INTERNATIONAL STANDARD

ISO 15746-3

First edition
2020-02

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

Part 3: Verification and validation

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

Partie 3: Vérification et validation

Reference number
ISO 15746-3:2020(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 5, *Interoperability, integration and architectures for enterprise systems and automation applications*.

A list of all parts in the ISO 15746 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

As a crucial part of the increasingly complex manufacturing systems, automation and control applications which are enabled by advanced process control and optimization (APC-O) methodology and solutions are implemented under the direction of production planning and scheduling. This task involves initially the specific use of APC-O that will eventually enable the integration of manufacturing operations management (MOM) with the automation and control of manufacturing process and equipment.

Automation solutions equipped with both software and hardware components are provided by different suppliers to accomplish APC-O functions. Due to the diversity of development environments and the variety of demand focus, the automation solutions from various suppliers tend to be isolated and relatively independent, which make it harder for the automation solutions to be integrated. Consequently, various automation solution components that the customers can have access to are filled with redundant and duplicated functions, resulting in a waste of resources and limited interoperability. This document offers an interoperability framework for advanced process control and optimization with the intention of maximizing both the integration and the interoperability of automation solutions.

It is not the intent of this document to suggest that there is only one way of implementing APC-O or to force users to abandon their current way of implementing APC-O.

The target users of this document include users and providers of advanced process control and optimization 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 advanced process control and optimization software, and relevant government and academic organizations.

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

Part 3: Verification and validation

1 Scope

This document defines the principle of verification and validation according to the activity models and workflow of an advanced process control and optimization (APC-O) system, analyses and defines the general process for verification and validation of APC-O systems, and specifies a set of indicators and checkpoints used for verification and validation.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
checkpoint
point where *verification* (3.6) and *validation* (3.5) activities needed to be performed throughout the APC-O lifecycle

3.2
indicator
measurement of an aspect of the system or component

Note 1 to entry: There are two types of indicators: *quantitative indicators* (3.3) and *judgement indicators* (3.4).

3.3
quantitative indicator
indicator (3.2) that is calculated using formulae

3.4
judgement indicator
indicator (3.2) that is evaluated using the evaluation method

3.5
validation
process of evaluating an APC-O system to determine whether it satisfies the stakeholders' requirements for that system

3.6
verification
process of evaluating an APC-O system to determine whether the output of a phase satisfies the conditions imposed at the start of that phase

4 Abbreviated terms

APC-O Advanced Process Control and Optimization

MOM Manufacturing Operations Management

V&V Verification and Validation

5 Principle and purpose

5.1 Principle of verification and validation

This document provides a specification for both users and suppliers of the APC-O systems. The APC-O system that conforms to the specification will satisfy the customer requirements and facilitate the integration between different APC-O systems, as illustrated in Figure 1.

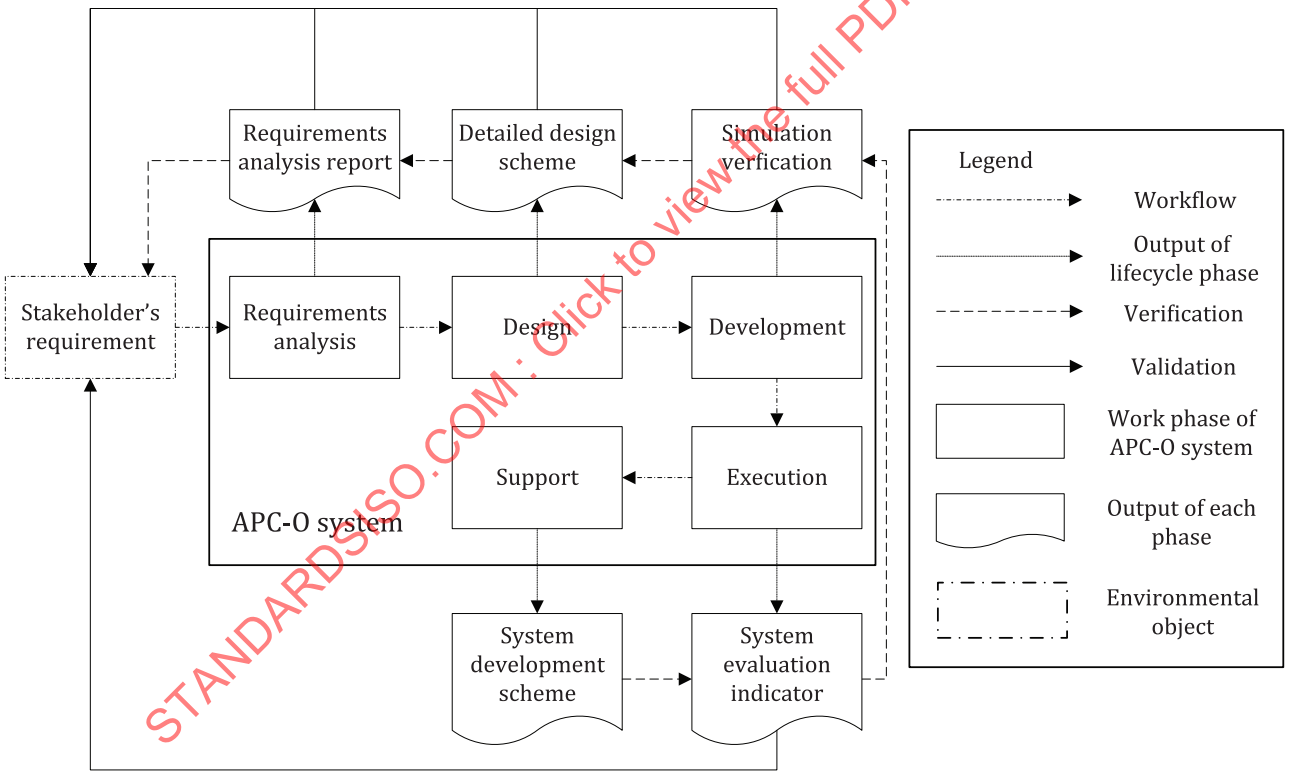

Figure 1 — Verification and validation of APC-O systems

Workflow: The workflow of an APC-O system relates to the phases of the lifecycle.

Output of lifecycle phase: Each work phase has an object.

Work phase: The lifecycle of an APC-O system consists of the following phases:

a) Requirements analysis;

b) Design;

c) Development;

d) Execution;

e) Support.

5.2 Structures of indicators

5.2.1 General

Both the quantitative indicators and the judgement indicators are expressed in the manner of the structure specified in ISO 22400-2. The structure identifies the descriptive element of indicator in the left column and gives a description of each element in the right column.

5.2.2 Structure of quantitative indicators

Table 1 presents an overview of the main elements of quantitative indicator structure.

Table 2 is an example of quantitative indicator.

Table 1 — Quantitative indicator structure

Name	Name of the indicator
ID	Unique identification
Description	A brief description of the indicator
Scope	The object that the indicator is used for, including the lifecycle phases or the elements/activities within a lifecycle phase
Formula	The mathematical formula of the indicator defined in terms of elements
Unit of measure	The basic unit or dimension of the indicator
Range	Defines the upper and lower logical limits of the indicator
Trend	The information that indicates the direction for improvement, e.g. if a higher or lower value is better
Audience	Users and providers of 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 government and academic organizations

Table 2 — Example of quantitative indicator

Name	Mean squared error (MSE)
ID	
Description	This checkpoint is used to describe the stable rate NOTE Definition of MSE
Formula	Mean[(SV – PV) ^2]
Unit of measure	%
Range	Min: 0 % Max: 100 %
Trend	The lower, the better
Audience	Engineers and operators of process

5.2.3 Structure of judgement indicator

Table 3 presents an overview of the main elements of judgement indicator structure.

Table 4 is an example of judgement indicator.

Table 3 — Judgement indicator structure

Name	Name of the indicator
ID	Unique identification
Description	A brief description of the indicator
Scope	Determine the object that the indicator is used for, which can be a lifecycle phase or the elements/activities within the lifecycle phase
Evaluation method	Check whether the object meets the desired requirements
Evaluation result	Pass or fail
Audience	Users and providers of 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 government and academic organizations

Table 4 — Example of judgement indicator

Name	Optimal scheme of realization of an APC-O project
ID	
Description	
Scope	Requirement analysis phase
Evaluation method	
Evaluation result	Pass or fail
Audience	Managers of the APC-O project

5.3 General process for verification and validation

The general process of verification and validation in the workflow of the APC-O system is illustrated in Figure 2.

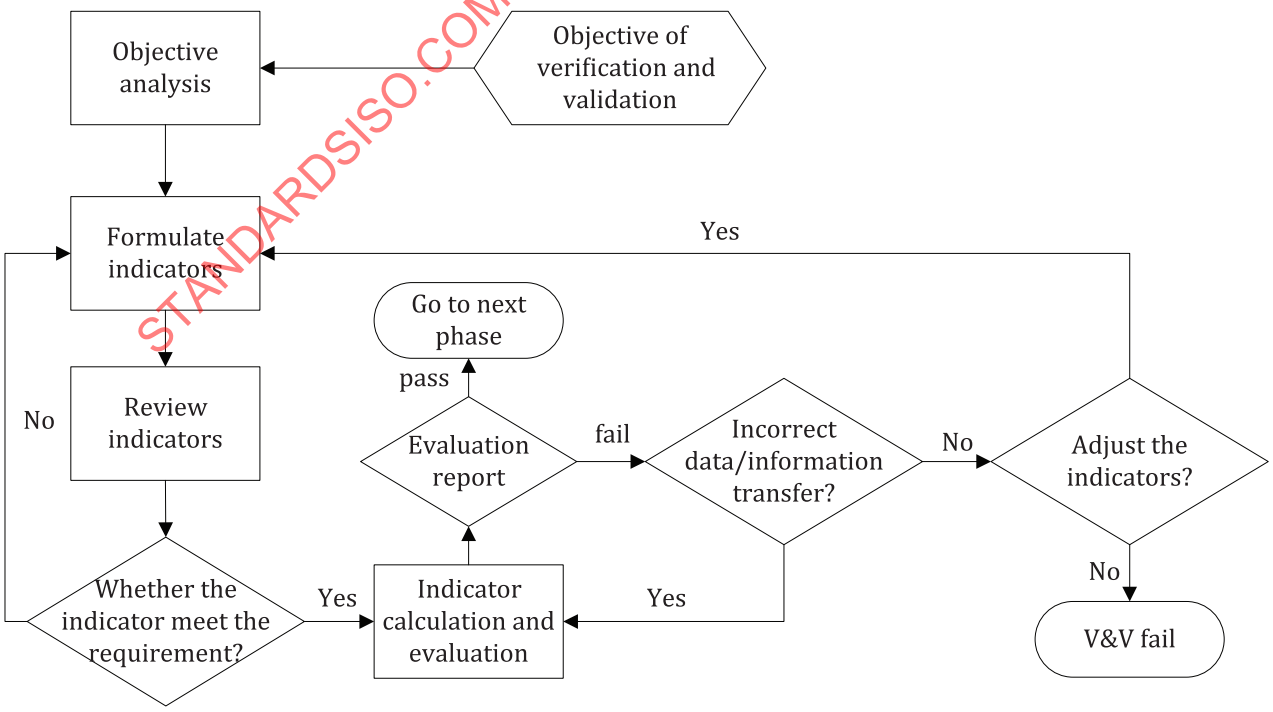

Figure 2 — General process for verification and validation

The aim of verification and validation is to check whether the work meets the needs of users.

a) Define the objective of V&V according to the users' requirements.

b) Analyse the objective and make sure that the objective applies to the work in this phase.

c) Define the indicators and the checkpoints, the applicable formula and the evaluation method in order to establish the checklist.

d) Review the indicators and the checkpoints to ensure that the checklist meets the requirements of V&V. Update the indicators and the checkpoints if necessary.

e) Calculate the indicators, evaluate the checkpoints according to the checklist, and generate the evaluation report.

f) Assess the evaluation report. There are three situations that indicate whether the evaluation report fails or passes:

   1) Errors have occurred during the process of indicator calculations and checkpoint evaluations, and modification is needed.

   2) The indicators and the checkpoints are not appropriate and need to be adjusted.

   3) The work in this phase does not meet the requirements, and modification is needed.

5.4 Verification

The verification process for lifecycle phases complies with the general method of verification process in 5.3.

5.5 Checkpoints in requirement analysis phase

Table 5 presents an overview of the checklist in the requirement analysis phase.

Tables 6 to 13 describe the indicators in the requirement analysis phase.

Table 5 — Checklist in requirement analysis phase

Number	Checkpoint	Name	ID	Evaluation result
1	Requirement analysis	Scope of application for APC-O system		
		Selection of APC-O modules		
		User's goal		
		Process description		
		Workflow		
		Planned coverage of APC-O modules		
		Planned return on investment		
		Planned implementation efficiency		

Table 6 — Scope of application for APC-O system

Name	Scope of application for the APC-O system
ID	
Description	Determine the scope of the APC-O system application based on stakeholders' requirements

Table 6 *(continued)*

Scope	Requirement analysis phase
Evaluation method	Check whether the scope of APC-O system application is consistent with requirements of stakeholders. EXAMPLE The object can be distribution column and absorption column. Q1: What part of the physical plant will the APC-O system be applied to? Answer to Q1: The APC-O system will be applied to distillation column and absorption column in this project. EXAMPLE The whole process includes totally five units according to the stakeholders' requirements, while only three out of the five units will be applied with APC-O system. This checkpoint is to check whether the determined three units have been correctly included.
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Manager of APC-O project

Table 7 — Selection of APC-O modules

Name	Selection of APC-O modules
ID	
Description	Specify the APC-O modules and the system structure
Scope	Requirement analysis phase
Evaluation method	Check whether the selected modules satisfy the stakeholder's requirement
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of APC-O project, engineers of process

Table 8 — User's goal

Name	User's goal
ID	
Description	Analyse and quantify the goal of the users
Scope	Requirement analysis phase
Evaluation method	Check whether the user's goal is clear and quantified
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Managers and Engineers of APC-O project

Table 9 — Process description

Name	Process description
ID	
Description	Specify the characteristics of the equipment and the process
Scope	Requirement analysis phase
Evaluation method	Check whether the characteristics of the equipment and the process are described clearly enough for the design of an APC-O system and whether the process description accurately describe the real process Check whether the relevant data is complete
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of the APC-O project, engineers of process

Table 10 — Workflow

Name	Workflow
ID	
Description	Specify the project implementation procedures.
Scope	Requirement analysis phase
Evaluation method	Check whether the project implementation procedure is confirmed by stakeholders
Evaluation result	Yes. Pass; no, fail
Audience	Managers and engineers of APC-O project

Table 11 — Planned coverage of APC-O modules

Name	Planned coverage of the APC-O modules (PCM)
ID	
Description	Number of the APC-O modules applied (NMA)/Total number of the APC-O modules (TNM) Q2: How many modules of the APC-O system will be used? Answer to Q2: could be one to many following APC-O modules: — Soft sensor module — APC module — Optimization module — Performance analysis module
Scope	Requirement analysis phase
Formula	PCM = (NMSA/TNM) * 100 %
Unit of measure	%
Range	0-100
Trend	The higher, the better
Audience	Managers and engineers of APC-O project

Table 12 — Planned return on investment

Name	Planned return on investment (PROI)
ID	
Description	Definition: Estimated increase in annual profit by implementing APC-O systems (EIAP)/cost of investment of APC-O systems (CIS) The inverse is called payback period, i.e. the length of time required to recover the cost of investment.
Scope	Requirement analysis phase
Formula	PROI = (EIAP/CIS) * 100 %
Unit of measure	%
Range	
Trend	The higher, the better
Audience	Manager of APC-O project

Table 13 — Planned implementation efficiency

Name	Planned implementation efficiency (PIE)
ID	

Table 13 *(continued)*

Description	Definition: Duration period for implementing APC-O systems/Total number of variables defined in this APC-O system NOTE Total number of variables defined in the APC-O system accounts for the APC-O system complexity
Scope	Requirement analysis phase
Formula	Planned implementation period of the APC-O system/Total number of variables defined in this APC-O system
Unit of measure	
Range	
Trend	The lower, the better
Audience	Managers of the APC-O project

5.6 Checkpoints of design phase

Table 14 presents an overview of the checklist in design phase.

Tables 15 to 18 describe the indicators in design phase.

Table 14 — Checklist in design phase

Number	Checkpoint	Name	ID	Evaluation result
1	Design	Requirement specification		
		Design for framework of system modules		
		Logic protection design		
		Ability to handle model mismatch		

Table 15 — Requirement specification

Name	Requirement specification
ID	
Description	Requirement specifications in design phase
Scope	Design phase
Evaluation method	Check whether the requirement specifications are provided
Evaluation result	Yes: pass; No: fail, to be modified.
Audience	Engineers and operators of process, engineers of APC-O project

Table 16 — Design for framework of system modules

Name	Design for framework of system modules
ID	
Description	Specify the APC-O modules
Scope	Design phase
Evaluation method	Check whether the design and integration of APC-O modules satisfy the requirements
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Manager of APC-O project

Table 17 — Logic protection design

Name	Logic protection design
ID	
Description	Undisturbed switch
Scope	Design phase
Evaluation method	Check whether the conversion between advanced process control and regular process control is available and functional
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of process, engineers of APC-O project

Table 18 — Ability to handle model mismatch

Name	Ability to handle model mismatch
ID	
Description	Evaluation of the robustness of controller
Scope	Design phase
Evaluation method	Evaluate whether system robustness is satisfactory
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineer of APC-O project

5.7 Checkpoints in development phase

Table 19 presents an overview of the checklist of development phase.

Tables 20 to 26 describe the indicators in development phase.

Table 19 — Checklist in development phase

Number	Checkpoint	Name	ID	Evaluation result
1	Module assembling	Historical data analysis		
		Step test design		
		Test result verification		
		Specification of definition of data information		
2	Module testing	System verification		
3	Component constructing	Data structure verification		
4	Module testing	Data structure verification		
5	Module downloading	Data structure verification		
		Verification of logic switch and protection mechanism		

Table 20 — Historical data analysis

Name	Historical data analysis
ID	
Description	Analysis of the historical data
Scope	Development phase: Module assembling

Table 20 *(continued)*

Evaluation method	Analyse historical data and check whether available data is sufficient to implement APC-O modules
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of the APC-O project

Table 21 — Step test design

Name	Step test design
ID	
Description	Design of step test
Scope	Development phase: Module assembling
Evaluation method	Check whether the design of step test is in accordance with safety and design requirements
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of APC-O project, engineers and operators of process

Table 22 — Specification of definition of data information

Name	Specification of definition of data information
ID	
Description	Validation of interaction information
Scope	Development phase: Module assembling
Evaluation method	Check whether the definition of interaction information conforms to specification. The specification could be standard specifications or user's specification.
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Application engineers of APC-O project, engineers of process

Table 23 — Test result verification

Name	Test result verification
ID	
Description	Verification of test result.
Scope	Development phase: Module assembling
Evaluation method	Check whether the test result satisfies the design requirements
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineer of APC-O project

Table 24 — System verification

Name	System verification
ID	
Description	Verification of simulation
Scope	Development phase: Module testing
Evaluation method	Check whether the system achieves the desired goals
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of the APC-O project

Table 25 — Data structure verification

Name	Data structure verification
ID	
Description	Verification of data structure
Scope	Development phase: Component constructing, Module testing, Module downloading
Evaluation method	Check whether the data structure meets the specification and satisfies the communication requirements between modules
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of the APC-O project

Table 26 — Verification of logic switch and protection mechanism

Name	Verification of logic switch and protection mechanism
ID	
Description	Verification of logic switch and protection mechanism
Scope	Development phase: Module downloading
Evaluation method	Test whether the logic switch and protection mechanism satisfy the design requirements
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers and operators of process

5.8 Checkpoints in execution phase

Table 27 presents an overview of the checklist in execution phase.

Tables 28 to 37 describe the indicators in execution phase.

Table 27 — Checklist in execution phase

Number	Checkpoint	Name	ID	Evaluation result
1	Module updating	Online simulation		
2	Runtime parameter setting	Online simulation		
		User training and confirmation		
		Specification of definition of data information		
		Data validity		
3	Task scheduling	Online simulation		
4	Executive management	User training and confirmation		
5	Module updating	User training and confirmation		
6	Module component set executing	Online simulation		
		Control system examination		
		Disturbance analysis		
		Supervisory control and alert of the key point		
7	Result set and signal set output	Emergency plan preparation		
		Specification of definition of data information		
		Data validity		

Table 27 *(continued)*

Number	Checkpoint	Name	ID	Evaluation result
8	Performance tracking and analysing	Specification of definition of data information		
		Data validity		
		APC-O running rate		
		Standard deviation of controlled variable (SDCV)		

Table 28 — Online simulation

Name	Online simulation
ID	
Description	Online simulation before commissioning
Scope	Execution phase: Module updating, Runtime parameter setting, Task scheduling, Module component set executing
Evaluation method	Simulate the system online and check whether each index achieves system design requirements, such as computing time of controller
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of the APC-O project

Table 29 — Control system examination

Name	Control system examination
ID	
Description	Examination of control system before commissioning
Scope	Execution phase: Module component set executing
Evaluation method	Check whether the system satisfies the requirements for development
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of the APC-O project

Table 30 — User training and confirmation

Name	User training and confirmation
ID	
Description	User training before commissioning
Scope	Execution phase: Executive management, Module updating, Runtime parameter setting
Evaluation method	Check whether the users are trained and capable of using the advanced control system correctly
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers and operators of process

Table 31 — Emergency plan preparation

Name	Emergency plan preparation
ID	
Description	Preparation for emergency plan
Scope	Execution phase: Result set and signal set output
Evaluation method	Check whether emergency plan is well prepared and working conditions are all included

Table 31 *(continued)*

Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of process, application engineers of APC-O project

Table 32 — Specification of definition of data information

Name	Specification of definition of data information
ID	
Description	Validation of interaction information
Scope	Execution phase
Evaluation method	Check whether the definition of interaction information conforms to specification. The specification could be standard specifications or user's specification.
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Application engineers of APC-O project, engineers of process

Table 33 — Data validity

Name	Data validity
ID	
Description	Verification of data
Scope	Execution phase: Runtime parameter setting, Result set and Signal set output, Performance tracking and analysing
Evaluation method	Check whether input data matches the process
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Application engineers of the APC-O project

Table 34 — Disturbance analysis

Name	Disturbance analysis
ID	
Description	Disturbance should be estimated and confirmed with the user
Scope	Execution phase: Module component set executing
Evaluation method	Check whether disturbance in implementation process is analysed and confirmed with the user, and relevant emergency plan is made
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Application engineers of the APC-O project

Table 35 — Supervisory control and alert of the key point

Name	Supervisory control and alert of the key point
ID	
Description	Supervisory control and alert of the key point would be conducive to reducing the operating cost
Scope	Execution phase: Module component set executing
Evaluation method	Check whether the monitoring system and the alert system function well
Evaluation result	Yes: pass; No: fail, to be modified
Audience	Engineers of process

Table 36 — APC-O running rate

Name	APC-O running rate (ART)
ID	
Description	Verification of system usage
Scope	Execution phase: Performance tracking and analysing
Formula	ARR = ART/PT ARR: APC-O running rate ART: APC-O running time PT: Production time
Unit of measure	%
Range	0~100
Trend	The higher, the better
Audience	Application engineers of APC-O project, managers of process

Table 37 — Standard deviation of controlled variable

Name	Standard deviation of controlled variable (SDCV)
ID	
Description	System control effort on controlled variable
Scope	Execution phase: Performance tracking and analysing
Formula	SDCV = Std(CV) CV: controlled variable
Unit of measure	%
Range	>0
Trend	The lower, the better
Audience	Application engineers of APC-O project, operators of process

5.9 Checkpoints in support phase

Table 38 presents an overview of the checklist in support phase.

Tables 39 to 42 describe the indicators in support phase.

Table 38 — Checklist in support phase

Number	Checkpoint	Name	ID	Evaluation result
1	Data acquisition and storage	Completeness of system data		
2	Performance evaluation	Problem confirmation		
3	Improvement type identifying	Solution verification		
		Improvement of ARR		
		Improvement of stable rate (ISR)		

Table 39 — Completeness of system data

Name	Completeness of system data
ID	
Description	Verification of system data completeness
Scope	Support phase: Data acquisition and storage