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Information technology — Upper level ontology for smart city indicators

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Foreword

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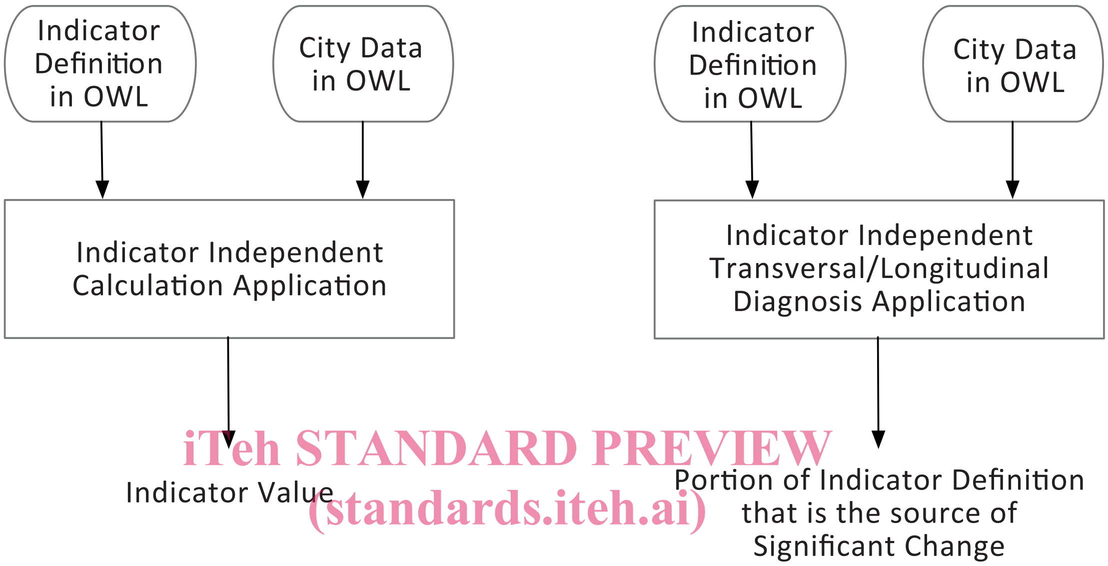
This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*.

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

To paraphrase Lord Kelvin, you cannot manage what you cannot measure[11]. For cities to be smart, their decisions need to be based on precisely defined and accurate metrics. For smart city information and communication technology to be used to aid cities in making smart decisions, then the digital data models they use need to precisely and accurately reflect what they represent of the city and how it is measured. This document specifies a data model that can be used to represent city indicator definitions. The data model is defined using the Semantic Web OWL 2 Web Ontology Language (OWL). Figure 1 depicts two intended uses of this document.



a) Definition-based Calculation of Indicator from Base Data

b) Definition-based Diagnosis of Indicator-based City Performance

Figure 1 — Possible uses of this document

Figure 1 a) depicts the indicator definition being used to automate the computation of an indicator value. In this case, an indicator definition plus city data is input into the indicator independent calculation application, which uses the definition to select subsets of city data, to compute the indicator. This approach makes it possible to create an indicator calculation application that is not programmed for a specific set of indicators. Figure 1 b) depicts a diagnosis system that uses the definition of an indicator as a basis for determining the root cause of transversal or longitudinal deviations in an indicator's value over place or time. A diagnosis system must understand what data was selected and how it was combined in order to determine the sources of change. In the remainder of this Introduction, the motivation for and the purpose of this document are elaborated.

Cities are moving towards policy-making based on data[33]. Yet it has been recognized by urban researchers, city professionals and political leaders that city level data is both incomplete and inconsistent. In 2007, it was recognized that "there are thousands of different sets of city (or urban) indicators and hundreds of agencies compiling and reviewing them. Most cities already have some degree of performance measurement in place. However, these indicators are usually not standardized, consistent or comparable (over time or across cities), nor do they have sufficient endorsement to be used as ongoing benchmarks."[27]

In response, ISO 37120 was developed to provide a set of indicators, across 17 themes, to measure city performance. These indicators spanned areas such as education, finance, shelter, transportation and environment.

Indicator definitions are people oriented; they are provided in natural language, e.g., English, and not in a more formal, possibly computer readable language. The reader of the definition imposes their own interpretation of the definition based on their understanding of the language and the environment in which they live (e.g., how their own city may define some terms).

Consider the definition of a student/teacher ratio as provided in Reference [21]: "Student/teacher ratio". This has been expanded[34] to: "Student/teacher ratio", where the numerator is "Number of Students", and the denominator is "Number of Teachers". One problem is whether "student" refers to full time students, or part time students. Are they regular students or special needs students? Do they include kindergarten students or not? It is also difficult to compare an indicator for a single city across time if the definition of student changes. For example, today the educational system includes students with special needs, but 30 years ago they may not have been enrolled. Without a more precise definition of terms, it makes it difficult to compare an indicator across cities where each city interprets what a student is differently, or against itself where definitions change.

Obviously, the definition and documentation of indicators can be expanded, as has been done in ISO 37120:2018, 6.4.2.

The definition of student/teacher ratio clearly addresses some of the issues raised above. Nevertheless, there is always a disconnect between the actual value of a city's indicator and the data sources and processes used to measure it; while the indicator's value is recorded in a machine-readable form (e.g., database or semantic web), the sources and measurement processes are buried in datasets and documents that are inaccessible or only human readable. In the end, all that is left is a record of indicator values without an understanding of what they actually measure and how they were measured.

The purpose of this document is to support the precise and unambiguous specification of indicator definitions using the technology of ontologies[24][25] as implemented in the semantic Web[13]. By doing so, it:

— enables the computer representation of precise definitions thereby reducing the ambiguity of interpretation;

— takes indicators out of the realm of humans and into the realm of computers where the world of big data, open source software, mobile apps, etc., can be applied to analyze and interpret the data;

— achieves semantic interoperability, namely the ability to access, understand, merge and use indicator data available from datasets spread across the semantic web;

— enables the publishing of indicator definitions, indicator values and their supporting data using semantic Web and ontology standards;

— enables the development of indicator independent indicator calculation applications; and

— enables the automated detection of indicator data inconsistency, and the root causes of variations.

Without a clear semantics for indicator definitions, it is not possible to perform consistency analysis. Without determining consistency, the ability to validate any comparisons based on indicators is lacking.

In this document, the indicator upper level ontology (IULO) is introduced. The IULO provides the concepts and properties for representing the basic structure of the definitions of indicators (see Clause 6). It does not provide concepts for representing theme specific concepts, such as education, finance, shelter, etc.

The IULO has been devised to communicate the meaning of data. It does not attempt to provide concepts to describe the metadata of indicators, for example, validity and provenance of data.

The IULO does not replace existing data models where they exist, but by mapping from a local model to the IULO, semantic interoperability of data can be achieved.

The IULO has been devised to represent any aggregate level of indicator, whether it is for neighbourhoods, villages, cities, states/provinces and/or countries.

The IULO has been devised to represent any indicator, and is not restricted to indicator standards, such as ISO 37120, which is normative to this document.

This document is aimed at organizations that define indicators, the information and communications technology (ICT) organizations that provide services to cities, states and countries, and manage the resulting data, as well as ICT and open data developers.

This document is based on work developed in the Enterprise Integration Laboratory of the University of Toronto[18][20][21].

Information technology — Upper level ontology for smart city indicators

1 Scope

This document establishes general principles and gives guidelines for an indicator upper level ontology (IULO) for smart cities that enables the representation of indicator definitions and the data used to derive them. It includes:

— concepts (e.g., indicator, population, cardinality); and

— properties that relate concepts (e.g., cardinality_of, parameter_of_var).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced documents (including any amendments) applies.

ISO 37120:2018, *Sustainable development of communities — Indicators for city services and quality of life*

"Time Ontology in OWL, W3C Recommendation 19 October 2017". Accessed at https://www.w3.org/TR/owl-time/

ISO 4217, *Codes for the representation of currencies*

ISO 80000 (all parts), *Quantities and units*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 37120 and the following 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
cardinality
number of elements in a set

[SOURCE: ISO/IEC 11179-3:2013, 3.2.13]

3.2
description logic
DL
family of formal knowledge representation languages that are more expressive than propositional logic but less expressive than first-order logic

3.3
manchester syntax
user-friendly compact syntax for OWL 2 ontologies

Note 1 to entry: The syntax is frame-based (as opposed to the axiom-based other syntaxes for OWL 2) where a collection of information about a class or property is given in one large syntactic construct, instead of being divided into a number of atomic chunks [as in most *description logics* (3.2)] or even being divided into even more triples (as when writing OWL as RDF graphs [RDF Concepts]).

[SOURCE: https://www.w3.org/TR/owl2-manchester-syntax/]

3.4
measure
value of the measurement (via the numerical_value property) which is linked to the both Quantity and Unit_of_measure

3.5
namespace
collection of names, identified by a URI reference, that are used in XML documents as element names and attribute names

3.6
ontology
formal representation of phenomena of a universe of discourse with an underlying vocabulary including definitions and axioms that make the intended meaning explicit and describe phenomena and their interrelationships

[SOURCE: ISO 19101-1:2014, 4.1.26]

3.7
OWL 2 Web Ontology Language
ontology language for the *semantic Web* (3.8) with formally defined meaning

Note 1 to entry: OWL 2 ontologies provide classes, properties, individuals, and data values and are stored as Semantic Web documents.

[SOURCE: https://www.w3.org/TR/owl2-overview/]

3.8
semantic Web
W3C's vision of the Web of linked data

Note 1 to entry: Semantic Web technologies enable people to create data stores on the Web, build vocabularies, and write rules for handling data.

[SOURCE: https://www.w3.org/standards/semanticweb/]

3.9
unit_of_measure
definite magnitude of a quantity, defined and adopted by convention and/or by law

4 Symbols and abbreviated terms

OWL Ontology Web Language

RDF Resource Description Framework

In the figures, arrows with a closed arrowhead denote the "rdfs:subClassOf" relation. Arrows with an open arrowhead denote an attribute relation and have the name of the attribute attached. Where a prefix (denoted by a ":") appears in front of a class or attribute name, the prefix denotes the namespace, the class or attribute originate. Colours of classes (boxes) in the diagrams are used to enhance readability, to distinguish the namespaces from which they originate. They correspond to the namespaces that concepts and properties are drawn from. Each namespace prefix is included in the boxes and redundant with the colour. A subset of concepts is incorporated into this document as OM is not a standard, enhance not normative. Classes and attributes without a prefix are defined in this document.

The following namespace prefixes are used in this document:

— ex: signifies an example for which an IRI does not exist

— gcie: http://ontology.eil.utoronto.ca/GCI/Education/GCI-Education.owl#

— geo: http://www.geonames.org/

— gis: http://www.opengis.net/ont/geosparql#

— om: http://www.wurvoc.org/vocabularies/om-1.8/

— time: http://www.w3.org/2006/time#

— owl: http://www.w3.org/2002/07/owl#

— rdf: http://www.w3.org/1999/02/22-rdf-syntax-ns#

— rdfs: http://www.w3.org/2000/01/rdf-schema#

— sc: http://schema.org/

— xsd: http://www.w3.org/2001/XMLSchema#

5 Basic indicator ontology pattern

Indicator definitions conform to a basic ontology pattern. Figure 2 depicts the pattern (only a portion is shown). For example, an ISO 37120 indicator (usually) has associated a unit of measure that is the ratio of two populations, the year it was measured, and the city it is for. It is composed of a numerator and a denominator which are both quantities. Each is a quantity that is a measure of the size of a population. (Cardinality can be replaced with other measures of a population, such as the mean of a specific property such as age.) The population members are defined, in this example, by another class and city. Concept names without prefixes are defined in this document. Concept names with prefixes are imported into this document. The prefix "time" refers to OWL-Time, and "sc" to Schema.org.

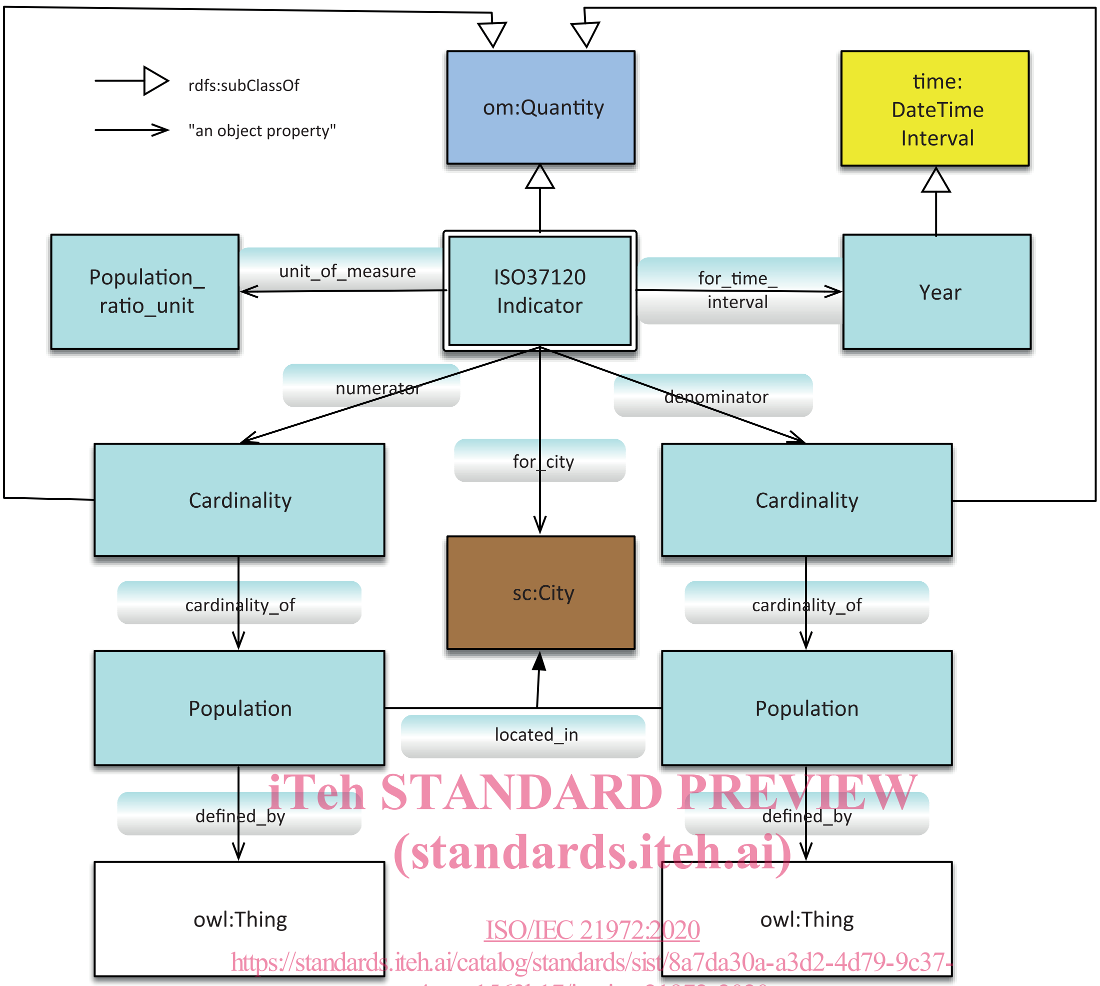


Figure 2 — Indicator ontology pattern

The following clauses describe and define the classes and properties for representing indicator definitions. Formal specifications are provided in the OWL 2 Web Ontology Language[8][9] using a subset of the manchester syntax.

6 Time

6.1 General

Indicator data in a smart city need to be understood in the context of the time at which the data were generated and/or published. It is important to understand not just at what time something occurred, but whether something occurred before, after or during some other event. To answer these questions, a much richer understanding of time that supports reasoning about time points, time intervals and the relationships among them is needed. In summary, the time ontology needs to be able to support the answering of questions such as:

— At what time did some event or measurement occur?

— What was the duration of the event?

— Did the event occur before, after or during some other event?

Many time ontologies have been developed. "Time Ontology in OWL W3C Recommendation 19 October 2017" shall be used in the context of this document.

6.2 Core classes and properties

Fundamental to any conceptual model is the time at which things occur. For example, questions can arise regarding the temporal relationship among measurements, i.e. not just at what time something was measured, but whether it was measured before, after or during some event. For example, was "Total Employment" of New Orleans determined before or after Hurricane Katrina? Or did Katrina take place during the interval that the indicator was determined? To answer these questions, a notion of time that supports reasoning about time points, time intervals and the relationships amongst them is needed. The following summarizes a subset of classes and relationships in OWL-Time.

There are three top level classes:

— **TemporalEntity**: it specifies the two types of time: Instant and Interval.

— **DateTimeDescription**: a specification of a date and time using a year, month, day, hour, etc. set of properties.

— **DurationDescription**: a class that specifies a duration as any combination of years, weeks, days, hours, minutes, and seconds. Equivalent to ISO 19108 'TM_PeriodDuration'.

A TemporalEntity has 3 sub-classes:

— **Instant**: it represents a point in time. Equivalent to ISO 19108 'TM_Instant'.

— **Interval**: it represents a period of time with a beginning and an end. Equivalent to ISO 19108 'TM_Period'. If a DurationDescription is provided, then the difference between the beginning and end of the Interval should be equal to the DurationDescription.

— **ProperInterval:** it is an Interval where the beginning time is less than the end time.

A **TemporalEntity** has a beginning Instant, an ending Instant and a duration, which are denoted by the following properties:

— **hasBeginning**: links a TemporalEntity (domain) to an Instant (range) where the latter denotes the beginning of the TemporalEntity. Equivalent to ISO 19108 'Beginning'.

— **hasEnd:** links a TemporalEntity (domain) to an Instant (range) where the latter denotes the end of the TemporalEntity. Equivalent to ISO 19108 'Ending'.

— **hasDurationDescription**: links a TemporalEntity (domain) to an Interval (range) where the latter denotes the duration of the DurationDescription.

NOTE Properties in RDF are uni-directional, linking a subject to an object. The domain of a property restricts what the subject can be, and the range restricts what the object can be.

Finally, there is a set of properties that relate ProperInterval's, including intervalOverlaps, intervalAfter, intervalContains, etc. Since both OWL-Time and ISO 19108 are based on Allen's temporal[12], each temporal relation in OWL-Time has an equivalent in ISO 19108[7].

6.3 Graphical depiction

The directed graph in Figure 3 depicts the core classes that comprise OWL-Time.