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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

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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.

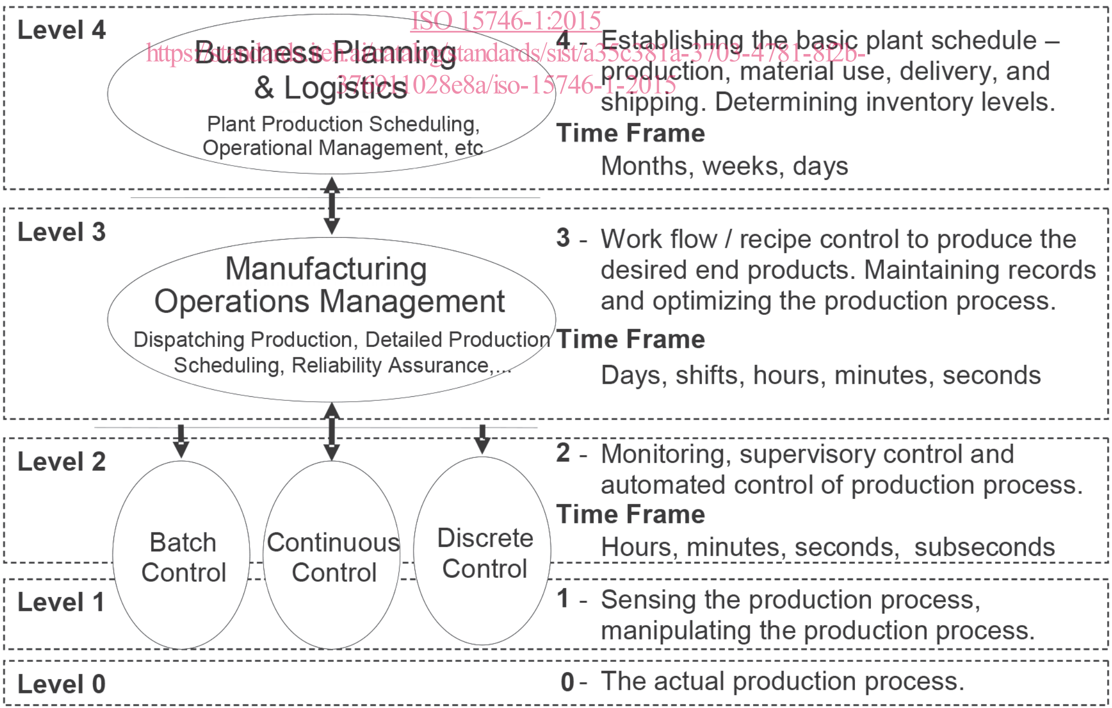

Figure 1 — Functional hierarchy

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.

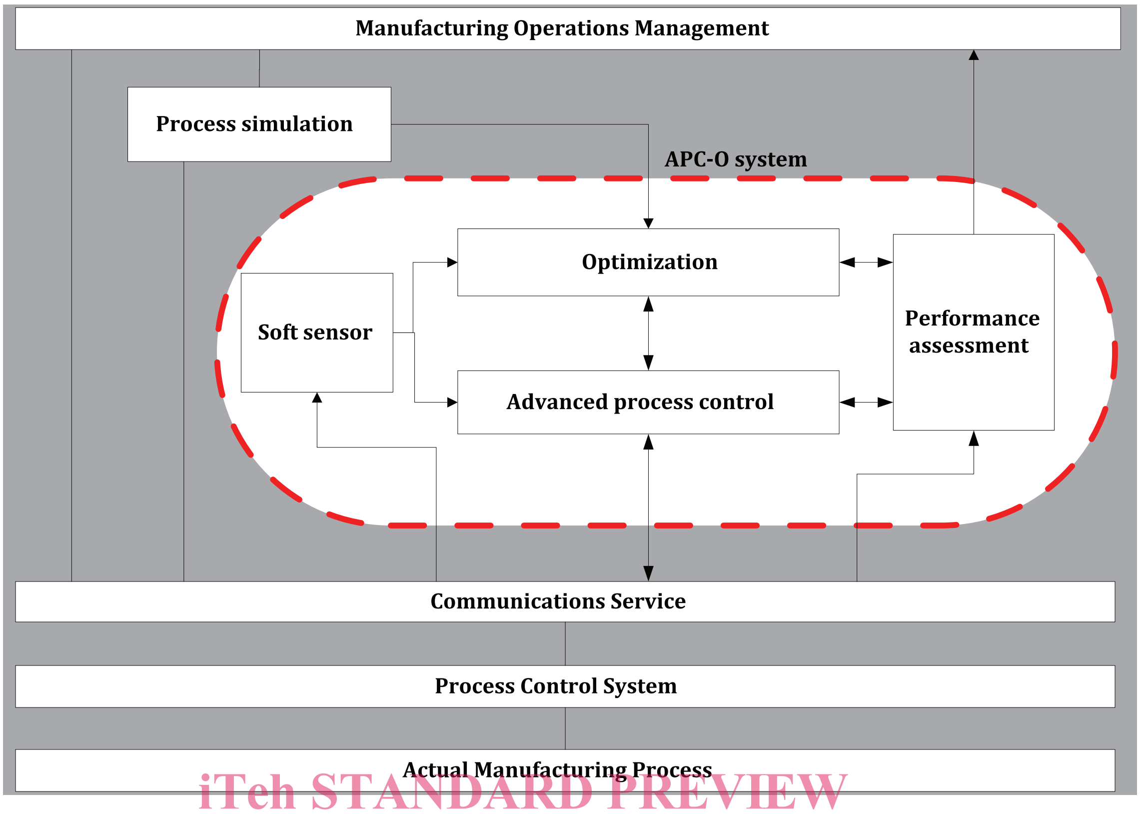

Figure 2 — Functional architecture of APC-O system

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

