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Industrial automation systems and integration — Formal semantic models for the configuration of global production networks

Systèmes d'automatisation industrielle et intégration — Modèles sémantiques formels pour la configuration des réseaux de production mondiaux

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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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This document was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 4, *Industrial data*.

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.

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Introduction

In reacting to change, competitive manufacturing industry aims to best understand the balance of possible options when making decisions on complex multi-faceted problems. Understanding how best to configure and re-configure a global production network, set against rapidly changing product-service requirements is one such complex problem area. Decisions consider multiple existing product and service variants, multiple new products and services to embrace the implications of new technological, economic, social, environmental and political requirements, and current production and service loads, as well as harmonizing and synchronizing production networks spread throughout the world, considering factors such as local supplier capabilities, transportation constraints, plant energy usage and production load forecasts.

While current Information and Communication Technology (ICT) tools play a significant role in support of such business development decisions, they need to do this in a well-integrated, trans-disciplinary way, with holistic solutions being critical to long-term competition (Huber 2014). Part of the solution to this problem lies in the exploitation of semantic technologies that provide a formal, logic base route to sharing meaning. This has been recognized as offering the potential to support interoperability across multiple related applications (Borgo et al. [23]; Chungoora et al. [24]). These provide formal, computer-based, methods of interpreting the meaning of concepts, their relationships to other concepts, and the constraints and rules that apply to their use.

The range of work in the use of formal semantics can be categorized into domain ontologies, foundation ontologies and reference ontologies. Domain ontologies tend to be limited to fairly narrow domains of applicability and so do not meet the holistic requirements mentioned above. Foundation ontologies are developed with a view to defining the semantics of everything but are too generic to offer positive constraints on any particular area of interest. The aim of reference ontologies for manufacture is to bridge the gap between these two and offer an effective support for interoperability, but in a targeted area or interest, i.e. in manufacturing. This document provides a contribution to such a manufacturing reference ontology by providing a formal semantic modelling approach to support the configuration of global production networks. It exploits the understanding gained from ISO 15531 and ISO 18629.

The manufacturing industry focus of this document is on how to design and configure a global production network (GPN) to produce and operate a new physical product or product-service. It does not address any operational aspects of production facilities, but rather models the flow relations between facilities in a production network. Future standards can build on this document to develop standard sematic models for in-factory systems.

The approach taken is based on exploiting the specialization capabilities of formal logic in order to progressively develop and constrain concepts and their relationships from foundation level descriptions to a level where the semantic models can be exploited by domain level software services and applications. The modelling approach starts from a systems functionality context as base from which to progressively represent global production systems, their relationships, constraints and related rules. The use of formal logic enables these semantic models to not only capture hierarchical relationships but also to capture and computationally exploit the constraints and rules that have been defined within these models.

The levels described in this document are different from the layered operational functionality of IEC 62264. The levels in this document are focused on levels of concept specialization. This starts from the key concepts from the context of any type of system through to specializations that are specific to manufacturing business systems. This is distinct from the layered operational functionality of IEC 62264, which is focused on the operational hierarchy of the business from higher-level production management down to shop floor.

This document uses some concepts that are common to supply chain models such as the Supply-Chain Operations Reference (SCOR) Model (Supply Chain Council 2014) and some concepts that follow from ISO 19440. SCOR is of limited relevance to this document as operational support is beyond its scope. Concepts from ISO 19440 have the greatest synergy with this document, which shares a business process oriented approach to enterprise modelling. While ISO 19440 provides model views to allow the identification of relevant object hierarchies and relationships between the different classes and

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subclasses, this document starts from a systems functionality context in order to build all subsequent hierarchies and relationships, including semantic constraints and rules.

This document is also distinct from the IEC/TR 62541 OPC Unified Architecture, although they both provide support to multi-vendor systems interoperability. IEC/TR 62541-1 provides a standard interface to facilitate the development of applications by multiple vendors that interoperate seamlessly together.

There are many semantic models that impinge on decision-making concerning the configuration and re-configuration of global production networks, as illustrated in Figure 1. This document provides the underpinning approach to the development of all of these models, but is necessarily focused on the production network concepts shown in Figure 1. Models of indicators, metrics, business, project, risk, location, scenario and product are therefore outside the scope of this document. The full value of this document can be gained through the development of future standards covering this full range of information, based on this document and drawing on existing standards in these areas wherever possible.

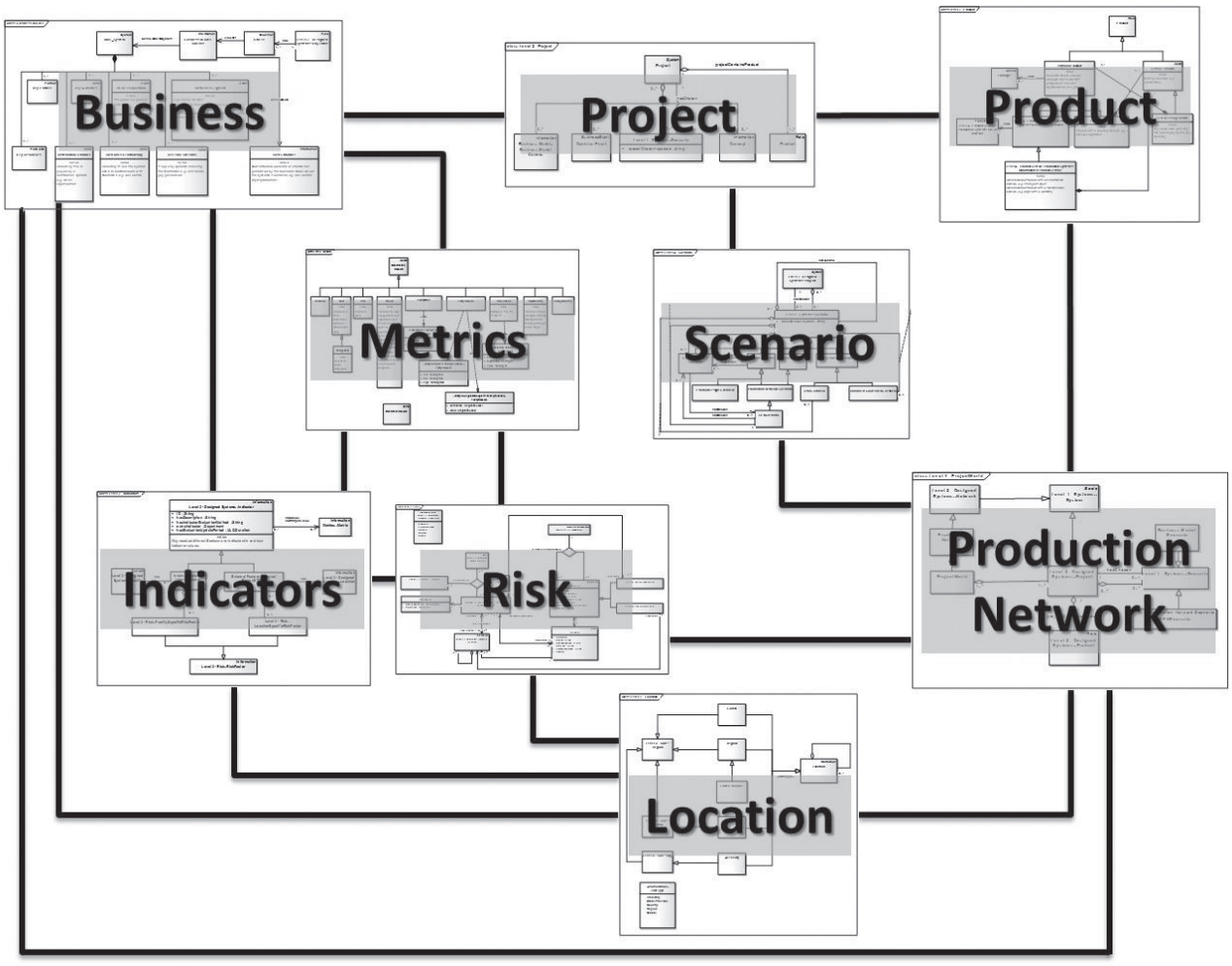

Figure 1 — Range of reference information needed to support production network configuration decisions

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Industrial automation systems and integration — Formal semantic models for the configuration of global production networks

1 Scope

This document specifies a formal logic-based concept specialization approach to support the development of manufacturing reference models that underpin the necessary business specific knowledge models needed to support the configuration of global production networks.

This document specifies the following:

— the formal sematic model approach;

— hierarchical levels for property specialization;

— contexts for each level;

— key properties at each level;

— property relationships;

— property axioms;

— applicability rules.

The following are within the scope of this document:

— production networks for discrete product manufacture;

— formal semantics for the configuration of global production networks;

— system level formal semantics;

— designed system formal semantics;

— manufacturing business system formal semantics;

— global production systems network formal semantics.

The following are outside the scope of this document:

— in-factory formal semantics;

— formal semantics for the operation of global production networks.

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.

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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
activity
function
function that transforms *inputs* (3.26) to *outputs* (3.38)

[SOURCE: ISO/IEC/IEEE 31320-1:2012, 2.1.53, modified — Adapted from definition of "function".]

3.2
actor
role (3.50) that is played by an *activity* (3.1)

Note 1 to entry: Actors are *processes* (3.41) that perform *functions* (3.1).

EXAMPLE A facility can act as a *supplier* (3.55), or as a *producer* (3.42), or as a *customer* (3.12).

3.3
axiom
well-formed formula in a formal *language* (3.28) that provides *constraints* (3.10) on the interpretation of symbols in the lexicon of a language

[SOURCE: ISO 18629-1:2004, 3.1.1]

3.4
basic
representation of an *entity* (3.19) or an *activity* (3.1)

Note 1 to entry: A basic requires no other concept to provide a *context* (3.11).

3.5
bill of materials
BOM
listing of all the subassemblies, parts and/or *materials* (3.30) that are used in the production of a *product* (3.43), including the quantity of each material required to make a product

Note 1 to entry: Adapted from IEC 62264-1:2013.

3.6
business event
event (3.20) that occurs in the business domain

3.7
business process
construct that represents a partially ordered set of business *processes* (3.41) or *enterprise* (3.18) *activities* (3.1), or both, that can be executed to realize one or more given objectives of an enterprise or a part of an enterprise to achieve some desired end-result

Note 1 to entry: Adapted from ISO 18629-1:2004.

3.8
cardinality
constraint (3.10) on the number of *entity* (3.19) *instances* (3.27) that are related to the subject entity through a *relationship* (3.47)

Note 1 to entry: Adapted from ISO/IEC 15474-1:2002, 4.2.

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3.9
control
condition or set of conditions required for a *function* (3.1) to produce correct *output* (3.38)

[SOURCE: ISO/IEC/IEEE 31320-1:2012, 2.1.32]

3.10
constraint
rule that specifies a valid condition of *data* (3.13)

[SOURCE: ISO/IEC/IEEE 31320-2:2012, 3.1.41 (B)]

3.11
context
immediate environment in which a *function* (3.1) operates

[SOURCE: ISO/IEC/IEEE 31320-1:2012, 2.1.30]

3.12
customer
organization or person that receives a *product* (3.43)

[SOURCE: ISO/IEC/IEEE 26511:2011, 4.6, modified — The words "or service" have been deleted at the end of the definition and the note to entry has been deleted.]

3.13
data
character strings, words or numbers without any given *context* (3.11)

3.14
date
string that specifies a date

Note 1 to entry: Aligned with the Highfleet Ontology Library Reference definition of "date" (see Annex A).

3.15
decision event
event (3.20) where decisions are made or taken

3.16
end event
end of a *process* (3.41) sequence

Note 1 to entry: A specialized type of *basic* (3.4) which has an *input* (3.26) *role* (3.50) only.

3.17
energy
quantity characterizing the ability of a *system* (3.56) to do work

[SOURCE: ISO 772:2011, 1.134]

3.18
enterprise
group of organizations sharing a set of goals and objectives to offer *products* (3.43), *services* (3.53) or both

[SOURCE: ISO 14258:1998, 2.1.1]

3.19
entity
concrete or abstract thing in the domain under consideration

[SOURCE: ISO 19439:2006, 3.29]

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3.20
event
construct that represents a solicited or unsolicited fact indicating a state change in the *enterprise* (3.18) or its environment

Note 1 to entry: Aligned with the Highfleet Ontology Library Reference definition of "event" (see Annex A).

[SOURCE: ISO 19440:2007, 3.1.33], modified — Original note to entry has been replaced by a new note to entry.

3.21
facility function
function (3.1) in an organization that performs one or more specific *activities* (3.1) by the provision of *resources* (3.49) in a given global *location* (3.29)

3.22
flow
relationship (3.47) from an *input* (3.26) to an *output* (3.38) or from an output to an input

Note 1 to entry: This is consistent with the Athena[28] definition: a flow is a relationship between two decision points: *process* (3.41) *roles* (3.50) [input, output, *control* (3.9), or *resource* (3.49)] or *gateways* (3.23) in a process.

3.23
gateway
element used to control how *process* (3.41) *flows* (3.22) interact as they converge and diverge within a *network* (3.35)Note 1 to entry: Adapted from Object Management Group[33] .

3.24
global production network
GPN
specialization of a *production network* (3.44), which contains *roles* (3.50) played by globally dispersed facilities

3.25
information
data (3.13) put in *context* (3.11)

EXAMPLE Facts, concepts, or instructions.

[SOURCE: ISO 10303-1:1994, 3.2.20, modified — The original definition is given as an example and a new definition has been provided.]

3.26
input
that which is transformed by an *activity* (3.1) into *output* (3.38)

[SOURCE: ISO/IEC/IEEE 31320-1:2012, 2.1.62, modified — The words "a function" have been replaced by "an activity".]

3.27
instance
individual occurrence of a *property* (3.46)

Note 1 to entry: This is distinct from the ":Inst" directive, which states what a property instantiates (see B.2.3).

Note 2 to entry: Adapted from ISO/IEC 15474-1:2002, 4.2.

3.28
language
combination of a lexicon and a grammar

[SOURCE: ISO 18629-1:2004, 3.1.12]

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3.29
location
site or position

3.30
material
representation of an *entity* (3.19) that is comprised of physical materials

3.31
manufacturer
business *enterprise* (3.18) that is involved in the full *product* (3.43) life cycle

Note 1 to entry: The product life cycle includes the product design, production, operation and end of life phases.

3.32
manufacturing
function (3.1) or act of converting or transforming *material* (3.30) from raw material or semi-finished state to a state of further completion

[SOURCE: ISO 15531-1:2004, 3.6.22, modified — Note to entry has been deleted.]

3.33
manufacturing network
network (3.35) which is concerned with full life cycle of a *manufactured product* (3.34)

Note 1 to entry: The life cycle of a manufactured product includes the design, production, operation and end of life phases.

3.34
manufactured product
product (3.43) that exploits/consumes a raw *material* (3.30)

3.35
network
arrangement of nodes and interconnecting branches

[SOURCE: ISO/IEC 2382:2015, 2121314, modified — Notes to entry have been deleted.]

3.36
ontology
logical structure of the terms used to describe a domain of knowledge, including both the definitions of the applicable terms and their *relationships* (3.47)

[SOURCE: IEEE 1175-1:2002, 3.9]

3.37
organization function
key *function* (3.1) that an *enterprise* (3.18) provides

3.38
output
that which is produced by an *activity* (3.1)

[SOURCE: ISO/IEC/IEEE 31320-1:2012, 2.1.89, modified — The words “a function” have been replaced by “an activity”.]

3.39
physical product
entity (3.19) that plays the *role* (3.50) of a *product* (3.43)

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3.40
plan
account of intended future course of action aimed at achieving specific goal(s) or objective(s) within a specific timeframe

3.41
process
structured set of *activities* (3.1), involving various *enterprise* (3.18) *entities* (3.19), that is designed and organized for a given purpose

[SOURCE: ISO 15531-1:2004, 3.6.29, modified — Note to entry has been deleted.]

3.42
producer
business *enterprise* (3.18) that produces goods or *services* (3.53) for sale

3.43
product
role (3.50) played by an *entity* (3.19) or *service* (3.53), or some combination of both, that is developed to be sold

3.44
production network
specialization of a *manufacturing network* (3.33) which is concerned with producing a *product* (3.43)

3.45
project
planned undertaking with specified targets

3.46
property
class
predicate that can apply to one *entity* (3.19) at a time and is used describe what the entity is

Note 1 to entry: Properties make up the taxonomic component of the *ontology* (3.36).

Note 2 to entry: The term "property" is used because the ontologies are semantic (modelling meaning) rather than set-theoretical (modelling categorizations).

3.47
relationship
real-world association among one or more *entities* (3.19)

Note 1 to entry: Adapted from ISO/IEC 15474-1:2002, 4.2.

3.48
requirement
condition or capability to be met or possessed by a *system* (3.56), *product* (3.43), *service* (3.53), result, or component to satisfy a contract, standard, specification, or other formally imposed document

Note 1 to entry: Adapted from Project Management Institute[34] .

3.49
resource
means used by an *activity* (3.1) to transform *input* (3.26) into *output* (3.38)

[SOURCE: ISO/IEC/IEEE 31320-1:2012, 2.1.71, modified — Adapted from definition of "mechanism", and the words "a function" have been replaced by "an activity".]

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3.50
role
part played by a *basic* (3.4) in an *activity* (3.1)

Note 1 to entry: A role cannot exist without a *context* (3.11).

Note 2 to entry: A *system* (3.56) provides a context for the roles it contains.

Note 3 to entry: To aid efficiency all roles are declared as pairwise disjoint.

Note 4 to entry: A basic can play more than one role.

3.51
semantics
meaning of the syntactic components of a *language* (3.28)

[SOURCE: ISO/IEC/IEEE 31320-2:2012, 3.1.175]

3.52
scenario
representation of a specific potential or actual configuration to achieve the functionality of a *system* (3.56)

Note 1 to entry: Different scenarios allow for different what-if analyses to be performed.

3.53
service
system (3.56) *function* (3.1) that plays the *role* (3.50) of a *product* (3.43)

3.54
start event
start of a *process* (3.41) sequence

Note 1 to entry: A specialized type of *basic* (3.4) which has an *output* (3.38) *role* (3.50) only.

3.55
supplier
facility in an organization that enters into an agreement with the acquirer for the supply of a *product* (3.43)

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.45, modified — The words “organization or an individual” have been replaced by “facility in an organization”, the words “or service” have been deleted at the end of the definition and the notes to entry have been deleted.]

3.56
system
combination of interacting *resources* (3.49) organized to achieve one or more stated purposes

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.46, modified — The word “elements” has been replaced by “resources” and the notes to entry have been deleted.]

3.57
system function
activity (3.1) in a *system* (3.56) that transforms an *input* (3.26) set of elements into a set of *output* (3.38) elements

3.58
timespan
period of time with a start date and an end date where *date* (3.14) can be specified down to fractions of second

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