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Industrial automation systems and integration — Process specification language —

Part 14: **Resource theories**

Systèmes d'automatisation industrielle et intégration — Langage de spécification de procédé —

Partie 14: Théories de ressource

Reference number
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Foreword

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Attention is drawn to the possibility that some of the elements of this part of ISO 18629 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 18629-14 was prepared by Technical Committee ISO/TC 184, *Industrial automation systems and integration,* Subcommittee SC4, *Industrial data.*

A complete list of parts of ISO 18629 is available from the Internet.

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Introduction

ISO 18629 is an International Standard for the computer-interpretable exchange of information related to manufacturing processes. Taken together, all the parts contained in the ISO 18629 Standard provide a generic language for describing a manufacturing process throughout the entire production process within the same industrial company or across several industrial sectors or companies, independently from any particular representation model. The nature of this language makes it suitable for sharing process information related to manufacturing during all the stages of a production process.

This part of ISO 18629 provides a description of the core elements of the language defined within ISO 18629.

All parts of ISO 18629 are independent of any specific process representation or model proposed in a software application in the domain of manufacturing management. Collectively, they provide a structural framework for improving the interoperability of these applications.

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Industrial automation systems and integration — Process specification language —

Part 14:
Resource theories

1 Scope

This part of ISO 18629 provides a representation of the concepts that belong to the outer core of the language, through a set of axioms and definitions. These axioms provide an axiomatization of the semantics for terminology in this part of ISO 18629.

The following is within the scope of this part of ISO 18629:

— resource;

— relationships between resources and activities;

— resource sets;

— additive quantities.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 8824-1: *Information technology — Abstract Syntax Notation One (ASN.1) — Part 1: Specification of basic notation.*

ISO 15531-1: *Industrial automation systems and integration — Industrial manufacturing management data — Part 1: General overview.*

ISO 18629-1 : *Industrial automation systems and integration — Process specification language — Part 1: Overview and basic principles.*

ISO 18629-11: 2005, *Industrial automation systems and integration — Process specification language — Part 11:PSL-core.*

ISO 18629-12 : *Industrial automation systems and integration — Process specification language — Part 12:PSL Outer core.*

3 Terms, definitions, and abbreviations

3.1 Terms and definitions

For the purpose of this document, the following terms and definitions apply:

3.1.1
axiom
well-formed formula in a formal language that provides constraints on the interpretation of symbols in the lexicon of a language

[ISO 18629-1]

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3.1.2
defined lexicon
set of symbols in the non-logical lexicon which denote defined concepts

NOTE Defined lexicon is divided into constant, function and relation symbols.

EXAMPLE terms with conservative definitions.

[ISO 18629-1]

3.1.3
definitional extension
extension of PSL-Core that introduces new linguistic items which can be completely defined in terms of the PSL-Core

NOTE: Definitional extensions add no new expressive power to PSL-Core but are used to specify the semantics and terminology in the domain application.

[ISO 18629-1]

3.1.4
extension
augmentation of PSL-Core containing additional axioms

NOTE 1 The PSL-Core is a relatively simple set of axioms that is adequate for expressing a wide range of basic processes. However, more complex processes require expressive resources that exceed those of the PSL-Core. Rather than clutter the PSL-Core itself with every conceivable concept that might prove useful in describing one process or another, a variety of separate, modular extensions need to be developed and added to the PSL-Core as necessary. In this way a user can tailor the language precisely to suit his or her expressive needs.

NOTE 2 All extensions are core theories or definitional extensions.

[ISO 18629-1]

3.1.5
grammar
specification of how logical symbols and lexical terms can be combined to make well-formed formulae

[ISO 18629-1]

3.1.6
language
combination of a lexicon and a grammar

[ISO 18629-1]

3.1.7
lexicon
set of symbols and terms

NOTE The lexicon consists of logical symbols (such as Boolean connectives and quantifiers) and non-logical symbols. For ISO 18629, the non logical part of the lexicon consists of expressions (constants, function symbols, and relation symbols) chosen to represent the basic concepts of the ontology.

[ISO 18629-1]

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3.1.8
manufacturing
function or act of converting or transforming material from raw material or semi-finished state to a state of further completion

[ISO 15531-1]

3.1.9
manufacturing process
structured set of activities or operations performed upon material to convert it from the raw material or a semifinished state to a state of further completion

NOTE Manufacturing processes may be arranged in process layout, product layout, cellular layout or fixed position layout. Manufacturing processes may be planned to support make-to-stock, make-to-order, assemble-to-order, etc., based on strategic use and placements of inventories.

[ISO 15531-1]

3.1.10
primitive concept
lexical term that has no conservative definition

[ISO 18629-1]

3.1.11
primitive lexicon
set of symbols in the non-logical lexicon which denote primitive concepts

NOTE Primitive lexicon is divided into constant, function and relation symbols.

[ISO 18629-1]

3.1.12
process
structured set of activities involving various enterprise entities, that is designed and organised for a given purpose

NOTE The definition provided here is very close to that given in ISO 10303-49. Nevertheless ISO 15531 needs the notion of structured set of activities, without any predefined reference to the time or steps. In addition, from the point of view of flow management, some empty processes may be needed for a synchronisation purpose although they are not actually doing anything (ghost task).

[ISO 15531-1]

3.1.13
resource
any device, tool and means at the disposal of the enterprise to produce goods or services

NOTE 1 Adapted from ISO 15531-1, so that resources as defined in ISO 15531-1 except raw material, products and components that are considered from a system theory point of view as parts of the environment of the system and do not belong to the system itself. Furthermore This definition includes ISO 10303-49 definition but is included in the definition that applies for ISO 18629-14 and ISO 18629-44 that also include raw materials and consumables as well as ISO 18629-13.

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NOTE 2 Resources as they are defined here include human resources considered as specific means with a given capability and a given capacity. Those means are considered as being able to be involved in the manufacturing process through assigned tasks. That does not include any modelling of an individual or common behaviour of human resource excepted in their capability to perform a given task in the manufacturing process (e.g.: transformation of raw material or component, provision of logistic services). That means that human resources are only considered, as the other, from the point of view of their functions, their capabilities and their status (e.g.: idle, busy). That excludes any modelling or representation of any aspect of individual or common «social» behaviour.

[ISO 15531-1]

3.1.14
theory
set of axioms and definitions that pertain to a given concept or set of concepts

NOTE this definition reflects the approach of artificial intelligence in which a theory is the set of assumptions on which the meaning of the related concept is based.

[ISO 18629-1]

3.2 Abbreviations

For the purpose of this part of ISO 18629, the following abbreviations apply:

FOL First-Order Logic

BNF Backus-Naur form

KIF Knowledge Interchange Format

PSL Process Specification Language

4 General information on ISO 18629

ISO 18629 specifies a language for the representation of process information, which is a process specification language. It is composed of a lexicon, an ontology, and a grammar for process descriptions.

NOTE 1 PSL is a language for specifying manufacturing processes based on a mathematically well defined vocabulary and grammar. As such, it is different from other languages such as EXPRESS (defined in ISO 10303-11) and used for example in ISO 10303-41, ISO 10303-42, ISO 10303-49, ISO 13584, ISO 15531 and ISO 15926, that are modelling languages. In the context of an exchange of information between two processes, PSL specifies each process independently of its behaviour. For example, an object viewed as a resource within one process can be recognised as the same object even though it is viewed as a product within a second process.

NOTE 2 PSL is based on Mathematical Set Core theory and Situation Calculus (see annex B). As such it follows a significantly different method of description from the method used by existing languages defined in ISO 10303. The meaning of the concepts within PSL follows from a set of axioms and supporting definitions rather than from a formal set of defined terms. A set of supporting notes and examples are provided to aid the understanding of the primitive lexicon of the language.

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The parts 11 to 19 of ISO 18629[1] specify core theories needed to give precise definitions and the axioms of the primitive concepts of ISO 18629, thus enabling precise semantic translations between different schemes.

The following are within the scope of parts 11 to 19 of ISO 18629:

— the representation of the basic elements of the language;

— standardized sets of axioms that correspond to intuitive semantic primitive concepts adequate to describe basic processes;

— the set of rules to develop other core theories or extensions in compliance with PSL-Core.

The following is outside the scope of parts 11 to 19 of ISO 18629:

— the representation of information involving concepts that are not part of core theories.

5 Organization of this part of ISO 18629

The core theories in this part of ISO 18629 are:

— Resource requirements theory (requires.th);

— Resource set theory (res_set.th);

— Additive quantity theory (additive.th).

All theories in this part of ISO 18629 are extensions of ISO 18629-12 and ISO 18629-11. The Resource set theory is an extension of the Resource requirements theory.

6 Resource requirements theory

This core theory provides axioms for characterizing resource requirements. The notion of resource is a relation between an object and an activity – an object is a resource if it is required by some activity.

NOTE The notion of resource here, that in fact is related to resource requirement, is basically different from the notion of resources from ISO 15531 that in conformity with the system theory excludes raw material , component and final product, that are transformed by the system. Then raw material, components, final products are not part of the system itself. They are part of its environment. Furthermore, in ISO 15531, a resource is defined independently of any activity (that is especially true for human resources) and is related to a given activity only in the framework of the system described, when the resource becomes the physical system in charge of the activity it has to perform. Before its participation in the system a resource is just idle and available for any kind of activity its able to perform. A Human resource may participate in a milling system on Monday and participate in a carrying system on Tuesday, or wait for any activity on Wednesday. See annex D of ISO 15531-31.

6.1 Primitive relations of the Resource requirements theory

The nonlogical lexicon of the Resource requirements theory contains one primitive relation symbol:

— requires.

[1] Certain parts are under development.

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6.2 Primitive functions of the Resource requirements theory

The nonlogical lexicon of the Resource requirements theory contains three primitive function symbols:

— resource_point;

— demand;

— agg_demand.

6.3 Defined relations of the Resource requirements theory

The nonlogical lexicon of the Resource requirements theory contains one defined relation symbol:

— resource.

6.4 Core theories required by Resource requirements theory

This theory requires the following core theories:

— additive.th;

— act_occ.th;

— complex.th;

— subactivity.th;

— occtree.th;

— disc_state.th;

— psl_core.th.

6.5 Definitional extensions required by Resource requirements theory

No definitional extensions are requires by the Resource requirements theory.

6.6 Informal Semantics of the Resource Requirements theory

6.6.1 requires

KIF notation for res_requires:

(res_requires ?a ?r)

Informal semantics for res_requires:

(res_requires ?a ?r) is TRUE in an interpretation of Resource Requirements theory if and only if ?r is an object that participates in an occurrence of the activity ?a such that ?r constrains the activities that contain ?a as a subactivity.

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6.6.2 resource_point

KIF notation for resource_point:

(resource_point ?r ?s)

Informal semantics for resource_point:

(= ?q (resource_point ?r ?s) is TRUE in an interpretation of Resource Requirements theory if and only if ?q is the quantity of the resource ?r that is available for the atomic activity occurrence ?s.

NOTE: The resource_point function takes an activity occurrence as an argument. Since activity occurrences have unique beginof and endof timepoints, temporal constraints on resource properties can be expressed by using the time interval over which the activity occurs.

6.6.3 demand

KIF notation for demand:

(demand ?r ?s)

Informal semantics for demand:

(= ?q (demand ?r ?s)) is TRUE in an interpretation of Resource Requirements theory if and only if ?q is the quantity of the resource ?r that is associated with the atomic activity occurrence ?s.

NOTE: The demand function takes an activity occurrence as an argument. Since activity occurrences have unique beginof and endof timepoints, temporal constraints on resource properties can be expressed by using the time interval over which the activity occurs.

6.6.4 agg_demand

KIF notation for agg_demand:

(agg_demand ?r ?s)

Informal semantics for agg_demand:

(= ?q (agg_demand ?r ?s)) is TRUE in an interpretation of Resource Requirements theory if and only if ?q is the total demand for the resource ?r prior to the atomic activity occurrence ?s.

NOTE: The agg_demand function takes an activity occurrence as an argument. Since activity occurrences have unique beginof and endof timepoints, temporal constraints on resource properties can be expressed by using the time interval over which the activity occurs.

6.6.5 resource

KIF notation for resource

(resource ?r)

Informal semantics for resource:

(resource ?r) is TRUE in an interpretation of Resource Requirements theory if and only if there exists an activity that requires ?r.

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6.7 Definitions in the Resource Requirements theory

6.7.1 Definition 1:

A resource is any object which is required by some activity occurrence.

```
(forall (?r) (iff (resource ?r)
    (and      (object ?r)
              (exists (?a)
                      (res_requires ?a ?r))))
```

6.8 Axioms of the Resource Requirements theory

6.8.1 Axiom 1

A resource is available for an activity iff the available quantity of the resource for the activity exceeds the difference between the quantity of the resource point and the sum of the aggregate demand for the resource and the demand for the resource by the activity.

```
(forall (?a ?a1 ?r ?s)
(implies  (and   (res_requires ?a ?r)
                 (subactivity ?a1 ?a)
                 (atomic ?a1))
          (iff  (and     (greater (resource_point ?r ?s)
                         (agg_demand ?r ?s))
                         (greater (agg_demand ?r ?s) zero_quantity))
                         (exists (?occ ?occ1)
                                 (and     (occurrence ?occ ?a)
                                          (occurrence ?occ1 ?a1)
                                 (subactivity_occurrence ?occ1 ?occ))))))
```

6.8.2 Axiom 2

An atomic activity res_requires an activity if and only if its demand for a resource is nonzero.

```
(forall (?r ?a ?s)
    (implies  (and  (atomic ?a)
                    (occurrence ?s ?a))
         (iff  (res_requires ?a ?r)
               (not (= (demand ?r ?s) zero_quantity)))))
```

6.8.3 Axiom 3

The demand of a concurrent superposition of activities for a resource is the sum of the demand of all of its subactivities for the resource.

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(forall (?a1 a2 ?r ?s)

(= (demand (?r (successor (conc ?a1 ?a2) ?s))

(quantity_plus (demand ?r (successor ?a1 ?s)) (demand ?r (successor ?a2 ?s)))))

6.8.4 Axiom 4

The aggregation of demand for a resource is the sum of demand by all activities that res_requires the resource.

(forall (?a ?r ?s)

(= (agg_demand ?r (successor ?a ?s))

(quantity_plus (agg_demand ?r ?s) (demand ?r (successor ?a1 ?s)))))

6.8.5 Axiom 5

The functions resource_point, demand, and agg_demand, all map resources to additive quantities at every activity occurrence.

(forall (?r ?s)

(iff (and (resource ?r)

(activity_occurrence ?s))

(and (additive (resource_point ?r ?s))

(additive (demand ?r ?s))

(additive (agg_demand ?r ?s)))))

7 Resource set theory

This theory characterizes the aggregation of resources into sets. Resource sets are sets whose elements are resources and which are themselves resources for some activity. This is denoted by the fluent function (resource_set ?i ?r), which associates the set ?i with the resource ?r. The actual set associated with the resource may change, as new resources are added or removed. Each resource that is a resource set is associated with a unique set of resources.

7.1 Primitive functions of Resource set theory

The nonlogical lexicon of Resource set theory contains one primitive function symbol:

— resource_set.

7.2 Defined functions of Resource set theory

The nonlogical lexicon of Resource set theory contains two defined function symbol:

— in_resource_set;

— resource_subset.

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7.3 Core theories required by Resource set theory

The Resource set theory requires the following core theories:

— additive.th;

— requires.th;

— act_occc.th;

— complex.th;

— subactivity.th;

— occtree.th;

— disc_state.th;

— psl_core.th.

.

7.4 Definitional extensions required by Resource set theory

No definitional extensions are required by the Resource set theory.

7.5 Informal semantics of the Resource set theory

7.5.1 resource_set

KIF notation for resource_set :

(resource_set ?i ?r)

Informal semantics for resource_set :

(prior (resource_set ?i ?r) ?occ) is TRUE in an interpretation of the Resource Set theory if and only if the set ?i associated with the resource ?r prior to the activity occurrence ?occ.

7.5.2 in_resource_set

KIF notation for in_resource_set:

(in_resource_set ?r1 ?r2)

Informal semantics for in_resource_set:

(prior (in_resource_set ?r1 ?r2) ?occ) is TRUE in an interpretation of the Resource Set theory if a resource ?r1 is an element of the set associated with ?r2 prior to activity occurrence ?occ.

7.5.3 resource_subset

KIF notation for resource_subset:

(resource_subset ?r1 ?r2)

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Informal semantics for resource_subset:

(prior (resource_subset ?r1 ?r2) ?occ) is TRUE in an interpretation of the Resource Set theory if and only if the resource set ?r1 is a resource subset of a resource set ?r2 (that is, every element of the set associated with ?r1 is an element of the set associated with ?r2) prior to activity occurrence ?occ.

7.6 Axioms for the Resource set theory

The set of axioms in the Resource set theory is as follows:

7.6.1 Axiom 1

If ?i is a resource set prior to an activity occurrence ?occ, then for every element of the set, there exists an activity that res_requires the element as a resource.

```
(forall (?i ?r ?occ)
    (implies    (prior (resource_set ?i ?r) ?occ)
                (forall (?rp)
                (implies  (set_member ?rp ?i)
                                (exists (?a)
                                        (res_requires ?a ?rp)))))))
```

7.6.2 Axiom 2

A resource set is required by the same activities that res_requires the elements of the resource set.

```
(forall (?i ?r1 ?r2 ?a ?occ)
    (implies    (and     (prior (resource_set ?i ?r1) ?occ)
                (set_member ?r2 ?i)
                (res_requires ?a ?r2))
                (res_requires ?a ?r1)))
```

7.6.3 Axiom 3

A resource set corresponds to a unique set of resources.

```
(forall (?i1 ?i2 ?r ?occ)
    (implies  (and       (prior (resource_set ?i1 ?r) ?occ)
                (prior (resource_set ?i2 ?r) ?occ))
          (= ?i1 ?i2))))
```

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7.7 Definitions for the Resource set theory

7.7.1 Definition 1

A resource ?r1 is in the resource set ?r2 iff ?r1 is an element of the set ?i associated with ?r2.

```
(forall (?r1 ?r2 ?occ)
    (iff   (holds (in_resource_set ?r1 ?r2) ?occ)
        (exists (?i)
            (and   (set_member ?r1 ?i)
                (holds (resource_set ?i ?r2) ?occ))))))
```

7.7.2 Definition 2

A resource set ?r1 is a resource subset of a resource set ?r2 iff every element of the set associated with ?r1 is an element of the set associated with ?r2.

```
(forall (?r1 ?r2 ?occ)
    (iff   (holds (resource_subset ?r1 ?r2) ?occ)
        (forall (?r ?i1 ?i2)
            (and   (holds (resource_set ?i1 ?r1) ?occ)
                (holds (resource_set ?i2 ?r2) ?occ)
                (set_member ?r ?i1))
            (set_member ?r ?i2)))))
```

8 Additive quantities theory

The structure of Additive quantities theory is equivalent to the mathematical structure of ordered commutative group.

8.1 Primitive categories in the Additive quantities theory

The nonlogical lexicon of the Additive quantities theory contains one primitive category:

— additive.

8.2 Primitive functions in the Additive quantities theory

The nonlogical lexicon of Additive quantities theory contains one primitive function symbol:

— plus.

8.3 Primitive constants in the Additive quantities theory

The nonlogical lexicon of Additive quantities theory contains one primitive constant symbols:

— zero_quantity.

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8.4 Primitive relations in the Additive quantities theory

The nonlogical lexicon of Additive quantities theory contains one primitive relation symbol:

— greater.

8.5 Core theories required by Additive quantities theory

The Additive quantities theory requires the following core theories:

— psl-core.th.

8.6 Informal Semantics of the Additive Quantities theory

8.6.1 additive

KIF notation for additive:

(additive ?q)

Informal semantics for additive:

(additive ?q) is TRUE in an interpretation of the Additive Quantities theory if and only if ?q is an element of an ordered group.

8.6.2 plus

KIF notation for plus :

(plus ?q1 ?q2)

Informal semantics for plus :

(= ?q3 (plus ?q1 ?q2)) is TRUE in an interpretation of the Additive Quantities theory if and only if.?q3 is the sum of ?q1 and ?q2 within the ordered group.

8.6.3 zero_quantity

KIF notation for zero_quantity :

zero_quantity

Informal semantics for plus :

(= ?q zero_quantity) is TRUE in an interpretation of the Additive Quantities theory if and only if zero_quantity is the identity of the ordered group.

8.6.4 greater

KIF notation for greater :

(greater ?q1 ?q2)

Informal semantics for greater :

(greater ?q1 ?q2) is TRUE in an interpretation of the Additive Quantities theory if and only if. ?q1 is greater than ?q2 within the ordered group.

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8.7 Axioms for the Additive Quantities theory

The set of axioms in the Additive Quantities theory is as follows:

8.7.1 Axiom 1

The element zero_quantity is additive.

```
(additive zero_quantity)
```

8.7.2 Axiom 2

The sum of any two additive elements is also additive.

```
(forall (?q1 ?q2)
    (implies  (and  (additive ?q1)
                (additive ?q2))
            (additive (quantity_plus ?q1 ?q2))))
```

8.7.3 Axiom 3

The quantity_plus function is associative.

```
(forall (?q1 ?q2 ?q3)
    (implies  (and  (additive ?q1)
                (additive ?q2)
                (additive ?q3))
            (= (quantity_plus (?q1 ?q2) ?q3) (quantity_plus (quantity_plus (?q1 ?q2) ?q3)))
```

8.7.4 Axiom 4

Zero_quantity is the identity element.

```
(forall (?q)
    (implies  (additive ?q)
            (= ?q (quantity_plus ?q zero_quantity)))
```

8.7.5 Axiom 5

For any additive element, there exists an additive inverse.

```
(forall (?q)
    (implies  (additive ?q)
            (exists (?p)
                (= zero_quantity (quantity_plus ?q ?p)))))
```

8.7.6 Axiom 6

The quantity_plus function is commutative.

```
(forall (?q1 ?q2)
```


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```
    (implies  (and  (additive ?q1)
                    (additive ?q2))
          (= (quantity_plus ?q1 ?q2) (quantity_plus ?q2 ?q1)))
```

8.7.7 Axiom7

If quantity ?q1 is greater than quantity ?q2, then adding any quantity to both preserves the ordering.

```
 (forall (?q1 ?q2 ?q3)
(implies  (and    (additive ?q1)
                  (additive ?q2)
                  (additive ?q3))
         (iff    (greater ?q1 ?q2)
                  (greater (quantity_plus ?q1 ?q3) (quantity_plus ?q2 ?q3))))
```

8.7.8 Axiom 8

If quantity ?q1 is equal to quantity ?q2, then adding any quantity to both preserves the equality.

```
(forall (?q1 ?q2 ?q3)
(implies  (and            (additive ?q1)
                          (additive ?q2)
                          (additive ?q3))
         (iff     (= ?q1 ?q2)
                  (= (quantity_plus ?q1 ?q3) (quantity_plus ?q2 ?q3)))))
```

8.7.9 Axiom 9

The ordering relation greater on additive elements is transitive.

```
(forall (?d1 ?d2 ?d3)
    (implies  (and        (greater ?d1 ?d2)
                   (greater ?d2 ?d3))
          (greater ?d1 ?d3)))
```

8.7.10 Axiom 10

No additive element is greater than itself.

```
(forall (?d)
    (not (greater ?d ?d)))
```

NOTE: The greater ordering relation is a strict ordering.

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8.7.11 Axiom 11

The ordering relation on additive elements is a linear ordering.

```
(forall (?d1 ?d2)
    (or   (greater ?d1 ?d2)
          (greater ?d2 ?d1)
          (= ?d1 ?d2)))
```


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Annex A
(normative)
Use of ASN.1 Identifiers in SC4 standards

To provide for unambiguous identification of an information object in an open system, the object identifier

```
iso standard 18629 part 14 version 1
```

is assigned to this part of ISO 18629. The meaning of this value is defined in ISO/IEC 8824-1 and is described in ISO 18629-1.

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Annex B
(informative)
Example of process description using ISO 18629-14

The purpose of this annex is to provide a detailed scenario in which the ISO 18629 PSL is used in a knowledge-sharing effort which involves multiple manufacturing functions.

This scenario is an "interoperability" manufacturing scenario. This means that its goal is to show how PSL can be used to facilitate the communication of process knowledge in a manufacturing environment. Specifically, this scenario is centred around the exchange of knowledge from a process planner to a job shop scheduler.

This annex extends the test case introduced in ISO 18629-11: 2005, annex C to illustrate the application of outercore concepts in the specification of the manufacturing process of a product named GT-350.

B.1 GT-350 Manufacturing Processes

This section unites the various departmental processes into a high-level collection of activities which are enacted to create a GT-350 product. As described in the GT-350 product structure (see ISO 18629-11: 2005, Table C.1), subcomponents of this product are either purchased, sub-contracted, or made internally. These process descriptions address the activities performed to manufacture the internal subcomponents. This top-down view of the manufacturing process provides an overall picture from an abstract, “make GT350” activity which is expanded down to the detailed departmental levels.

As the Figure B.1 below shows, the GT-350 manufacturing process is divided into 6 main areas of work. The first five: make interior, make drive, make trim, make engine and make chassis are all unordered with respect to each other but they must all be completed before final assembly takes place.

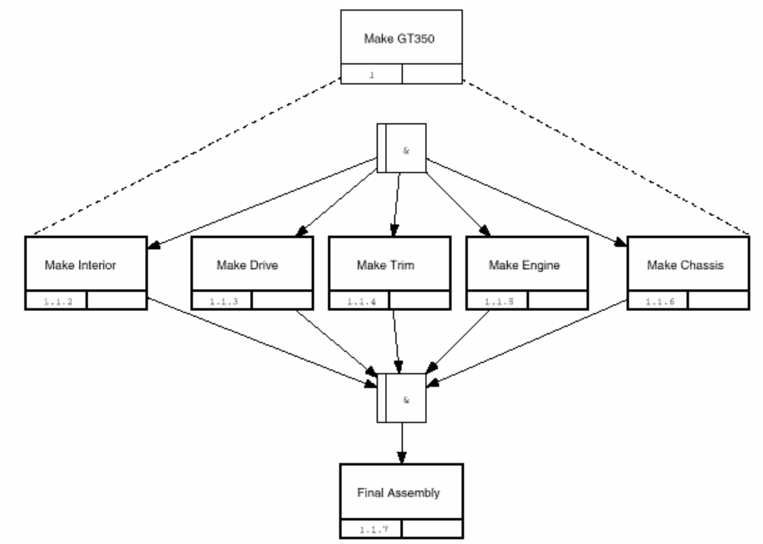

Figure B1: TOP level process for manufacturing a GT350 [10]

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The PSL-Outer-core-based representation of the top level process is :

```
(subactivity make-chassis make_gt350)
(subactivity make-interior make_gt350)
(subactivity make-drive make_gt350)
(subactivity make-trim make_gt350)
(subactivity make-engine make_gt350)
(subactivity final-assembly make_gt350)

(forall (?occ)
    (implies    (occurrence_of ?occ make_gt350)
                (exists (?occ1 ?occ2 ?occ3 ?occ4 ?occ5 ?occ6)
                        (and    (occurrence_of ?occ1 make_chassis)
                                (occurrence_of ?occ2 make_interior)
                                (occurrence_of ?occ3 make_drive)
                                (occurrence_of ?occ4 make_trim)
                                (occurrence_of ?occ5 make_engine)
                                (occurrence_of ?occ6 final_assembly)
                                (subactivity_occurrence ?occ1 ?occ)
                                (subactivity_occurrence ?occ2 ?occ)
                                (subactivity_occurrence ?occ3 ?occ)
                                (subactivity_occurrence ?occ4 ?occ)
                                (subactivity_occurrence ?occ5 ?occ)
                                (subactivity_occurrence ?occ6 ?occ)
```

Each of these abstract activities can be further detailed, however for the example proposed in this annex, we will not develop all of them.

On the basis of the IDEF3 [10] representation (in terms of process representation) of the abstract activities met during the different stages of the manufacturing process, we will extract some examples of process descriptions using the PSL-Outer-core presented in part 12 of the ISO 18629 standard.

B.2 The "make-engine" abstract activity

The 350-Engine is assembled from work performed in several CMW departments. The manufacturing process is shown in Figure B.2. The part is made up of an engine block, a harness, and wiring. The sub-processes are detailed in the sub-sections below. The 350-Engine is assembled at the A004 assembly bench and takes 5 minutes per piece.

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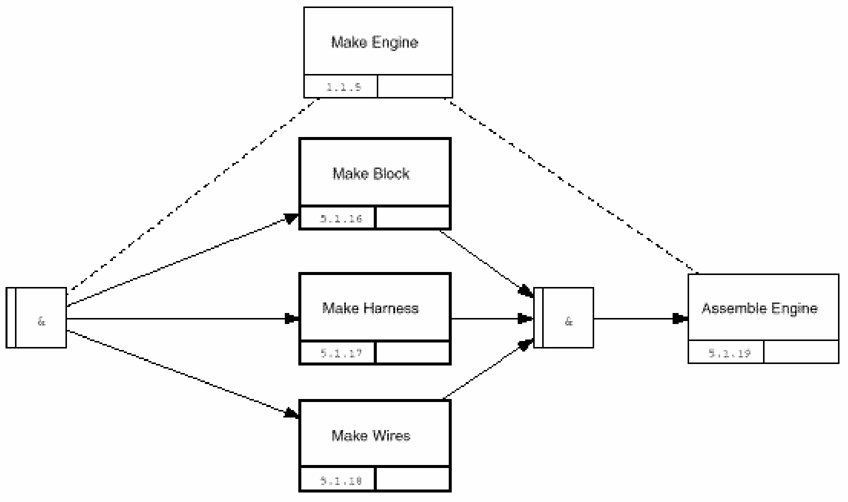

Figure B.2: PROCESS for manufacturing the 350–Engine [10]

The PSL-Outercore-based representation of some activities and of the process related information at the make-engine stage is :

(subactivity make_block make_engine)

(subactivity make-harness make_engine)

(subactivity make-wires make_engine)

(subactivity assemble_engine make_engine)

(and (requires make_engine ?r1)

(forall (?r)

(implies (engine_block ?r)

(resource ?r)))

(forall (?r)

(implies (harness ?r)

(resource ?r))

(forall (?r ?s)

(implies (wire ?r)

(exists (?i)

(prior (resource_set ?i ?r) ?s)))

(forall (?occ)

(implies (occurrence_of ?occ make_engine)

(exists (?occ1 ?occ2 ?occ3 ?occ4 ?r1 ?r2 ?r3 ?i)

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```
(and    (occurrence_of ?occ1 make_block)
        (occurrence_of ?occ2 make_harness)
        (occurrence_of ?occ3 make_wires)
        (occurrence_of ?occ4 assemble_engine)
        (subactivity_occurrence ?occ1 ?occ)
        (subactivity_occurrence ?occ2 ?occ)
        (subactivity_occurrence ?occ3 ?occ)
        (subactivity_occurrence ?occ4 ?occ)
        (requires make_engine ?r1)
        (engine_block ?r1)
        (= (demand ?occ1 ?r1)  1)
        (requires make_engine ?r2)
        (= (demand ?occ2 ?r2)  1)
        (harness ?r2)
        (requires make_engine ?r3)
        (prior (resource_set ?i ?r3) ?occ3)
        (prior (resource_point ?r3 5) ?occ3)))))
```

This representation formalizes the process depicted in Figure B.2.
The make_engine process requires three resources – an engine block, a harness, a set of wires, and a workcell. In particular, any occurrence of make_engine has a demand of one engine block, one harness, and a set of wires. Prior to the occurrence of make_engine, there exists a set of five wires that constitute a resource set.

B.2.1 Make Block

The 350-Block is manufactured as part of the 350–Engine sub-assembly. This involves an integration of work from the foundry and machine shop, as shown in the Figure B.3.

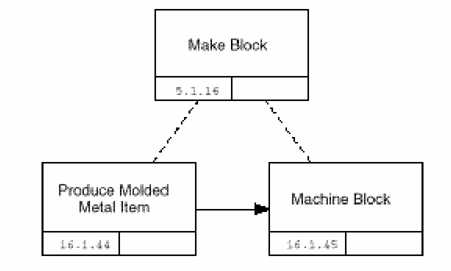

Figure B.3: PROCESS for manufacturing the 350–Block [10]

The PSL-Outercore-based representation of some activities and of the process related information is :

(subactivity produce_molded_metal make_block)

(subactivity machine_block make_block)

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(primitive machine_block)

(primitive produce_molded_metal)

(forall (?occ)
    (implies (occurrence_of ?occ make_block)
        (exists (?occ1 ?occ2 ?r1 ?r2)
            (and (occurrence_of ?occ1 produce_molded_metal)
                (occurrence_of ?occ2 machine_block)
                (piece_metal ?r1)
                (requires produce_molded_metal ?r1)
                (= (demand ?occ1 ?r1) 2)
                (block ?r2)
                (requires machine_block ?r2)
                (= (demand ?occ2 ?r2) 1)
                (min_precedes ?occ1 ?occ2 make_block)))))

This representation formalizes the process depicted in Figure B.3.
The make_block process requires two resources - metal piece and block. In particular, any occurrence of make_block has a demand of one block and two metal pieces.

B.2.2 Make Harness

The 350-Harness (Figure B.4) is manufactured as part of the 350–Engine sub-assembly. This involves work performed at the wire and cable department. Figure B.5 expands the harness wire production process. The 350-Harness is assembled by a bench worker at a wire and cable bench. It takes 10 minutes per set.

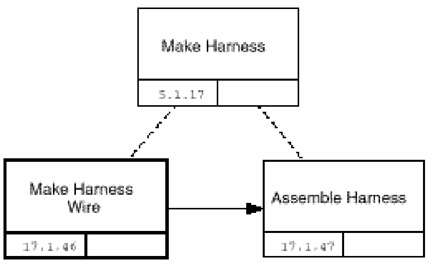

Figure B.4: PROCESS for manufacturing the 350–Harness [10]

The PSL-Outercore-based representation of some activities and of the process related information is :

(subactivity make_harness_wire make_harness)

(subactivity assemble_harness make_harness)

(primitive assemble_harness)

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```
(forall (?occ)
    (implies   (occurrence_of ?occ make_harness)
               (exists (?occ1 ?occ2 ?occ3 ?r)
                       (and    (occurrence_of ?occ1 make_harness_wire)
                               (harness ?r)
                               (requires make_harness_wire ?r)
                               (occurrence_of ?occ2 assemble_harness)
                               (requires assemble_harness ?r)
                               (leaf_occ ?occ3 ?occ1)
                               (min_precedes ?occ3 ?occ2 make_harness)))))
```

```
(forall (?occ ?r ?q)
    (implies   (and    (occurrence_of ?occ assemble_harness)
                       (requires assemble_harness ?r)
                       (prior (resource_point ?r ?q) ?occ))
               (holds (resource_point ?r ?q) ?occ)))
```

This representation formalizes the process depicted in Figure B.4.
The assemble_harness process requires one resource –a harness. Since this resource is used by the process and not consumed, the quantity of the resource (specified by the resource_point fluent) is not changed by any occurrence of the assemble_harness process.

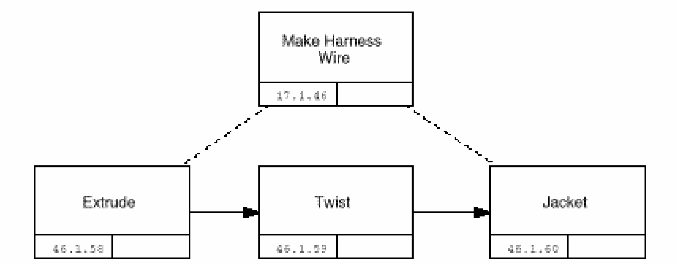

Figure B.5: PROCESS for manufacturing the harness wire [10]

B.2.3 Make Harness Wires

The 350-Wire-Set is manufactured as part of the 350–Engine sub-assembly. This involves work performed at the wire and cable department.

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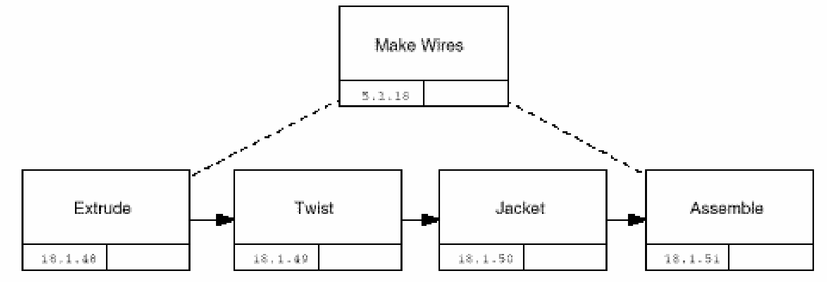
Figure B.6 : Process for manufacturing the 350-Wire [10]



The PSL-Outercore-based representation of some activities and of the process related information is :

(subactivity extrude make_harness_wire)

(subactivity twist make_harness_wire)

(subactivity jacket make_harness_wire)

(primitive extrude)

(primitive twist)

(primitive jacket)

```
(forall (?occ)
    (⇔      (occurrence_of ?occ make_harness_wire)
            (exists (?occ1 ?occ2 ?occ3)
                    (and    (occurrence_of ?occ1 extrude)
                            (occurrence_of ?occ2 twist)
                            (occurrence_of ?occ3 jacket)
                            (min_precedes ?occ1 ?occ2 make_harness_wire)
                            (min_precedes ?occ2 ?occ3 make_harness_wire))))
```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