.13
optimization
decision-making strategy to meet the business objective under a weighted set of conditions and concerns

2.14
soft sensor
virtual device using mathematical *model* (2.11) of sensing function to estimate process parameters using other known variables as inputs

2.15
statistical process control
strategy which uses statistical methods to monitor and control the manufacturing process in order to improve and maintain the system performance

2.16
steady state
equilibrium state at which the output variables are time-invariant

2.17
system identification
method, based on the observation of inputs and outputs, used to generate a *model* (2.11) of the system from a set of models by suitably adjusting model parameters

Note 1 to entry: The key factors of system identification include model structure, observed information and objective function.

2.18
time delay
time period that starts from when there is variation of the input variable until it influences the system output variable

Note 1 to entry: Time delay is also referred to as deadtime.

3 Abbreviated terms

APC advanced process control

APC-O advanced process control and optimization

KPI key performance indicator

MOM manufacturing operations management

OPM object process methodology

PID proportional-integral-derivative

PLS partial least squares

4 Concepts and capabilities

4.1 Background concepts

Process control is one of the most important branches of industrial automation. It aims at the control problems of process parameters, such as temperature and pressure. It covers a diversity of industrial fields, such as petroleum, chemicals, electric power, metals, textiles, building materials, light industry, nuclear energy, and pharmaceuticals.

With the development of modern industries, controlled objects are becoming increasingly sophisticated, which brings along with it new difficulties and challenges, such as multiple time varying parameters, large time delays, high nonlinearity, and complex coupling among input and output variables. Normal single loop control strategies can no longer achieve the desired objective of modern industrial automatic control. Since the 1970s, with the development of control theory and technology, a series of APC-O strategies have been proposed, such as multi-loop control and optimization strategy based on a system model, control strategy based on artificial intelligence and supervisory control strategy based on stochastic statistical analysis. The typical examples of APC-O include multivariable model predictive control, gain-based optimization, adaptive control, expert control and stochastic statistical process control.

4.2 Capabilities of the APC-O system

APC-O is the general definition of control and optimization strategies, which is used to cope with the optimal operation problems of complicated multi-variable processes in manufacturing processes. It can effectively solve problems such as large time delays, non-minimum phase, nonlinearity, open loop instability, multi-variable coupling, manipulated variable and control variable with constraints, multi-objective optimization.

APC-O is a type of dynamic coordinate control and optimization strategy with constraint handling to supervise the regulatory control system in Level 2. An APC-O system interfaces with control systems in Level 2 and provides real-time adjustments using these interfaces. These adjustments are intended to adapt the control system in Level 2 to the system dynamics and varying operation requirements of the manufacturing processes. In this way, a local and/or global optimization of the production processes can be achieved, either yielding the desired benefits or suggesting strategies wherever compromises are required. APC-O focuses on stationary and economic indicators to direct the optimization activity. Overall, APC-O helps to:

— enhance the stability and reliability of the entire system such as improving the robustness and safety of the equipment, and enforcing the safety and environmental operating constraints;

— improve overall system performance, such as reducing variance in system variables;

— improve the consistency of product quality, such as minimizing the quality giveaway;

— ensure the system operates as close to a constraint limit as possible such as operating close to economic and physical constraints, and increasing throughput.

5 Functional architecture of the APC-O system

The functional architecture of an APC-O system is described by the integration of the following functional modules: soft sensor, advanced process control (APC), optimization, and performance assessment, which is shown in Figure 2.

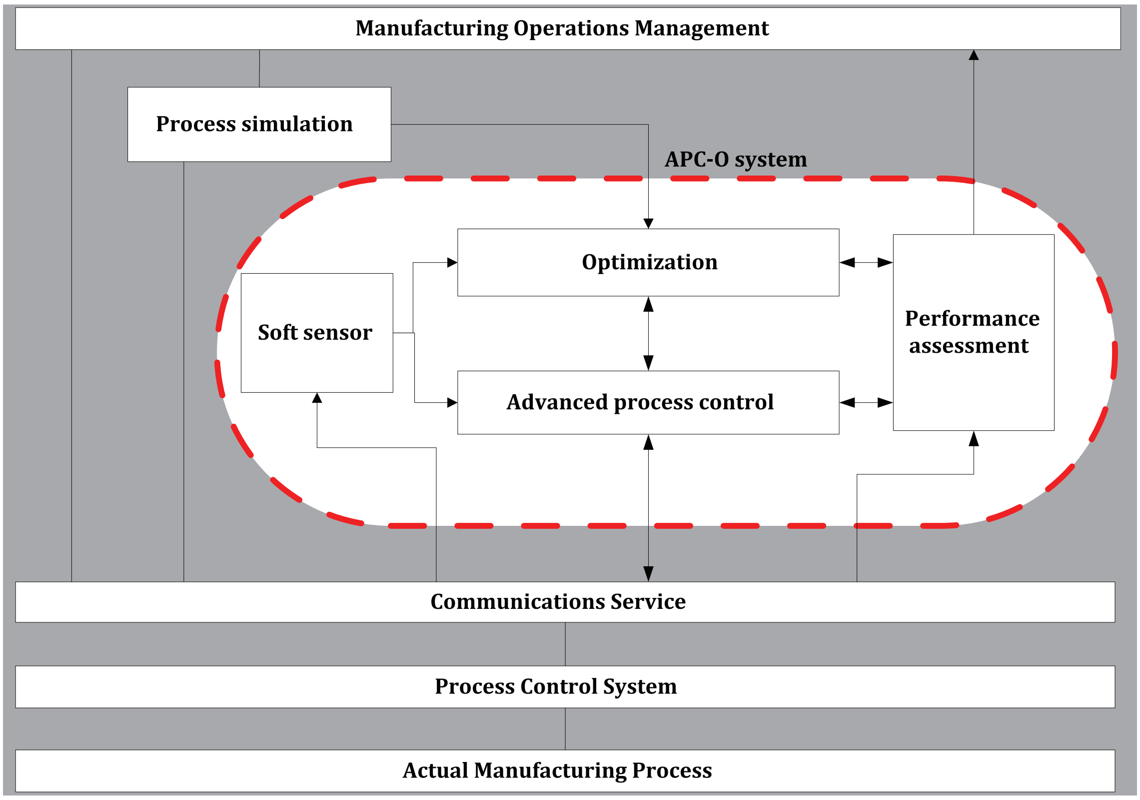


Figure 2 — Functional architecture of APC-O system

The soft sensor module serves in the same function as a physical sensor, except that values are obtained from a mathematical model of the physical sensor using other known variables as inputs. The soft sensor consequently enhances variable monitoring by increasing sampling frequency and replacing inaccurate measurements. The soft sensor module collects input data, and its outputs serve as inputs of the modules of APC and optimization to replace the measurements that are obtained from laboratory analysis or online analyzers with long cycle times.

The APC module includes a broad range of techniques and methodologies implemented within industrial control systems. APC differs from regulatory loop control strategies and it is intended to generate better control performance. The APC module collects input data from all the other modules of APC-O system. Its outputs serve as inputs of the regulatory control system in Level 2 and all the other modules in APC-O system except soft sensor module.

The optimization module intends to adjust the industrial equipment and processes to optimize a specified set of parameters without violating constraints. The most common optimization goals are minimizing cost, maximizing throughput and/or efficiency. The optimization module is based on a mathematical model including a first principle model and/or a data driven model. The optimum of the objective function is obtained by using analytical, numerical, programming or reasoning methods. The optimization module collects input data from all the other modules of APC-O system, and its outputs serve as inputs of all the other modules in APC-O system except soft sensor module.

The performance assessment module includes techniques and methodologies which help to maintain a highly efficient operating performance of the industrial automation systems. It monitors and diagnoses operating conditions of the industrial equipment and processes based on techniques such as control theory, system identification, probability and statistics, and signal processing. The performance assessment module intends to adjust the optimization and APC module to guarantee that the desired performance indicators are met. The performance assessment module collects input data from all the other modules of APC-O system except soft sensor module, its outputs serve as inputs of all the other modules in APC-O system except soft sensor module.

6 Capabilities of modules within the APC-O system

6.1 Soft sensor module

Soft sensor module has the capability to estimate/predict the key process variables that are directly related to the quality of the process output. The role of the soft sensor module is therefore of fundamental importance for process control and management. Such key process variables can only be determined by either online analysis at low sampling rates or through off-line analysis. Soft sensor module can, therefore, deliver additional information about these variables at higher sampling rate and at lower cost. Soft sensors module also have the capability to build features which are relevant to the process fault state. Based on these features, soft sensor module allows the early detection of incipient process faults.

NOTE Soft sensor techniques are classified into data-driven techniques and first principle techniques.

Data-driven soft sensor techniques are used when a first principle model is not available or not accurate enough . A soft sensor is designed on the basis of experimental data as well as industrial routinely collected data. There are two main approaches to building data-driven soft sensors: multivariate statistics and artificial intelligence such as neural networks, fuzzy logic and support vector machine.

First principle techniques estimate variables based on the principles of chemical reaction kinetics, material balance, energy balance and other known concepts. It complements the data-driven soft sensor technique. The first principle technique is intended to improve the system response accuracy and robustness while keeping the overall architecture scalable.

6.2 APC module

APC module is able to address difficult control problems including large time delays, non-minimum phase, nonlinearity, open loop instability and multivariable coupling. It can handle interactions of a multivariable system and has good robustness to model and environmental uncertainty. APC module has the capability to reduce the variance of controlled variables and allows the processes to be operated closer to economic and physical constraints. It can improve product yield, reduce energy consumption, increase capacity, improve product quality/consistency; reduce loss of production, increase responsiveness, improve process safety and reduce environmental emissions. It is able to support the real-time process optimization. It mainly includes control strategies such as predictive control and adaptive control.

6.3 Optimization module

Optimization module has the capability to respond to the production schedule in Level 3 and supply the optimal process operating conditions or set points to the APC system. Such set points can ensure that the process operates to achieve optimal objective function and satisfy operational constraints as well as model constraints.

NOTE In one example, a steady state model with constraints operates in an offline or online calculation mode to search for set points (operating points) to optimize an objective function while the process operates in steady state mode.

As the complexity of the process increases, the optimal solution may not be the global optimal solution, but it should satisfy the business requirements within the constraints.

In the APC-O system, optimization module can be implemented through a variety of technologies such as linear programming, quadratic programming, sequential quadratic programming (SQP), interior point method and active-set method.

6.4 Performance assessment module

Performance assessment module is used to detect and diagnose the performance degradation in the APC-O system. The performance assessment module has the capabilities to provide the information for determining whether the specified control/optimization performance targets and response characteristics are being met by the APC-O systems. Performance assessment module can determine the capability of the running APC-O system by selecting a benchmark, detect poor performing loops, diagnose the underlying causes and suggest how to improve such loops.

NOTE In the APC-O system, the main purpose of performance assessment module is to evaluate and improve the performance of the APC and Optimization module, and help operators to analyse the operational state of equipment and Level 2 control systems, and determine when APC-O system maintenance is needed.

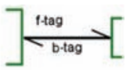
Some examples of performance assessment techniques include key performance indicators (KPIs) of the APC-O system, process data statistics for key process measurements, and tracking of model biases.

7 Structure and lifecycle phases of APC-O modules

7.1 Generic structure of APC-O modules

The following module structures are depicted using the object process methodology (OPM), which is a compact conceptual approach, language, and methodology for modelling and knowledge representation of automation systems and their interoperation. OPM is a formal yet intuitive paradigm for systems design, engineering, development, life cycle support, communication, and evolution. OPM notation supports the conceptual modelling of systems. Its holistic approach can describe the functional, structural and behavioural aspects of a system. In this part of ISO 15746, the structure of module is depicted by the unfolded function of OPM. Table 1 defines the OPM notations used in the module structure diagrams.

Table 1 — OPM notations

Symbol	Name	Definition
	Object	An object is an item that exists or can exist once constructed, physically or informatically. Associations among objects shall constitute the object structure of the system being modelled, i.e. the static, structural aspect of the system.
	Process	A process is an item that expresses the behavioural, dynamic system aspect: how processes transform objects in the system and how the system functions to provide benefit. Processes complement objects by providing the dynamic, procedural aspect of the system.
	Aggregation-participation relation link	The fundamental structural relation aggregation-participation is a source item that aggregates one or more other participant items, the destination items, into a meaningful whole.
	Exhibition-characterization relation link	The fundamental structural relation exhibition-characterization means that an item exhibits, or is characterized by, another item. The exhibition-characterization relation binds a source item, the exhibitor, with one or more destination items, which shall identify features that characterizes the exhibitor.
	Bidirectional tagged structural link	Relation between two objects: relation names are entered by architect, and are recorded along link.

The generic structure applies to soft sensor, APC, optimization and performance assessment modules. The componnets within different APC-O modules may be integrated or interacted.

EXAMPLE Calculators of different modules may interact through the same information exchange component; and may be monitored by the same monitor; and may be managed by the same task scheduler.

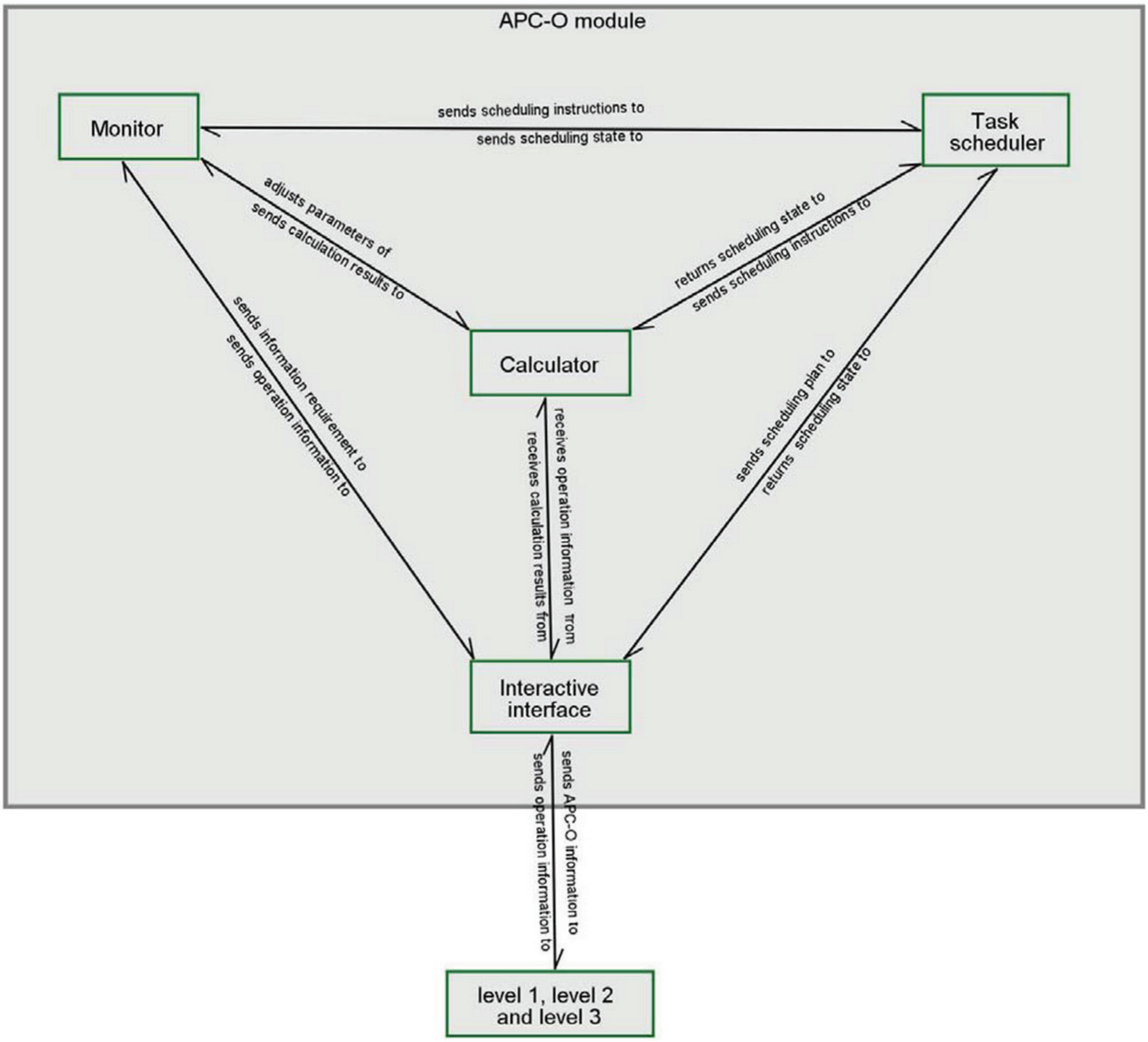


Figure 3 — Generic structure of APC-O modules

7.2 Life cycle phases of the soft sensor module

7.2.1 Life cycle phases of soft sensor module are depicted in Figure 4. The first level is soft sensor module. The second level defines five different life cycle phases of soft sensor module. Soft sensor module is constructed by going through requirement analysis, design and development phases. In execution phase, soft sensor module operates online and its structure is described in 7.1. In support phase, soft sensor module is maintained to satisfy the design requirements.

Each phase contains several jobs to achieve the respective functions. Description of each job is given as follows.

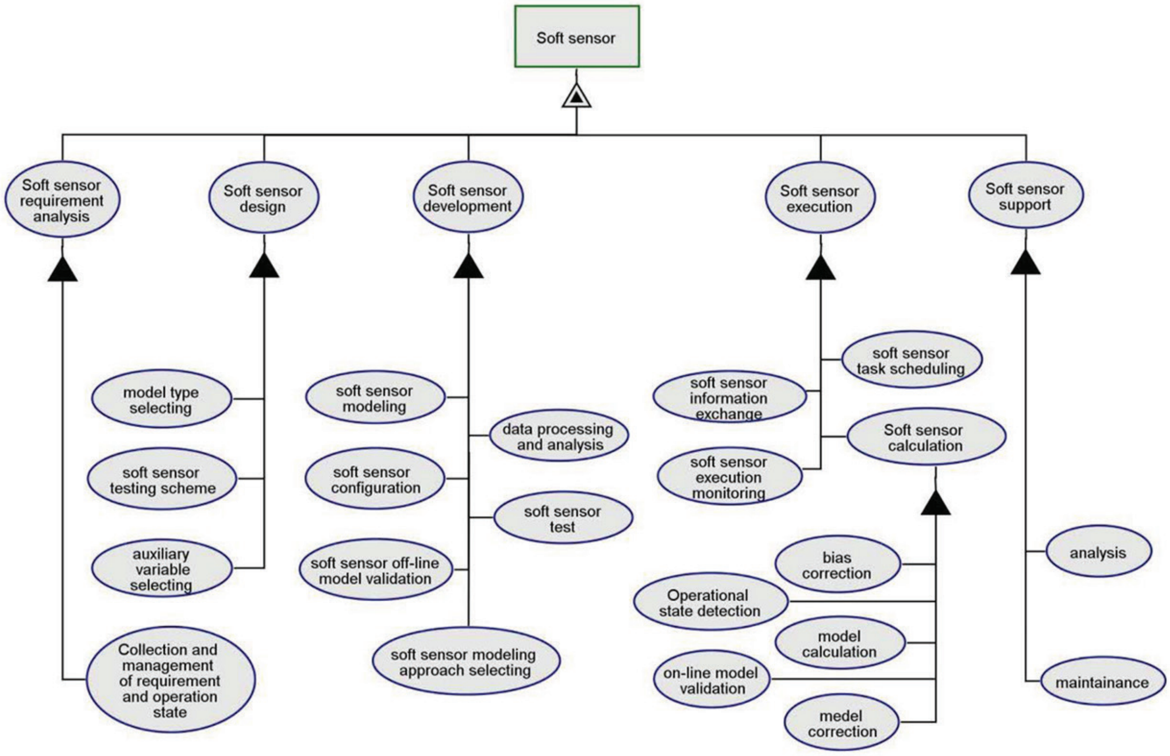


Figure 4 — Life cycle phases of the soft sensor module

7.2.2 In the soft sensor module, the requirement analysis phase includes collection and management of requirement and operation state: it gathers the project requirements, analyzes the requirements based on process status and completes the requirement specification.

7.2.3 The design phase includes the following jobs:

a) Auxiliary variable selecting: It selects and confirms related variables as auxiliary variables according to the process.

b) Model type selecting: Model type selecting within soft sensor module should consider not only the actual process situations and index requirements, but also the reality and implementation cost. In design phase, the above factors are considered to determine the model type.

c) Soft sensor testing scheme: Based on historical data and operating conditions, soft sensor testing scheme is designed to satisfy the requirements.

7.2.4 The development phase includes the following jobs:

a) Data processing and analysis: According to scheme or modelling requirement, process and analyse acquired data, such as removing noises, normalization.

b) Soft sensor modelling approach selecting: Modelling processes and methods of different soft sensor models are different. Although the models are the same, using different optimization methods will result in different results. Engineers need to select modelling methods according to actual situations and requirements; even to select several methods to compare or evaluate.

NOTE 1 Various approaches are available for soft sensor module. Engineers need to select modelling methods according to process characteristics and requirements. Several methods can be selected and integrated for modelling.

c) Soft sensor modelling: Based on soft sensor design scheme, it analyzes soft sensor sample data and builds soft sensor model.

d) Soft sensor off-line model validation: It validates and analyzes the soft sensor model by process historical data.

e) Soft sensor configuration: Based on design scheme, it configures project documents and operation interface of soft sensor.

f) Soft sensor test: Data driven soft sensor module establishes its model by testing data. The test should be implemented based on the testing scheme.

NOTE 2 Soft sensor test takes longer time. Orthogonal test is usually applied to enhance the efficiency.

7.2.5 The execution phase includes the jobs operated by the components under the generic structure of soft sensor module:

a) Soft sensor task scheduling: Management behaviour within soft sensor module, including loading, execution and unloading of the components, as well as their execution order. The objective is to transform and disaggregate each work plan into specific tasks.

b) Soft sensor information exchange: Communication interface between intra-system and inter-system (Level 1, Level 2 or Level 3) to achieve man-machine interaction within soft sensor module.

c) Soft sensor execution monitoring: Within soft sensor module,acquire module execution status, and ensure the status to follow the design scheme.

d) Soft sensor calculation: Soft sensor calculation includes:

   1) Model correction: Under specific situation, analyse, adjust and optimize model by accumulated historical data.

   2) Bias correction: Eliminate deviation between outputs of soft sensor model and laboratory value (actual measured data), to make sure that outputs of soft sensor model is consistent with laboratory value.

   3) Online model validation: When the module is running online, use real-time data to make a quick validation on the effectiveness of the soft sensor model by applying posterior and recursive methods.

   4) Model calculation: Calculate outputs of soft sensor model through the inputs and soft sensor model.

   5) Operational state detection: Within soft sensor module,detect process operation state to ensure the system applicability. If some abnormal situations appear, exception handling mechanism will be triggered to ensure safety.

7.2.6 The support phase includes the following jobs:

a) Analysis: Analyse the process or existing problems to determine post-maintenance strategy.

b) Maintenance: According to maintenance strategy, complete maintenance tasks, and achieve the aim of solving problems or improving process performance.

7.2.7 In the design phase, auxiliary variables and the model type are determined based on the output of requirement analysis phase. The testing scheme should be designed on the basis of a soft sensor model type and used as test inputs of development phase. Based on data processing and analysis, a soft sensor is modelled and validated. The configuration output is taken as an input of the execution phase. In support phase, after analysing operation data of soft sensor model, maintenance strategy is determined to maintain the system for desired performance.

7.3 Life cycle phases of the APC module

7.3.1 Life cycle phases of APC module are depicted in Figure 5. The first level is APC module. The second level defines five different life cycle phases of APC module. APC module is constructed by going through requirement analysis, design and development phase. In execution phase, APC module operates online and its structure is described in 7.1. In support phase, APC module is maintained to satisfy the design requirements.

Each phase contains several jobs to achieve the respective functions. Description of each job is given as follows.

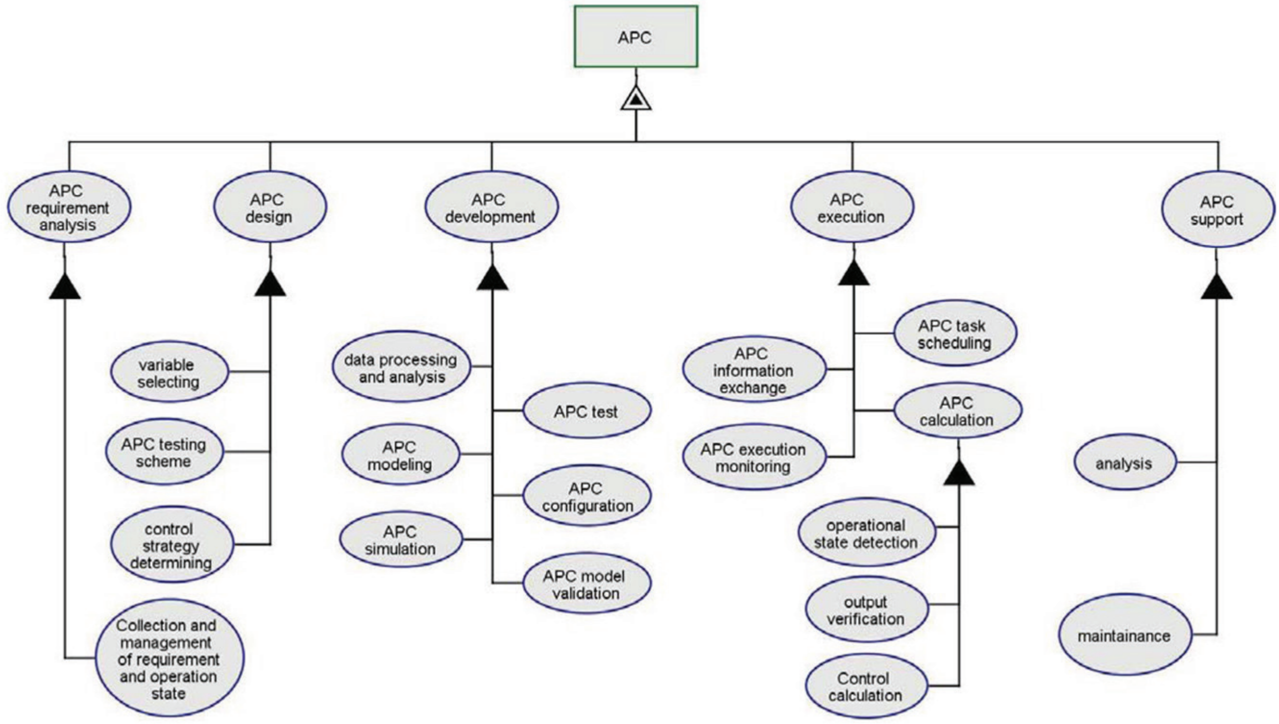


Figure 5 — Life cycle phases of the APC module

7.3.2 In the APC module, the requirement analysis phase includes collection and management of requirement and operation state: it gathers the project requirements, analyzes the requirements based on process status and completes the requirement specification.

7.3.3 The design phase includes the following jobs:

a) Variable selecting: It determines the controlled variables, manipulated variables and disturbance variables according to the requirement specification.

b) Control strategy determining: It generates control strategy according to the requirement specification.

c) APC testing scheme: Based on historical data and operating conditions, it designs APC testing scheme to satisfy the requirements.

7.3.4 The development phase includes the following jobs:

a) Data processing and analysis: According to scheme or modelling requirement, process and analyse acquired data, such as removing noises, normalization.

b) APC modelling: Based on the analysis of process data, it builds APC model, such as step response model for predictive controller.

c) APC model validation: It assists in analysing the model effectiveness based on the analysis of the process data on the model.

d) APC configuration: It configures the controller which includes auxiliaries such as logic switching and safety protection based on regular control system. It includes variable configuration and control strategy configuration.

e) APC simulation: Under nominal conditions, it verifies whether the controller fits the requirements of the engineering scheme.

f) APC test: APC test indicates the process to acquire testing data based on APC testing scheme. The main objective is to provide APC test data.

NOTE APC test focuses on dynamic relation between the input and output variables.

7.3.5 The execution phase includes the jobs operated by the components under the generic structure of APC module:

a) APC task scheduling: Management behaviour within APC module, including loading, execution and unloading of the components, as well as their execution order. The objective is to transform and disaggregate each work plan into specific tasks.

b) APC information exchange: Communication interface between intra-system and inter-system (Level 1, Level 2 or Level 3) to achieve man-machine interaction within APC module.

c) APC execution monitoring: Within APC module,acquire module execution status, and ensure the status to follow the design scheme.

d) APC calculation: APC calculation includes:

   1) Operational state detection: Within APC module,detect process operation state to make sure the system applicability. If some abnormal situations appear, exception handling mechanism will be triggered to ensure safety.

   2) Control calculation: Operate the controller online.

   3) Output verification: Verify the outputs to satisfy the safety requirements.

NOTE The APC-O system, which contains many feedback loops, is intended to ensure the safety.

7.3.6 The support phase includes the following jobs:

a) Analysis: Analyse process or existing problems to determine later maintenance strategy.

b) Maintenance: According to maintenance strategy, complete maintenance tasks, and achieve the aim of solving problems or improving process performance.

7.3.7 In the design phase, variables and a control strategy are determined based on the output of requirement analysis phase. The testing scheme should be designed upon the variables and control strategy and used as test inputs of development phase. Based on data processing and analysis, the internal model of the controller is established and validated. The APC configuration output is taken as an input of the execution phase. In support phase, after analysing operation data of the controller, maintenance strategy is determined to maintain the system for design requirements.

7.4 Life cycle phases of the optimization module

7.4.1 Life cycle phases of optimization module are depicted in Figure 6. The first level is optimization module. The second level defines five different life cycle phases of optimization module. Optimization module is constructed by going through requirement analysis, design and development phase. In execution phase, optimization module operates online and its structure is described in 7.1. In support phase, optimization module is maintained to satisfy the process requirements.

Each phase contains several jobs to achieve the respective functions. Description of each job is given as follows.

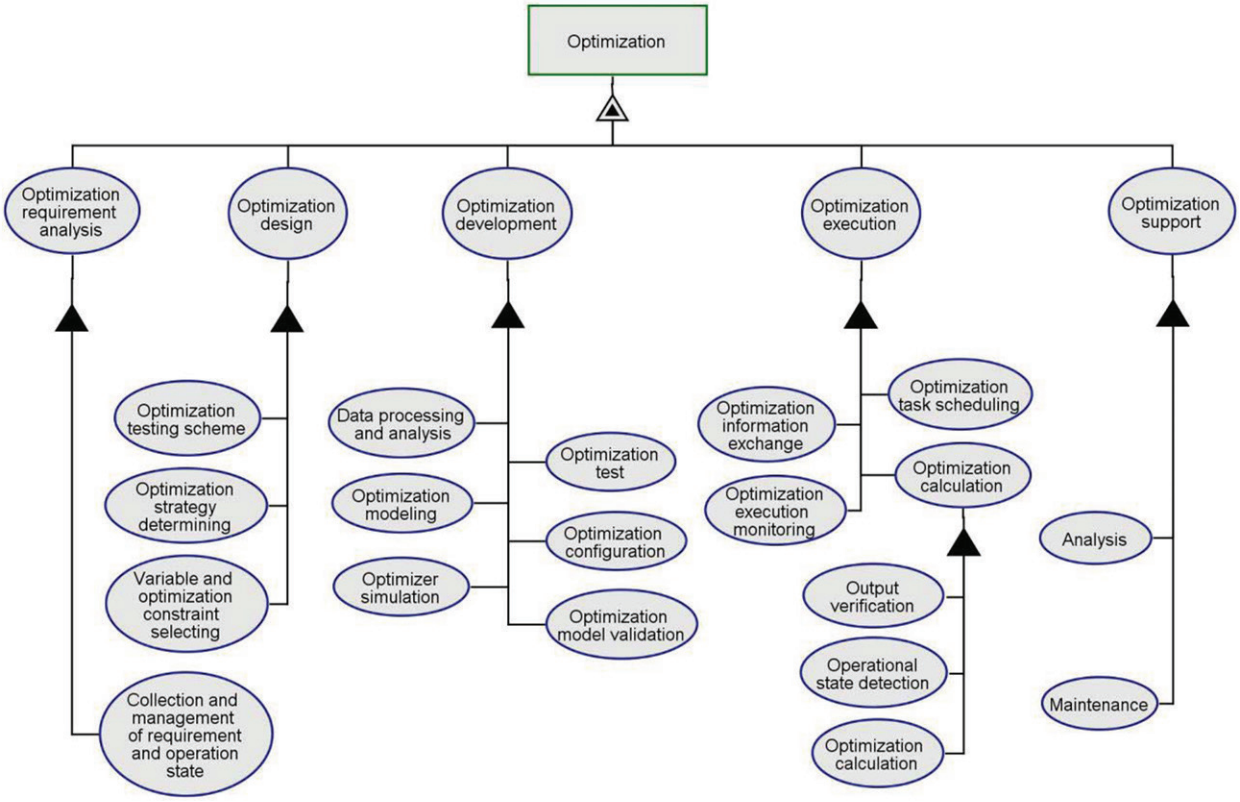


Figure 6 — Life cycle phases of the optimization module

7.4.2 In the optimization module, the requirement analysis phase includes collection and management of requirement and operation state: it gathers the project requirements, analyzes the requirements based on process status and completes the requirement specification.

7.4.3 The design phase includes the following jobs:

a) Optimization objective, variable and constraint selecting: It determines the objective according to requirement specification; determines the variables which affect the optimization objective; and then determines the optimizer constraints based on craft and process requirement.

b) Optimization strategy determining: It determines the method according to the optimization formulation.

c) Optimization testing scheme: Based on historical data and operating conditions, it designs optimization testing scheme to satisfy the requirements.

7.4.4 The development phase includes the following jobs:

a) Data processing and analysis: According to scheme or modelling requirement, process and analyse acquired data, such as removing noises, normalization.

b) Optimizer modelling: Based on prior knowledge and process data, it builds economic optimization objective, model and constraints.

c) Optimization model validation: It assists in analysing the effectiveness and accuracy of the optimization model.

d) Optimizer configuration: It configures the optimizer which includes the objective function, constraints, and auxiliaries such as logic switching and safety protection.

e) Optimizer simulation: Under nominal conditions, it verifies whether the optimizer fits the requirement of the design scheme.

f) Optimization test: Optimization test indicates the process to acquire testing data based on optimization testing scheme. The main objective is to provide optimization test data.

NOTE In general, optimization test refers to the process or mechanism.

7.4.5 The execution phase includes the jobs operated by the components under the generic structure of optimization module:

a) Optimization task scheduling: Management behaviour within optimization module, including loading, execution and unloading of the components, as well as their execution order. The objective is to transform and disaggregate each work plan into specific tasks.

b) Optimization information exchange: Communication interface between intra-system and inter-system (Level 1, Level 2 or Level 3) to achieve man-machine interaction within optimization module.

c) Optimization execution monitoring: Within optimization module,acquire module execution status, and ensure the status to follow the design scheme.

d) Optimization calculation: Optimization calculation includes:

   1) Operational state detection: Within optimization module,detect process operation state to make sure the system applicability. If some abnormal situations appear, exception handling mechanism will be triggered to ensure safety.

   2) Optimization calculation: Operate the optimizer online.

   3) Output verification: Verify the outputs to satisfy the safety requirements.

7.4.6 The support phase includes the following jobs:

a) Analysis: Analyse process or existing problems to determine later maintenance strategy.

b) Maintenance: According to maintenance strategy, complete maintenance tasks, and achieve the aim of solving problems or improving process performance.

7.4.7 In the design phase, optimization variables, constraints and objectives are determined and an optimization strategy is selected based on the output of requirement analysis phase. The testing scheme should be designed and used as test inputs of development phase. Based on data processing and analysis, the internal model of the optimizer is established and validated. The optimization configuration output is taken as an input of the execution phase. In support phase, after analysing operation data of the optimizer, maintenance strategy is determined to maintain the system for design requirements.

7.5 Life cycle phases of the performance assessment module

7.5.1 Life cycle phases of performance assessment module are depicted in Figure 7. The first level is optimization module. The second level defines five different life cycle phases of performance assessment module. Performance assessment module is constructed by going through requirement analysis, design and development phase. In execution phase, performance assessment module operates online and its structure is described in 7.4. In support phase, performance assessment module is maintained to satisfy the process requirements.

Each phase contains several jobs to achieve the respective functions. Description of each job is given as follows.

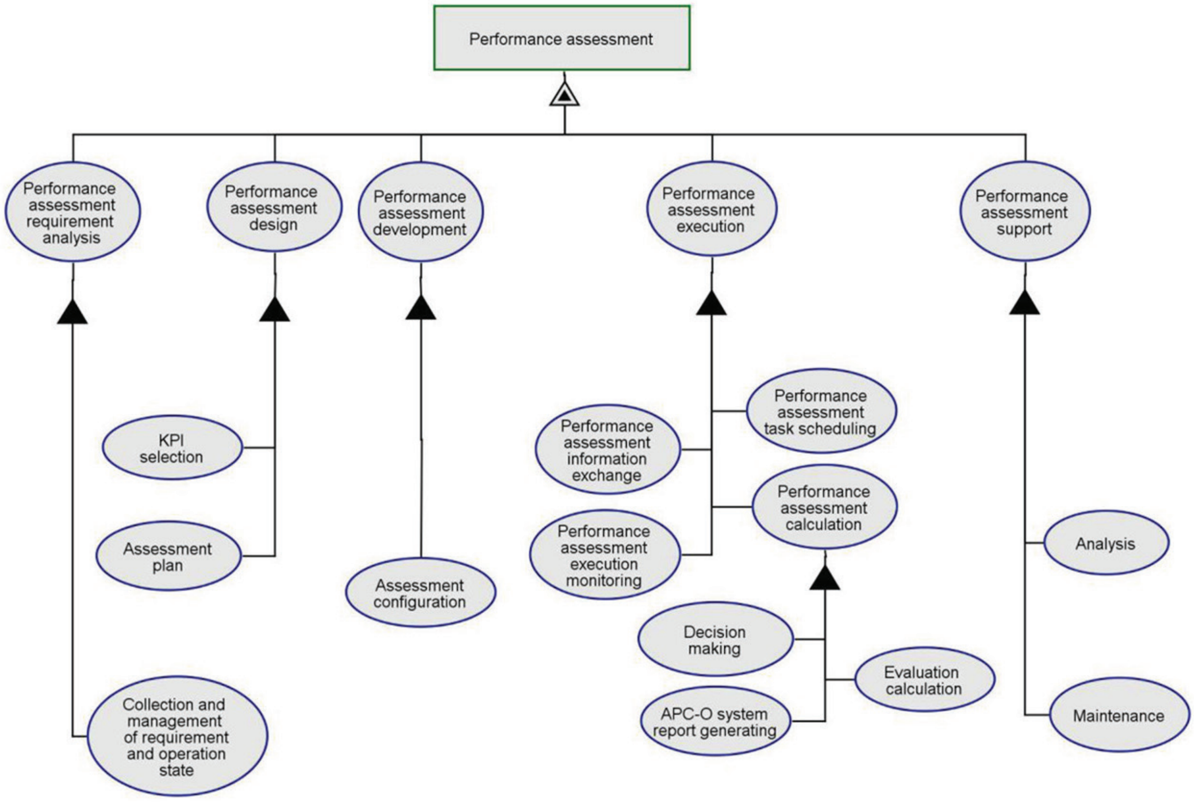


Figure 7 — Life cycle phases of the performance assessment module

7.5.2 In the performance assessment module, the requirement analysis phase includes collection and management of requirement and operation state: it gathers the project requirements, analyzes the requirements based on process status and completes the requirement specification.

7.5.3 The design phase includes the following jobs:

a) KPI selection: It selects KPIs by analysing production process and APC-O system, and designs KPI calculation methods.

b) Assessment plan: It is determined according to requirements specification and production process.

7.5.4 The development phase includes the following jobs:

a) Assessment configuration: Configurations related to the performance assessment, including selecting assessment methods, configuring parameters and assessment plan.

7.5.5 The execution phase includes the jobs operated by the components under the generic structure of performance assessment module:

a) Performance assessment task scheduling: Management behaviour within performance assessment module, including loading, execution and unloading of the components, as well as their execution order. The objective is to transform and disaggregate each work plan into specific tasks.

b) Performance assessment information exchange: Communication interface between intra-system and inter-system (Level 1, Level 2 or Level 3) to achieve man-machine interaction within performance assessment module.

c) Performance assessment execution monitoring: Within performance assessment module,acquire module execution status, and ensure the status to follow the design scheme.

d) Performance assessment calculation: Performance assessment calculation includes:

   1) Evaluation calculation: Collect data according to evaluation requirements. Calculate and save evaluation results.

   2) APC-O system report generating: After evaluation calculation, combining prior knowledge or configuration parameters, analyse evaluation results, and generate assessment reports.

   3) Decision-making: Analyse assessment report; estimate APC-O system operational performance and supply reference to user.

7.5.6 The support phase includes the following jobs:

a) Analysis: Analyse process or existing problems to determine later maintenance strategy.

b) Maintenance: According to maintenance strategy, complete maintenance tasks, and achieve the aim of solving problems or improving process performance.

7.5.7 Performance assessment evaluates the operating state of the APC-O implementation. According to the requirement, which is the out of the requirement analysis phase, the KPIs and the assessment plan should be determined. After the assessment configuration, the assessment plan is executed. The outputs of the execution phase are the assessment report and maintenance suggestions on which basis the user can determine maintenance plan for APC and optimization modules. In support phase, after analysing operation data of performance assessment module, maintenance strategy is determined to maintain the system for design requirements.

Annex A
(informative)

Typical example of APC-O system integration

A typical APC-O system consists of four functional modules, where each module can either work independently or be integrated to work as a whole. Figure A.1 presents a typical example for online integration of the APC-O modules which shows the interaction between each module.

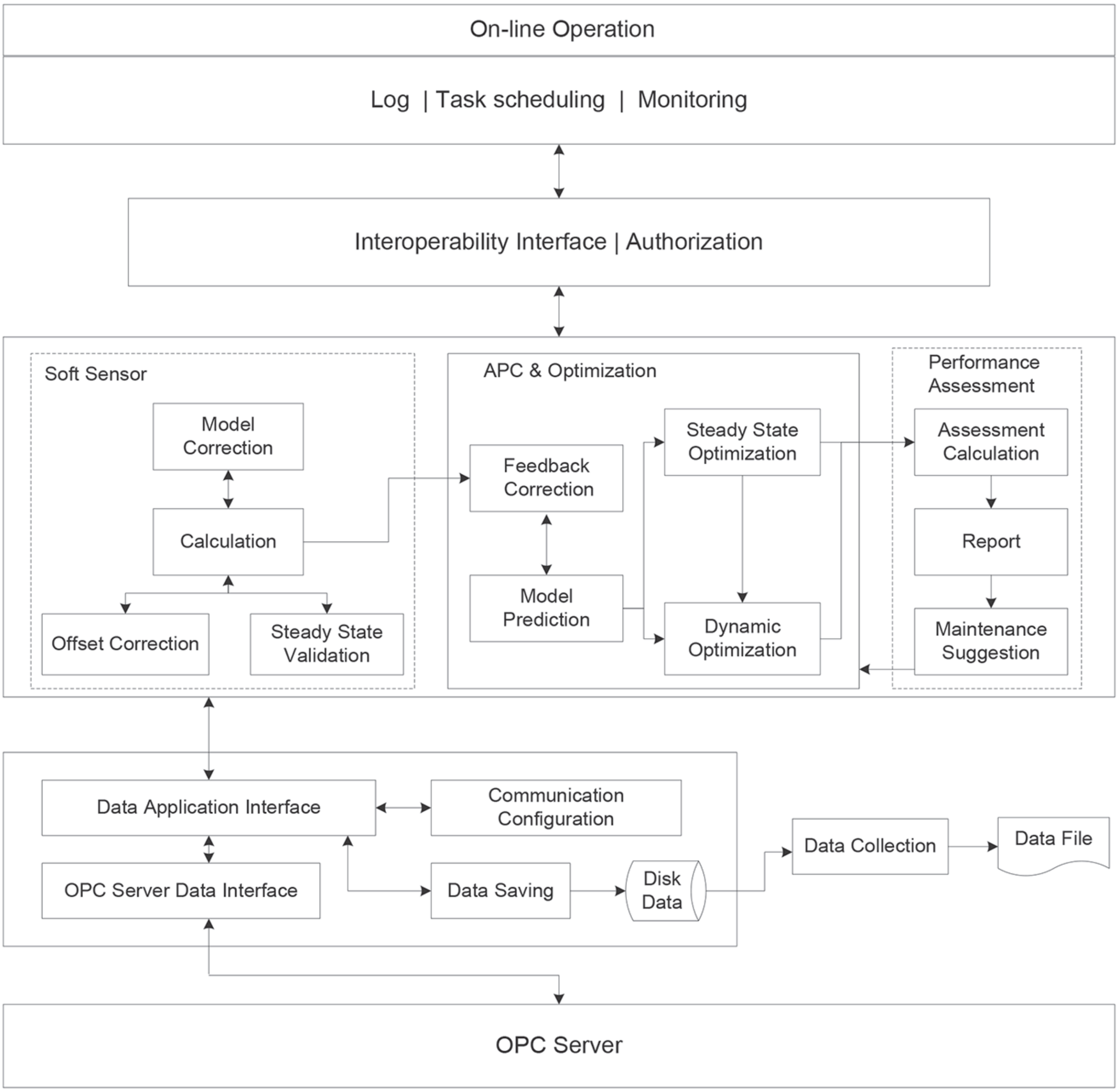


Figure A.1 — Typical example of APC-O system integration

The soft sensor, APC, optimization and performance assessment modules are implemented in execution phase. The APC module applies a model predictive control technique, which also specifies the optimization module. The APC and optimization modules are implemented through an integrated module in the example.

Online operation provides interface tools which help engineers to debug the APC-O system. It consists of log, management and monitoring units.

Each phase associated with different functional modules contains various jobs. However, some jobs with the same functionality are involved in different modules.

NOTE 1 These jobs can be handled through an integrated platform to operate the whole APC-O system. Such a platform could provide common functionality, such as data communication service, data processing and analysis, authority management, and online engineering management and operation. The platform could supply an operating environment for APC-O system, and support soft sensor, APC, optimization and performance assessment module by implementing common behaviour properties of the four modules.

These software components may include:

a) Log: Save operation log for convenient viewing. The log saves operation state of APC-O system, user operating command, and assists user to learn historical operation situation.

b) Authorization: Manage users and their passwords, assign user authorities according to user roles, and validate user authority when user operates.

c) Monitoring: It operates and monitors the APC-O system. It also allows the user to scan operation state of APC-O system, adjust system parameter, execute operating command, and monitor trend graph of data and communication state of APC-O in real time.

d) Task scheduling: It manages and maintains the APC-O system, such as the unloading, reloading, execution, stopping execution, resetting.

e) Interoperability interface: It is the interface through which the APC-O system interacts with Level 2 systems, such as basic process control systems, and Level 3 systems, such as MOM.

f) Data collection: It selects process variables and retrieves real-time and/or historical data from APC-O system.

g) Communication configuration: It configures the communication interface and process variables.

h) Data saving: It saves the production process data in real time.

i) OPC server data interface: Based on data interfaces developed by OPC communication protocol standard, it transforms OPC data format into APC-O system format.

   NOTE 2 If other data servers are available, the corresponding interfaces are required, such as DDE server.

j) Data application interface: It provides unified data interface service for APC-O system to avoid developing different interfaces for different data server of each module.

k) Data saving: Save the real-time data in the data server.

Annex B
(informative)

PLS technique

Partial least squares (PLS) is a typical soft sensor technique. It is widely used as a method of linear data modelling and has beneficial properties in the presence of large variable sets that show significant correlation by preventing over-fitting.

The soft sensor module, utilizing PLS, can be categorized by off-line and online procedures. Off-line procedures include data processing and analysis, PLS modelling, PLS configuration. Online procedures include execution and monitoring. The module requires some software components, including data communication interfaces, user interfaces, task scheduling and data collection.

a) Data processing and analysis: It filters and double-samples the data collected from process data files and lab data files to achieve the effective sample data.

b) PLS modelling: It selects input/output variables and models parameters to solve the PLS model. Check the model verification results and simulation curve to validate the PLS model and export the results.

c) PLS configuration: It configures the PLS model based on the engineering requirements, such as tag configuration, filtering methods and protection logic.

d) PLS execution: Online calculation of PLS, including predictive output calculation, bias correction, model correction and model verification.

e) Online monitoring: It acts as user interfaces between users and PLS module.

NOTE The structure of PLS model is determined by PLS methods.

Annex C
(informative)

Predictive control and steady state optimization

A predictive control technique is a widely used advanced control strategy. It can effectively solve complicated industrial process control problems such as multi-variable, large time delays and significant coupling. The same model is also used for steady state optimization. Consequently, when designing a steady state optimizer and predictive controller, the two modules are integrated in one software package.

The off-line part of predictive control and steady state optimization includes data processing and analysis, identification, configuration, simulation and auxiliary design. The online part includes execution and online monitoring. The detailed specifications of the above software components are as follows.

a) Data processing and analysis: It collects process measured data, and acquires desired data for modelling through filtering and double sampling.

b) Identification: It selects input variables, output variables and identification method to identify dynamic model between input variables and output variables. Conventional identification methods include FIR identification, ARX identification, PEM identification and subspace identification.

NOTE Identification refers to modelling of APC and optimization modules.

c) Configuration: It inputs model to configure optimization strategy, constraints, control strategy, tag number and logic protection.

d) Simulation and aided design: It assists user to initialize parameter design. It also verifies the effects of controller and optimizer, and debug s continually until the requirement is satisfied, then prepare to online execute.

e) Online execution: It acquires process data through data communication. If necessary, it also acquires the output data of one or more soft senso. It then calculates the trend of model outputs under open-loop condition, and corrects the deviation between the APC-O model outputs and process measurements. The corrected APC-O model is then used by the optimization module to determine the optimum steady state settings for the process based on the control strategy and constraints. The control module uses the output of the optimization module, its control strategy, and constraints to calculate incremental adjustments to manipulated variables. Finally, it writes new process settings to the production process through data communication.

f) Online monitoring: It acts as user interfaces to operate and use APC-O system.

Annex D
(informative)

PID performance assessment

Conventional proportional-integral-derivative (PID) control is widely used in control systems. It is important to ensure that the advanced control system is running smooth. The PID control performance is the basis of a stable and efficient operation of production process. PID performance assessment can assist engineers to identify loops which show a poor or degrading performance, and can also decrease maintenance cost. PID performance assessment module include loop configuration, planning, online execution, online monitoring, report scanning.

a) Loop configuration: It configures PID loop information, tag number, loop category and open-loop stabilization time.

b) Plan: It makes assessment plan according to production requirement, such as assessing every eight hours.

c) Online execution: PID assessment modules execute assessment plan automatically and save the assessment results in database, then make assessment report.

d) Online monitoring: Users are able to monitor the execution status of assessment plan through online monitoring.

e) Report scanning: Engineers are able to scan assessment results to find out the loops which are poor or degrading in performance. If the performance degeneration is caused by the controller, PID parameters need to be tuned. If the performance degeneration is caused by process such as valve, disturbance, maintenance is needed to improve performance.

NOTE Online monitoring and report scanning are two parts of monitoring subcomponents.

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ICS 25.040.40

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