A Fire and Emergency Ontology for City Indicators

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EIL Working Paper, First Published: October 21, 2017

Abstract

ISO 37120 defines 100 indicators for measuring city performance. Six of these indicators focus on Fire and Emergency services. In order to build automated tools to support the longitudinal and transversal analysis of cities, it is necessary to create a ontology for representing both the definitions of indicators, and the data used to derive them. In this paper we define an ontology for representing fire and emergency response concepts that includes fire-related deaths, natural disaster-related deaths and response time for emergency response services. We demonstrate it by showing how the ISO 37120 Fire and Emergency indicator definitions are represented and used to answer questions.

1.Introduction

Today, many cities openly publish data sets that could be used to measure service performance. Unfortunately, most of these datasets remain unused due to the lack of software tools that can read, understand and analyse the data with respect to the desired metrics. ISO 37120 defines one hundred indicators to measure city performance. The standard provides detailed definitions and methodologies to guide their application. These indicators are categorized into 17 themes such as Economy, Education, Energy, Environment, Transportation, Urban Planning, Wastewater, Shelter, Governance, Safety.

The PolisGnosis project (Fox, 2017) aims to automate the longitudinal analysis (i.e. how and why a city's indicators change over time) and the transversal analysis (i.e. how and why cities differ from each other at the same time) to discover the root causes of differences. The main idea is to develop an intelligent agent that takes as input: all the knowledge connected to an indicator, a set of consistency and diagnosis axioms, and applies the axioms to determine the main causes of a city performance. In order to build an intelligence agent to perform the analysis, four categories of knowledge need to be represented:

1. How do we represent the definition of an indicator? In order for the analysis of indicators to be automated, the PolisGnosis system must be able to read and understand the definition of each indicator, which may change over time.
2. How do we represent ISO 37120 theme specific knowledge? Each theme, such as Education, Health, Shelter, etc., has a core set of "common sense" knowledge, that has to be represented in both defining an indicator and publishing an instance of an indicator and its supporting data.
3. How do we represent the supporting data that a city uses to derive the value of an indicator? What was the source data? How was it aggregated?
4. How do we represent a city's theme specific knowledge? Each city may define concepts such as "primary school", "grades", "teachers", etc. differently. Differences in indicator values may be due to differences in the interpretation of these terms between cities.

This paper defines the GCI Fire and Emergency Response (FER) Ontology for representing the definitions and data used to support the FER indicators. The paper is organized as follows. In Section 2, the overview of indicators is present together with their competency requirements. Section 3 describes the existing standards and ontologies representing the knowledge needed to represent the indicators. Section 4 presents the architecture of the Global City Indicator Ontology. In Section 5 provides the definition of the GCI Fire and Emergency Response Ontology. Section 6 and Section 7 describes respectively the GCI Foundation Ontology infrastructures and the ISO 37120 Fire and Emergency Response Indicators Ontology. An evaluation of the indicators is provided in Section 8. Conclusions are drawn in Section 9.

2 Indicators and their competency requirements

In this section, the ISO 37120 Fire and Emergency Response indicators are listed. For each indicator, a set of Competency Questions (CQs) has been defined following the Ontology Engineering methodology of Grüninger & Fox (1995). CQs are questions the ontology must be able to answer and they are derived from the definition of the indicators; CQs can belong to the following categories:

- Factual (F): questions that ask what the value of some property is.
- Consistency-Definitional (CD): questions that determine whether the instantiation of an indicator by a city is consistent with the ISO 37120 definition.
- Consistency-Internal (CI): questions that determine whether different parts of the instantiation are consistent with each other.
- Deduced (D): a value or relationship that can be deduced from the instantiation.

Into the following subsections, a definition of each indicator and the related CQs are provided.

2.1 ISO 37120 Fire and Emergency Response Indicators

2.1.1 *Number of firefighters per 100,000 population (core indicator)*

"The number of firefighters per 100,000 population shall be calculated as the total number of paid full-time firefighters (numerator) divided by one 100,000th of the city population

(denominator). The result shall be expressed as the number of firefighters per 100,000 population.

A firefighter shall refer to a full-time operational staff member located in the fire suppression unit that regularly responds to daily calls, and shall not include staff from fire prevention, safety, training, administration, senior management not directly involved in fire suppression, communication, and dispatch.

This indicator is only intended to identify the number of paid firefighters engaged in a fire suppression or directly related activities. This indicator shall not include volunteer firefighters and shall be reported as a separate indicator.

NOTE: The choice of 100,000 population was chosen to permit cities of different sizes to be able to compare results with each other relatively easily and effectively. It should be noted that in some countries this statistic is typically collected per 1,000 capita and a slight mathematical adjustment may be necessary to reflect this difference to obtain an accurate comparison."

Competency Questions:

(F) What city is the indicator for?
(F) What is the population of the city?
(F) In which division can a full-time firefighter work?
(CD) Is the full-time firefighter X resident of the city in which his fire brigade is located?
(D) What category of firefighter does the city X have?
(D) Is the firefighter X a full-time firefighter?
(D) Is the full-time firefighter X part of the emergency operational staff?
(CD) In which department have a full-time firefighter to work to be considered for this indicator?
(F) What brigades is the department composed of?
(F) Is the firefighter full-time, part-time or volunteer?
(CI) Is the distinction between division and brigade common?
(D) Which type of firefighter works in division X?
(CI) Can a firefighter work in a fire brigade located in a city that is not his resident city?

2.1.2 *Number of fire-related deaths per 100,000 population (core indicator)*

"The number of fire-related deaths per 100,000 population shall be expressed as the number of deaths directly attributed to a fire incident with death occurring within 30 days. This indicator shall be calculated as the total number of citizen fire-related deaths recorded in a 12-month period (numerator) divided by one 100,000th of the total population (denominator). The result shall be expressed as the number of fire-related deaths per 100,000 population.

NOTE: Some of the factors that can influence the rate of fatalities in a city include: Age and density of housing, fire prevention and education efforts, socio-demographics, enforcement of Fire Code, and presence of working smoke detectors and alarm systems."

Competency Questions:

(CI) What is a citizen for the city?
(D) How many fire-related death there are in a calendar year?
(CD) What is the time period in which is the number of death measured?
(D) Was the death of the person X related to a fire?
(D) Was the household Y of the city X involved in a fire?
(D) Did the household X have a smoke detector?
(F) How can a person die during a fire?/ Which are the possible cause of death during a fire?

2.1.3 *Number of natural disaster-related deaths per 100,000 population (core indicator)*

"The number of natural disaster-related deaths per 100,000 population shall be expressed as the number of deaths directly attributed to a natural disaster incidents. This indicator shall be calculated as the total number of natural disaster-related deaths recorded in a 12-month period (numerator) divided by one 100,000th of the total population (denominator). The result shall be expressed as the number of fire-related deaths per 100,000 population.
NOTE: As natural disasters are generally not restricted to the exact geographic confines of a city, disaster database content may need slight readjustment/recalculation to produce result matching a given city's defined geographic boundary."

Competency Questions:

(F) What city is the indicator for?
(F) What is the population of the city?
(F) What is a natural disaster death?
(CD) What is the time period in which is the number of death measured?
(CD) Which type of disaster are considered for this indicator?
(D) How many natural disaster-related death there are in a calendar year for the city X?
(D) Was the death of the person X related to a natural disaster?
(D) Was the household Y of the city X involved in a natural disaster?
(F) How can a person die during a natural disaster?/ Which are the possible cause of death during a natural disaster?

2.1.4 *Number of volunteer and part-time firefighters per 100,000 population (supporting indicator)*

"The number of volunteer and part-time firefighters per 100,000 population shall be calculated as the total number of volunteer and part-time firefighters (numerator) divided by one 100,000th of city's total population (denominator). The result shall be expressed as the number of volunteer and part-time firefighters per 100,000 population.

Volunteer firefighters shall refer to individuals who respond to incidents without pay.

Part-time firefighters shall refer to individuals who are not considered full-time career firefighters and are paid only for incidents that they respond to.

NOTE: The term 'volunteer' may be used in reference to a group of part-time or call firefighters who may have other occupations when not engaged in occasional firefighting. Therefore, volunteer and part-time firefighters are considered to be the same classification."

Competency Questions:

(F) In which division can a part-time firefighter work?
(F) In which division can a firefighter volunteer?
(CD) Is the part-time/volunteer firefighter X resident of the city in which his fire brigade is located?
(D) What type of firefighter is the person Z?
(D) Is the firefighter X a part-time/volunteer firefighter?
(D) Is the part-time/volunteer firefighter X part of the emergency operational staff?
(D) In which department have a part-time/volunteer firefighter to work to be considered for this indicator?
(CD) Is the number of part-time/volunteer firefighters certified by the government?
(D) How the city Y define a part-time/volunteer firefighter?
(F) Is the firefighter full-time, part-time or volunteer?

2.1.5 *Response time for emergency response service from initial call (supporting indicator)*

"The response time for the emergency and rescue department from the initial call shall be calculated as the sum of all initial distress calls to the on-site arrival of the emergency personnel and equipment in minutes and seconds for the year (numerator) divided by the number of emergency responses in the same year (denominator). The result shall be expressed as the response time for emergency response service from initial call in minutes and seconds.

The total number of minutes and seconds taken to respond to all emergency rescue call shall include the time elapsed from receiving the initial call for assistance to arrival on-site of emergency personnel and equipment is calculated for the preceding 12 months.

NOTE: Because it has the appearance of objectivity, emergency response time is a valuable key operational measure used to assess system performance from the citizen's perspective."

Competency Questions:

(F) What types of initial call (text, call)?
(F) When was the call made?
(CD) When does the response time start and when does it end?
(F) When does the first responder team receive notification?
(F) What types of first responder team can the emergency office number call?
(D) Which is the city involved to the operation X?
(D) When was the request Y received?
(F) For which city does the emergency number office operate?

2.1.6 *Response time for fire department from initial call (supporting indicator)*

"The response time for a fire department from the initial call shall be calculated as the sum of all initial distress calls to the on-site arrival of the fire department personnel and equipment in minutes and seconds for the year (numerator) divided by the number of fire department

responses in the same year (denominator). The result shall be expressed as the response time for fire department from initial call in minutes and seconds.

The total number of minutes and seconds taken to respond to all emergency rescue call shall include the time elapsed from receiving the initial call for assistance to arrival on-site of fire department personnel and equipment is calculated for the preceding 12 months.

NOTE: Because it has the appearance of objectivity, response time is a valuable and key operational measure used to assess system performance from the citizen's perspective"

Competency Questions:

(F) What types of emergencies?
(F) What types of initial call (text, call)?
(F) When was the call made?
(CD) When does the response time start and when does it end?
(F) When does the firefighter team receive notification?
(F) When does the firefighter team leave?
(D) Which is the place related to the operation X?
(D) When was the text Y received?
(F) For which city does the emergency number office operate?

2.2 Ontology Requirements

An ontology as a "specification of a conceptualization" (Gruber, 1993). Gruber states that a formal representation of a set of knowledge is a conceptualization, i.e. a set of objects, concepts, and relationships between them that exist in a particular area of interest. A conceptualization is, therefore, a simplified and abstract representation of the particular field of knowledge that needs to be represented, for any purpose.

The aim of this paper is to create an ontology formulating concepts and relationships that allow describing in a reasonably unambiguous format the city indicators and the related concepts defined in the Fire and Emergency Response section of ISO 37120.

This ontology, together with the other sixteen related to the different themes of ISO 37120, will allow creating a complete vocabulary and its related semantics: all information will finally have a complete meaning in its context as expected by the International Standard Organization, and moreover it will be written in a machine-readable format, a fundamental characteristic to automatize the process of evaluation and comparison of service and quality of life performance.

For the Fire and Emergency Response indicators theme, the concepts based on the six indicators and their CQs shown in the previous section, have been defined. The first four indicators, of which three are considered as core indicators and one as supporting indicator, cover some ratio measures referred to a population, that involve the following concepts that must be defined:

- Natural disaster-related death
- Fire-related death

The last two, instead, are supporting indicators covering the response time of different first-time responder team and the concepts that need to be defined inside the ontology are:

- First response team
- Emergency call
- Initial distress call
- First response team

3 Background

This section will first present a State of the Art of indicators and general knowledge related to the Fire and Emergency Response theme. Then, it will provide a list of vocabularies and ontologies which have covered a fundamental role in the development process of the ISO 37120 Fire and Emergency Response Ontology. At the end, this section will introduce the GCI Foundation Ontology.

3.1 Fire and Emergency Response Indicators and Standards

Performance measures are the quantitative representation of activities that help evaluate whether a public service is meeting its goal. The National Fire Protection Association (NFPA) is one of the most active and it delivers information and knowledge through more than 300 consensus codes and standards. Among this high number of publications, one of the most important standards related to Emergency Medical Services (EMS) benchmark is the NFPA 1710 (NFPA 1710), a standard for the organization and deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments.

The NFPA 1710 standard has been released after more than 30 years of study, research, testing, and validations and contains a collection of accepted practices. The International Association of City/County Managers (ICMA) is also part of the NFPA 1710 committee.

Considering the EMS calls, the NFPA standard establishes a turnout time of one minute, and an arrival time of a First Responder unit at an incident location of four minutes or less. It also defines these thresholds should be met 90% of the time, considering the response-time standard as a vital part of the mission of any EMS agency.

3.2 Emergency related Ontologies and Vocabularies

In this section, the most important ontologies and vocabularies related to an emergency response and its possible response team, will be reviewed. The ontologies/vocabularies will be first analyzed specifying also how the Fire and Emergency Response ontology uses their concepts.

3.2.1 Km4City Ontology

Km4City (Bellini et al, 2014) is a knowledge base mainly developed into the context of Smart City H2020 projects. It is formed by seven macro categories dedicated to different types of

concepts and data that are all interconnected: Administration; Street Guide, that is a geolocated representation of a road system; Points of Interest, that includes all services, activities which might be useful to the citizen; Local Public Transport, which provides scheduled time, real time transit forecasts, lines, stops of different typology of means of transport in a city; Sensors, which includes traffic sensors, parking sensors, weather sensors and their measures; Temporal, that includes all the concepts related to time inside the ontology and allows to create a timeline on a recorded event; Metadata, which contains context information such as license, process, and descriptions.

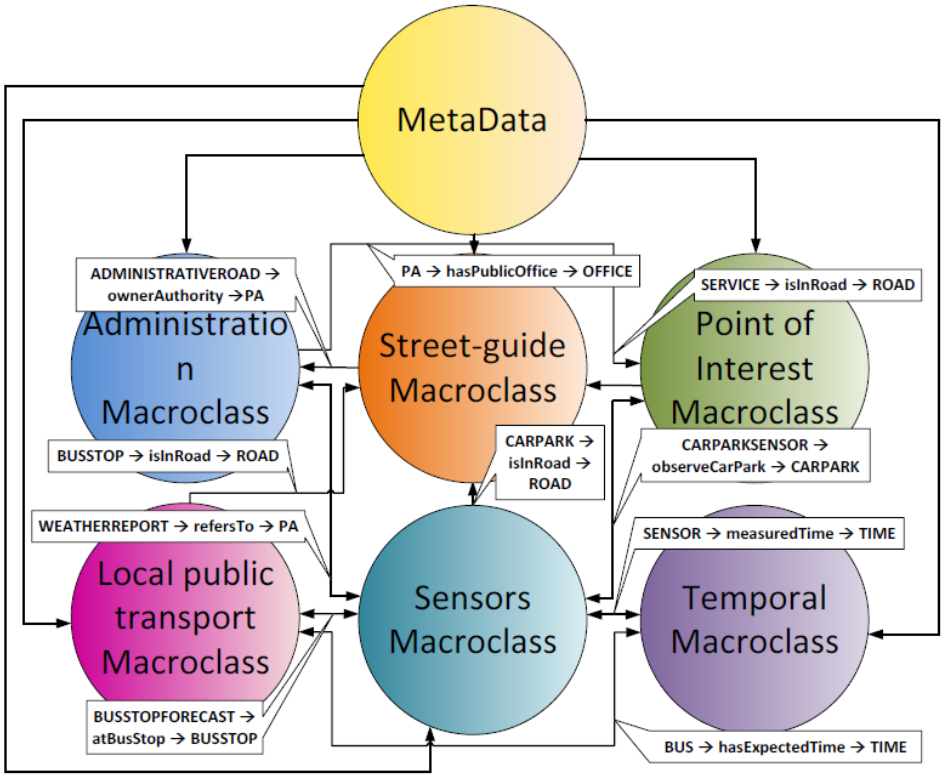

Figure 1 - Km4city Macro classes

This ontology provides an interesting high-level definition of sensors and measures based on the Semantic Sensor Network Ontology [section 3.2.4] which could be used to define fire-involved sensors, such as the smoke sensor or the heat sensor. Unfortunately, Km4city defines a Fire Brigade only as a geolocated point of interest, representation that is too limited in the context of the Global City Indicator ontology.

3.2.2 SUMO Ontology

The Suggested Upper Merged Ontology (SUMO) and its domain ontologies form the largest public ontology available today. SUMO provides definitions for general-purpose terms and acts as a foundation for more specific domain ontologies (Niles & Pierce, 2001). SUMO was created by merging publicly available ontological content into a single, comprehensive, and cohesive structure, such as: the ontologies available on the Ontolingua server, John Sowa's upper-level ontology, the ontologies developed by ITBM-CNR, and various other sources.

To explain the structure and content of the SUMO it is necessary to show its highest-level concepts and the relations between them. Figure 2 presents these concepts, and the

indentations indicate subsumption relations. As in many other ontologies, the root node of the SUMO is ‘Entity’, and this concept subsumes ‘Physical’ and ‘Abstract’. The first category includes everything that has a position in space/time, and the second one, instead, includes everything else.

```
Physical
    Object
        SelfConnectedObject
            ContinuousObject
            CorpuscularObject
        Collection
    Process
Abstract
    SetClass
            Relation
    Proposition
    Quantity
        Number
        PhysicalQuantity
    Attribute
```

Figure 2 - SUMO highest level concepts

The Fire and Emergency Response Ontology reuses some concept from the SUMO ontology like *SocialUnit* to define the *HouseHold* concept.

3.2.3 Semantic Sensor Network Ontology (sensor, measure)

It is possible to find on the Web many ontologies relating to sensor networks, and between them, the Semantic Sensor Network (SSN) Ontology (SSN, 2017) has been chosen because it provides elements for the description of sensors and their observations. This ontology has been defined using OWL 2 ontology language and it has been created starting from the review of standard and existing ontology. The SSN ontology is conceptually organized into ten modules; the full ontology consists of 41 concepts and 39 object properties, directly inheriting from 11 DUL (DOLCE Ultra Light) concepts and 14 DUL object properties. The SSN ontology can describe sensors, the accuracy, and capabilities of such sensors, observations and methods used for sensing. It can also represent concepts for operating, survival ranges (as these are often part of a given specification for a sensor), and its performance within those ranges. The SSN ontology is built around a central Ontology Design Pattern (ODP), shown in Figure 3 (Gangemi, 2005) which describes the relationships between sensors, stimulus, and observations, the Stimulus–Sensor–Observation (SSO) pattern. The SSN ontology allows to observe the represented domain from four different perspectives: a sensor perspective, focused on what senses, how it senses, and what is sensed; an observation perspective, focused on observation data and related metadata; a system perspective, focusing on systems of sensors and deployments; and a feature and property perspective, focusing instead on what senses a particular property.

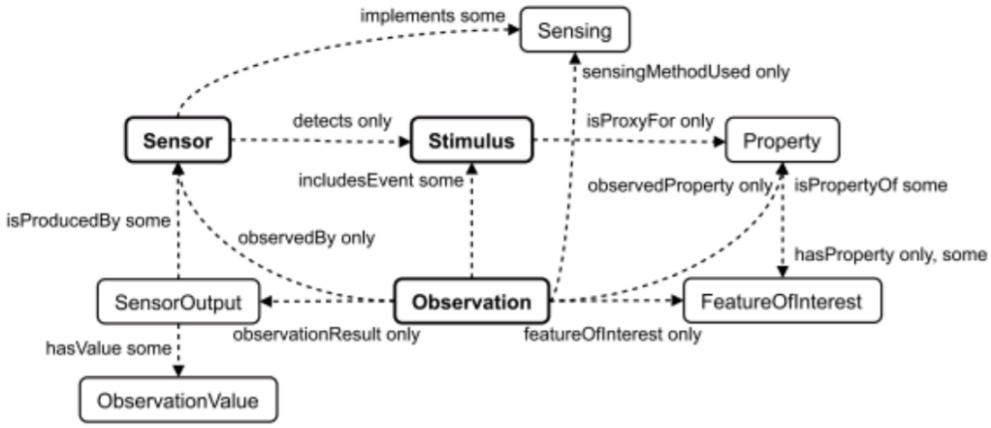

Figure 3 - SSN central ODP

The Fire and Emergency Response Ontology uses some entities and relationship from the SSN ontology to define the smoke and hot temperature sensors and the location in which they have been installed.

3.2.4 TOVE Organization Ontology

The TOVE Organization Ontology (Fox et al., 1996), available at http://ontology.eil.utoronto.ca/organization.owl, defines an organization as a set of constraints on the activities performed by agents. Furthermore, it specifies that an organization consists of a set of divisions and subdivisions (recursive definition), a set of organization-agents (said to be members of a division of the organization), a set of roles that the members play in the organization, and the goals the members try to achieve. This ontology also defines an activity as the basic transformational action with which processes and operations can be represented, to specify how the world is changed. The enabling state represents what must be true in order for the activity to be performed. A caused state, instead, represents what is true once the activity has been completed.

The relation between state and activity has been reused to define some of the classes of the Emergency Response Ontology.

3.2.5 Building Ontology

The Building Ontology (Katsumi & Fox, 2017) has been defined to track building change over time. This ontology, available at the address http://ontology.eil.utoronto.ca/icity/iCity-Building_v1.owl, presents the following classes: Building, defining the main entity, which represent a structure with some location in the urban system; BuildingPD to define the changes to the building, such as ownership and occupancy; a taxonomy of building formed by Building, House, Townhouse, ApartmentBuilding, OfficeBuilding, IndustrialBuilding subclasses. TimeVaryingConcept and Manifestation essentially divide the class of building based on its variant and non-variant properties. In fact, BuildingPD is meant to represent a "snapshot" of the properties of a building at a given point in time. The property used to connect the two classes is "manifestationOf". Lastly, a Building can have one or more BuildingUnit.

The taxonomy of building has been reused in the Fire-related and Natural-Disaster-related death Ontology.

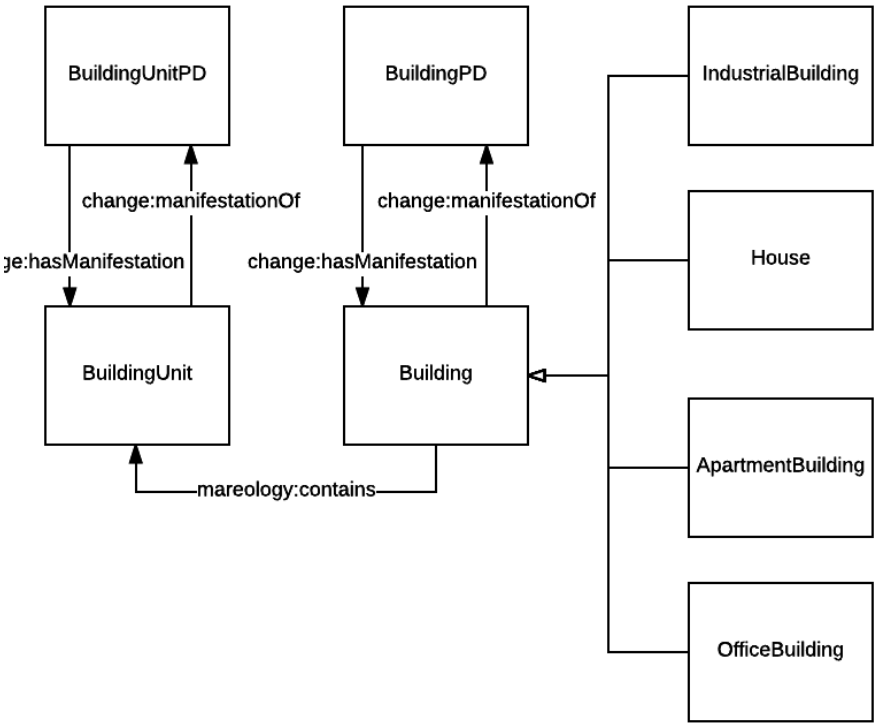

Figure 4 - Building Ontology

3.2.6 BFER Domain Model

As Clark, Sammut, & Willans (2008) states, a meta-model is a model of a model which captures a particular domain's essential properties and a list of relevant relationships between these concepts. a Building Fire Emergency Response (BFER) (Nunavath et al., 2016) domain model has been developed to facilitate an integration process of the knowledge that can be used in fire emergency response search and rescue operations inside a building. The model has been drawn from an extensive literature review in combination with interviews with emergency organizations. The domain model is composed of four components: the Event component (Figure 5), which answers the question *what* and *when*; the Actor component, which answers the *who* question; the Objective component, answering the *how* question; the Building component which answers the questions *where* and *how*. Each component contains several different elements and all components capture the complete building fire emergency response. The model has been designed through a domain modeling approach aiming at designing the information system for different emergency responders.

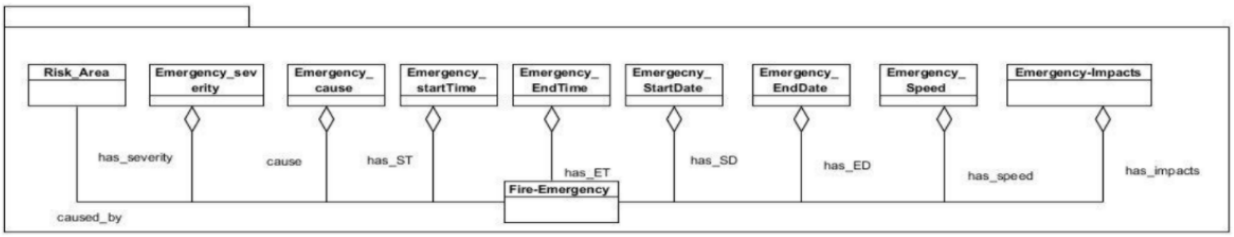

Figure 5 - BFER Event component

In any emergency, there is a diversity of responders from different organizations who need to coordinate to manage the emergency efficiently (Nunavath, Radianti, Comes, & Prinz, 2015). These responders are typically dispersed geographically at the emergency site or remotely in a coordination cell (Comes, Hiete, & Schultmann, 2013). In addition, the responders have different roles to perform, tasks to handle, and modes to communicate. As such, their individual insights need to be shared to attain an overview of the emergency and shared situational awareness (Van de Walle et al., 2016).

The Fire and Emergency Response Ontology expand the definition of Fire-Emergency provided by the BFER model in its Event component.

3.3 Global City Indicator (GCI) Foundation Ontology

The GCI Foundation Ontology (Fox, 2013) defines the representation of meta-data associated with each indicator, i.e. time and place name, and the classes and properties for representing the indicator's definition itself, i.e. population. This ontology represents the starting point of the Fire and Emergency Response Ontology development and it will be used also to clearly represent all the definitions the new ontology will need.

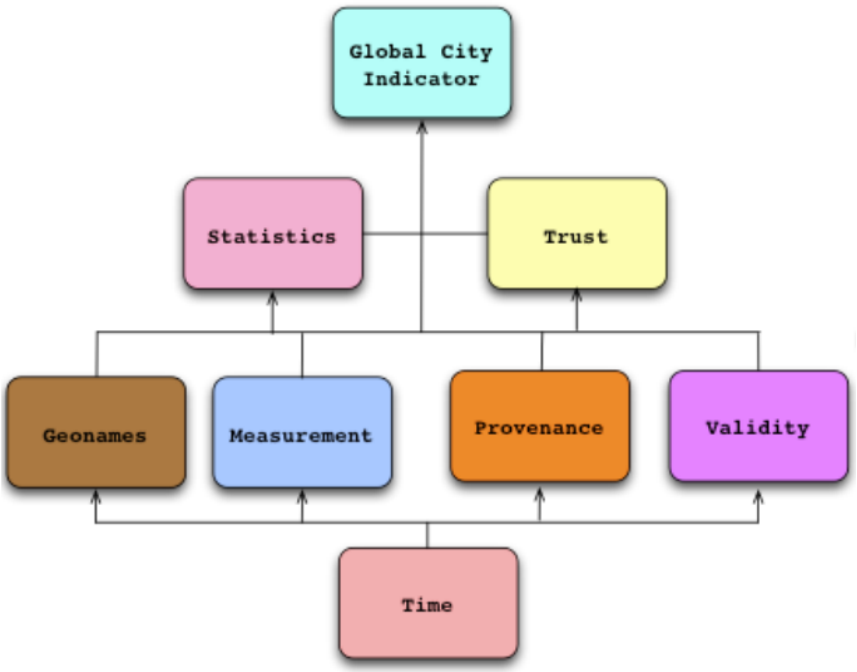

Figure 6- GCI-Foundation Ontology Components

The GCI Foundation ontology integrates and extends the following already-existing ontologies, as shown in Figure 6:

- Time (Hobbs & Pan, 2006)
- Measurement (Rijgersberg et al.,2011)
- Statistics (Pattuelli, 2009)
- Validity (Fox & Huang, 2006)
- Trust (Huang & Fox, 2006)
- Provenance (Lebo et al., 2013)
- Placenames (Geonames)

4 Architecture of the Global City Indicator Ontology

Figure 7 depicts the organization of files used to define the ISO 37120 ontology the PolisGnosis project is developing (Fox, 2017). At the highest level, i.e. ISO 37120 Ontology level, the ISO 37120 module contains the globally unique identifier (IRI) for each ISO 37120 indicator. For example, for the "number of natural disaster-related deaths per 100,000 population" indicator, the IRI is:

http://ontology.eil.utoronto.ca/ISO37120.owl#10.3

For each category of indicators in the ISO 37120 specification, for example, Fire and Emergency Response, there is a separate file that provides the definition of each indicator in that theme. For example,

http://ontology.eil.utoronto.ca/ISO37120/FireEmergencyResponse.owl

provides a complete OWL definition for the fire and emergency response theme indicators in the ISO 37120 specification.

The GCI Ontology level provides the theme-specific, generic ontologies required to define each theme's indicators. For example, to define the ISO 37120 Fire and Emergency Response indicators, it is necessary an ontology covering fire-response-related and emergency-response-related concepts such as full-time firefighter, initial distress call, city resident, natural disaster, fire-related death, etc.

http://ontology.eil.utoronto.ca/GCI/FireEmergency/GCI-FireEmergencyResponse.owl

provides the classes used by

http://ontology.eil.utoronto.ca/ISO37120/FireEmergencyResponse.owl.

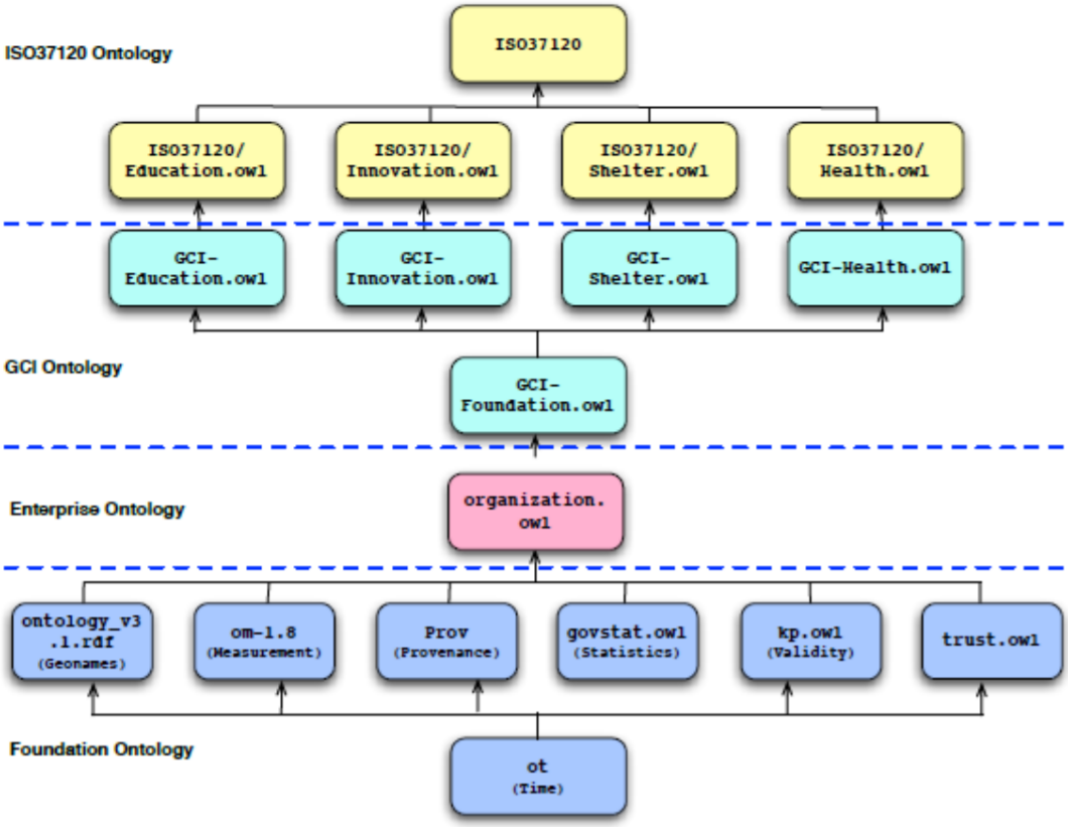

Figure 7 - ISO 37120 Ontology Modules [Fox, 2013]

All of the theme specific indicator ontologies rely on the GCI Foundation ontology for more generic concepts such as population counts and ratios, meta-information, etc.

As stated by (Fox, 2017), the Enterprise Ontology level builds on the TOVE Enterprise Modelling ontologies (Fox, 1992; Fox & Grüninger, 1998). In Figure 7, only the Organization Ontology file (Fox et al., 1996) is shown, which is one of the TOVE Enterprise Modelling ontologies. In addition to the Organization ontology, TOVE has ontologies spanning:

- Activities and States (Grüninger & Fox, 1994)
- Resources (Fadel et al., 1994; Fadel, 1994)
- Quality Measurement (Kim & Fox, 1994)
- Activity-Based Costing (Tham et al., 1994)
- Product (Lin et al., 1997)
- Product Requirements (Lin et al., 1996)
- Human Resources (Fazel-Zarandi & Fox, 2012)

Finally, the Foundation Ontology level provides very basic ontologies that were selected as the foundation for the GCI-Foundation.owl ontology described in the previous section.

5 GCI Fire and Emergency Response Ontologies

The GCI Foundation Ontology, unfortunately, does not contain all the concepts and relationships necessary to represent the definitions of ISO 37120 Fire and Emergency Response indicators. For this reason, three new ontologies defining respectively the

organization of Fire Brigade, the concept of death related to a disaster, and the process of an emergency phone call, have been developed.

The prefix *gcife* represents the URI of the three ontologies known as GCI Fire and Emergency Response ontology (http://ontology.eil.utoronto.ca/GCI/FireEmergency/GCI-FireEmergencyResponse.owl#), while the *gci* prefix refers to the GCI Foundation ontology (http:// ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl#), and class definitions from Organization ontology and GeoNames ontology have respectively the prefix *org* (http://ontology.eil.utoronto.ca/organization.owl#) and *geo* (http://www.geonames.org/ontology#).

In this section, these three ontologies will be presented.

5.1 Fire Brigade Organization Ontology

It is possible to find the ontology described in this section at the following address:

http://ontology.eil.utoronto.ca/GCI/FireEmergency/FBOrganization.owl

Most of the indicators included in the Fire and Emergency Response theme refer to types of firefighters. For example, the first indicator refers to the number of full-time paid firefighters as part of the competency questions related to this indicator:

(F) In which division can a full-time Firefighter work?
(CD) Is the full-time Firefighter X resident of the city in which his Fire Brigade is located?
(D) What category of Fire Fighter does the city X have?
(D) Is the Fire Fighter X a full-time firefighter?
(D) Is the full-time Fire Fighter X part of the Emergency Operational staff?
(CD) In which department have a full-time Fire Fighter to work to be considered for this indicator?
(F) Is the Fire Fighter full-time, part-time or Volunteer?
(D) Which type of Firefighter works in Division X?
(CI) Can a Firefighter work in a Fire Brigade located in a city that is not his resident city?

To answer these questions, it is necessary to define an ontology representing the structure of a fire brigade and all the roles people can cover. Looking at the list of useful ontologies presented in section 4, the Organization ontology is the only one can be used to define a fire brigade, seeing that this latter can be considered as an organization.

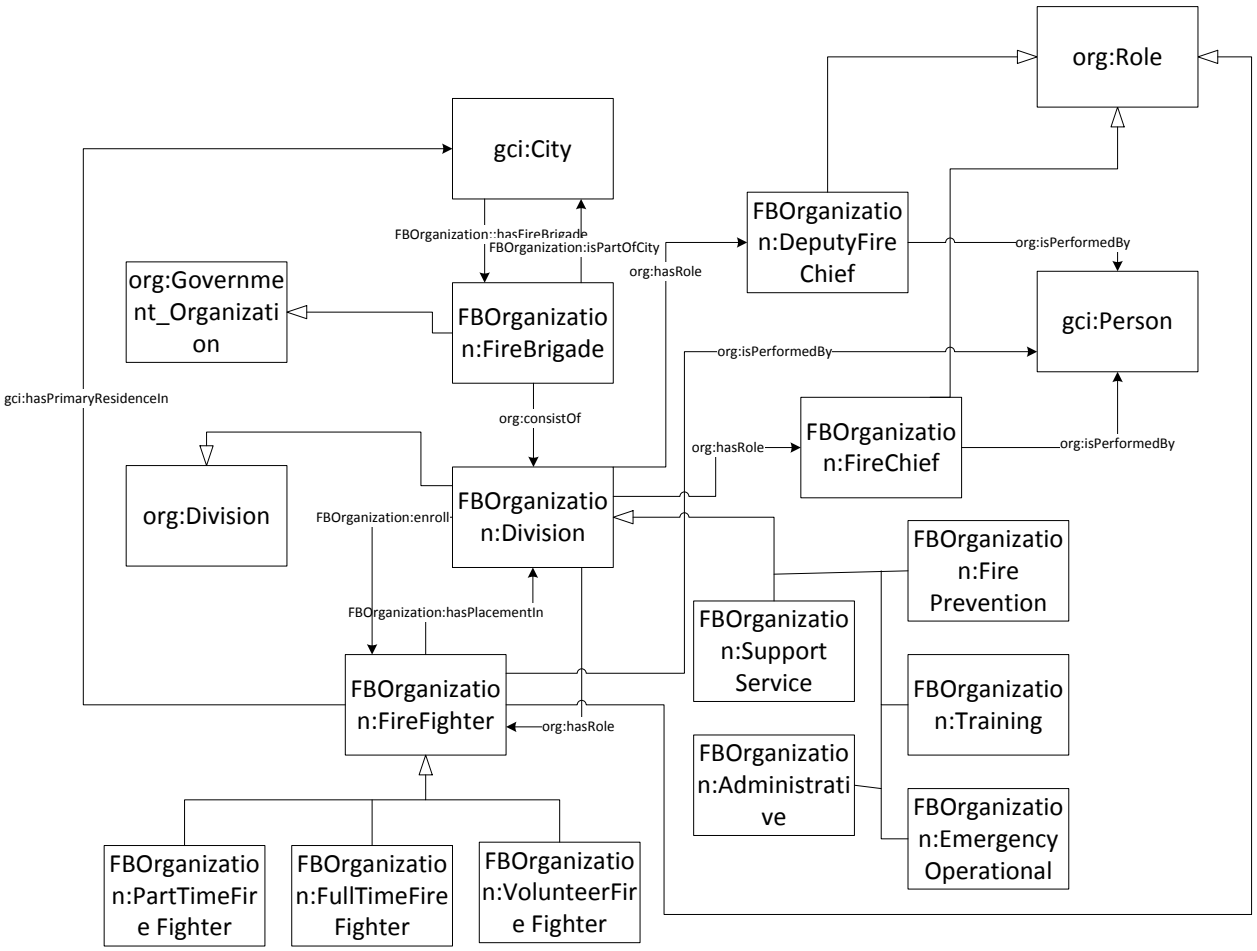

Figure 8 - Fire Brigade Organization ontology

As described in Figure 8, FireBrigade is sub class of org:Government_Organization and the properties hasFireBrigade and isPartOFCity define a 1:N relationship where each FireBrigade can be part of only 1 cities but a city can have more FireBrigade. Each FireBrigade is composed of some divisions (the gcife:Division class is a subclass of the same name class present in the Organization ontology, from which some properties have been inherited). The main divisions a FireBrigade can be composed of, are represented by Support Service, Fire Prevention, Administrative, Training, and Emergency Operational classes. Moreover, the roles of Deputy Fire Chief and Fire Chief are defined inside a Division: the first of them supervises and coordinates the activities of his/her battalions, including responding to emergencies, providing proper training, managing firefighters, conducting training and ensuring that department policies and procedures are followed; the second one, instead, is an experiencing firefighter which helps coordinate fire control, rescue, hazardous material clean-up and medical treatment efforts.

Some divisions, such as Fire Prevention and Emergency Operational, can enroll more than one type of firefighters and to represent this opportunity, the FBOrganization:FireFighter class is specialized in part-time (PT) firefighter, full-time (FT) firefighter and volunteer firefighter. A PT firefighter is an employee who works a minimum of 48 hours per month in a fire station. A volunteer firefighter has a paid job in other professions and is willing to answer an emergency

call day or night for no pay. Finally, a FT firefighter works an average of 56 hours per week, but the work hours are divided into 24-hours shifts.

Table 1 defines the classes and properties of the Fire Brigade Organization ontology.

gci:City	owl:subClassOf	geo:Feature
	hasFireBrigade	Some FBOrganization:FireBrigade
FBOrganization:FireBrigade	owl:subClassOf	org:GovernmentOrganization
	isPartOfCity	Exactly 1 gci:City
	org:consistOf	FBOrganization:Division
FBOrganization:DeputyFireChief	owl:subClassOf	org:Role
	org:superiorOf	FBOrganization:FireFighter
	org:roleOf	FBOrganization:Division
	org:isPerformedBy	gci:Person
FBOrganization:FireChief	owl:subClassOf	org:Role
	org:superiorOf	FBOrganization:FireFighter
	org:roleOf	FBOrganization:Division
	org:isPerformedBy	gci:Person
FBOrganization:Division	owl:subClassOf	org:Division
	FBOrganization:enroll	some gcife:FireFighter
	org:hasRole	FBOrganization:FireFighter, FBOrganization:DeputyFireChief, FBOrganization:FireChief
FBOrganization:FireFighter	owl:subClassOf	org:Role
	org:isPerformedBy	gci:Person
	FBOrganization:hasPlacement	exactly 1 FBOrganization:Division
	gci:hasPrimaryResidence	exactly 1 gci:City
	org:subordinateOf	FBOrganization:DuputyFireChief, FBOrganization:FireChief
FBOrganization:FullTime_FireFighter	owl:subClassOf	FBOrganization:FireFighter
FBOrganization:PartTime_FireFighter	owl:subClassOf	FBOrganization:FireFighter
FBOrganization:Volunteer_FireFighter	owl:subClassOf	FBOrganization:FireFighter
FBOrganization:Administrative	owl:subClassOf	FBOrganization:Division
FBOrganization:SupportService	owl:subClassOf	FBOrganization:Division
FBOrganization:EmergencyOperational	owl:subClassOf	FBOrganization:Division
FBOrganization:Training	owl:subClassOf	FBOrganization:Division
FBOrganization:FirePrevention	owl:subClassOf	FBOrganization:Division

Table 1 - Classes and properties of the Fire Brigade Organization ontology

5.2 Fire-related and Disaster-related death ontology

Looking at the competency questions of the 10.2 and 10.3 indicators it is clear we need to define the concept of a fire-related or natural disaster-related death to represent the numerators of these two indicators included in the Fire and Emergency Response ontology. The fire-related and disaster-related death ontology aims to provide a clear definition to both concepts and to connect them to other fundamental classes defined in other ontologies, like the HouseHold class from the Shelter ontology (Wang & Fox, 2015). In fact, for example, the 10.2 indicator of the ISO 37120 Fire and Emergency Response theme required to calculate the total number of fire-related death occurred in a period of 12 months in a specific city: this

means that the connection of each person to his/her house and a specific address in a city, assumes a considerable relevance in this context.

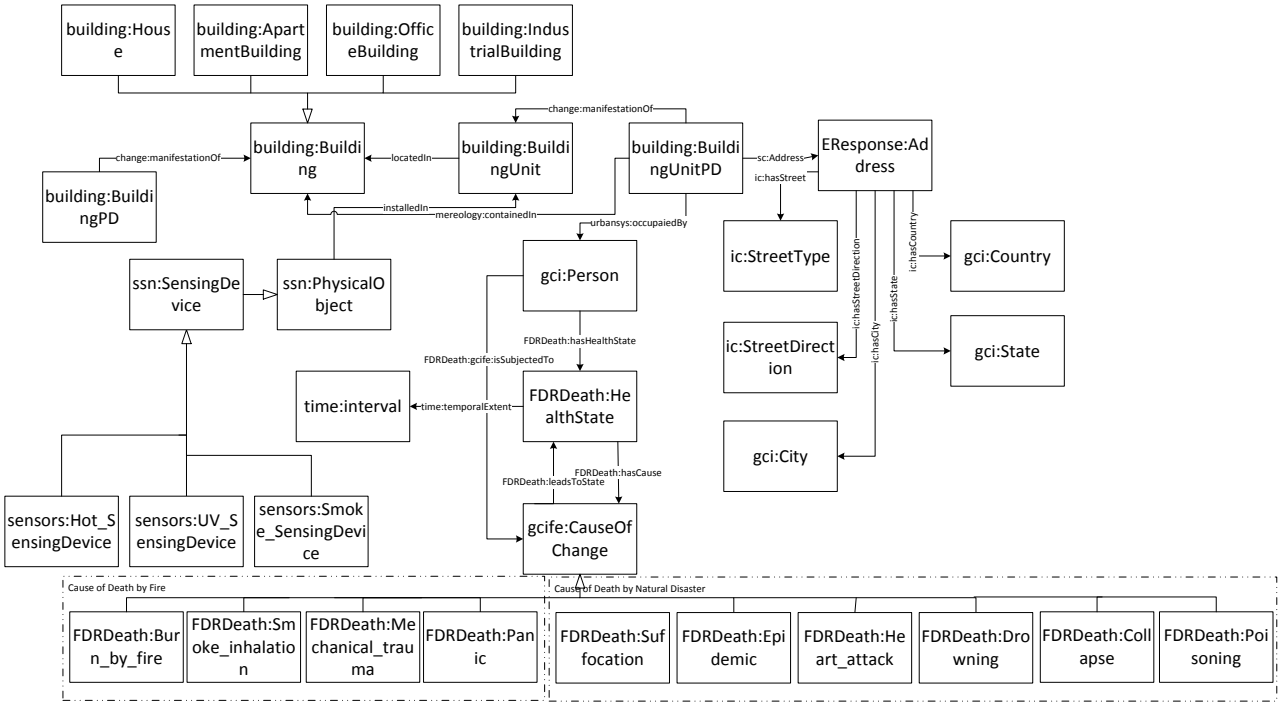

Figure 9 - Fire-related and Disaster-related death ontology

The main idea implemented in this ontology is to consider a person having a dynamic health state, represented by the HealthState class, to which a temporal interval has been associated, stating its validity. The CauseOfChange class allows to register the cause of a change in the health state and this represent the key concept to define a fire-related or a natural-disaster-related death: as stated in NFPA (2015) most of the death during a fire are caused by smoke inhalation, following by a mechanical trauma, panic, and, obviously, burning; during a natural disaster, instead, the major causes of death are drowning, suffocation, mechanical trauma, heart attack and panic. Using this ontology, to represent the number of fire-related death, for example, it is enough looking for the number of instances of the People class that have a HealthState equal to death due to one of the previously listed causes of death due to a fire.

The Person class is also connected to gci:HouseHold thanks to the hasMember property, also inherited from the Shelter Ontology available at *http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl*. A taxonomy of building has been also introduced from the Building Ontology presented in *http://ontology.eil.utoronto.ca/icity/iCity-Building_v1.owl*, which allow introducing the concept of a building unit directly connected to the HouseHold class. Each building unit is located in a building whom specialization is represented by the taxonomy itself, and which also have a state changing in time, called manifestation. Each manifestation allows keeping information about who is living in a specific building unit during a certain time interval. The building unit class is also connected thanks to the hasAddress property to the address class, which is represented using the iContact Ontology (http://ontology.eil.utoronto.ca/icontact.owl). The

building unit concept is also connected to the SSN Ontology [Section 3.2.2] to represent the most common sensors installed in apartments like the smoke sensor, the hot sensing device, and the UV sensing device, which use a laser to verify the presence of smoke in the area.

The following table contains all the classes and properties defined in the Fire-related and Natural Disaster-related death ontology.

ssn:SensingDevice	owl:subClassOf	ssn:PhysicalObject
	ssn:detects	some om:Quantity
	gci:haslocation	exactly 1 gci:Geocoordinates
	gci:installedIn	exactly 1 gci:BuildingUnit
FDRDeath:UV_Sensing_device	owl:subClassOf	ssn:SensingDevice
FDRDeath:Heat_Sensing_device	owl:subClassOf	ssn:SensingDevice
FDRDeath:Smoke_Sensing_device	owl:subClassOf	ssn:SensingDevice
FDRDeath:UV_Wavelenghts	owl:subClassOf	om:Quantity
	ssn:is_produced_by	exactly 1 ssn:SensingDevice
	temporal_average	some FireMeasure_average
	measures	exactly 1 FireMeasure
FDRDeath:Heat_Temperature	owl:subClassOf	om:Quantity
	ssn:is_produced_by	exactly 1 ssn:SensingDevice
	temporal_average	some FireMeasure_average
	measures	exactly 1 FireMeasure
FDRDeath:Smoke_Presence	owl:subClassOf	om:Quantity
	ssn:is_produced_by	exactly 1 ssn:SensingDevice
	pollution:temporal_average	some FireMeasure_average
	pollution:measures	exactly 1 FireMeasure
FDRDeath:FireMeasure_average	pollution:has_periodicity	exactly 1 gci:interval
FDRDeath:UV_FireMeasure	owl:subClassOf	Sensors:FireMeasure
	pollution:measures	Sensors:UV_Wavelenghts
	om:unit_of_measure	value gci:Nanometer
FDRDeath:Heat_FireMeasure	owl:subClassOf	Sensors:FireMeasure
	pollution:measures	FDRDeath:Heat_Temperature
	om:unit_of_measure	value gci:Farenightdegree
FDRDeath:Smoke_FireMeasure	owl:subClassOf	Sensors:FireMeasure
	pollution:measures	Smoke_Presence
	om:unit_of_measure	value gci:GlossUnit
building:Building	owl:subClassOf	change:Manifestation
	change:existsAt	exactly 1 TemporalEntity
	spatial_loc:hasLocation	exactely 1 spatial_loc:SpatialFeature
	equivalentClass	change:manifestationOf some building:BuildingPD and change:manifestationOf only building:BuildingPD
	mereology:contains	only building:BuildingUnit
	building:hasOwner	min 1 (gci:Person OR org:Organization)
	building:hasOccupant	some gci:Person or org:Organization OR org:BusinessEstablishment
building:House	owl:subClassOf	building:Building
building:ApartmentBuilding	owl:subClassOf	building:Building
building:OfficeBuilding	owl:subClassOf	building:Building

building:IndustrialBuilding	owl:subClassOf	building:Building
building:BuildingPD	owl:subClassOf	change:TimeVaryingConcept
	equivalentClass	change:hasManifestation some building:Building and change:hasManifestation only building:Building
	change:existsAt	exactly 1 Interval
building:BuildingUnitPD	subClassOf	change:TimeVaryingConcept
	change:existsAt	exactly 1 time:Interval
	equivalentClass	change:hasManifestation some building:BuildingUnit and change:hasManifestation only building:BuildingUnit
	mereology:containedIn	exactly 1 building:Building
	sc:Address	exactly 1 ci:Address
building:BuildingUnit	owl:subClassOf	change:Manifestation
	equivalentClass	change:manifestationOf some building:BuildingUnitPD and change:manifestationOf only building:BuildingUnitPD
	change:existsAt	exactly 1 TemporalEntity
	monetary:hasValue	only monetary:MonetaryValue
	hasFacility	only Facility
	hasUnitSize	only om:Quantity
	hasRooms	only xsd:int
	hasRent	only monetary:MonetaryValue
	urbansys:occupiedBy	some gci:Person or org:Organization
ic:Address	subClassOf	ic:Thing
	ic:hasStreetDirection	ic:StreetDirection
	ic:hasStreetType	ic:StreetType
	ic:hasState	gci:State
	ic:hasCity	gci:City
	ic:hasCountry	gci:Country
gci:Person	owl:subClassOf	TimeVaryingConcept
	owl:subClassOf	some act:State
	TemporalExtent	exactly 1 interval
FDRDeath:HealthState	owl:subclassOf	change:Manifestation
	FDRDeath:hasCause	exactly 1 FDRDeath:CauseOfChange
	TemporalExtent	exactly 1 time:interval
FDRDeath:CauseOfChange	FDRDeath:relatedTo	gci:Person
	FDRDeath:leadToState	exactely 1 FDRDeath:HealthState
FDRDeath:Burn_by_fire	subClassOf	FDRDeath:CauseOfChange
FDRDeath:Smoke_inhalation	subClassOf	FDRDeath:CauseOfChange
FDRDeath:Mechanical_trauma	subClassOf	FDRDeath:CauseOfChange

Table 2 - Classes and properties defined in the Fire-related and Natural Disaster-related death ontology

5.3 Emergency Response Ontology

This ontology has been developed to represent the whole process involved in an emergency, from its report by call or text to the closure of the emergency itself. The Emergency Response ontology also allows tracking arrival time of a first response team and the duration of its

action, as required by the 10.5 and 10.6 indicators of the Fire and Emergency response theme. In fact, the competency questions related to these two indicators include the following:

(F) What types of initial call (text, call)?
(F) When was the call made?
(CD) When does the Emergency start and when does it end?
(F) What types of First Responder Team can the Emergency office number call?

To answer these questions, the Emergency Response ontology represented in Figure 10 is necessary.

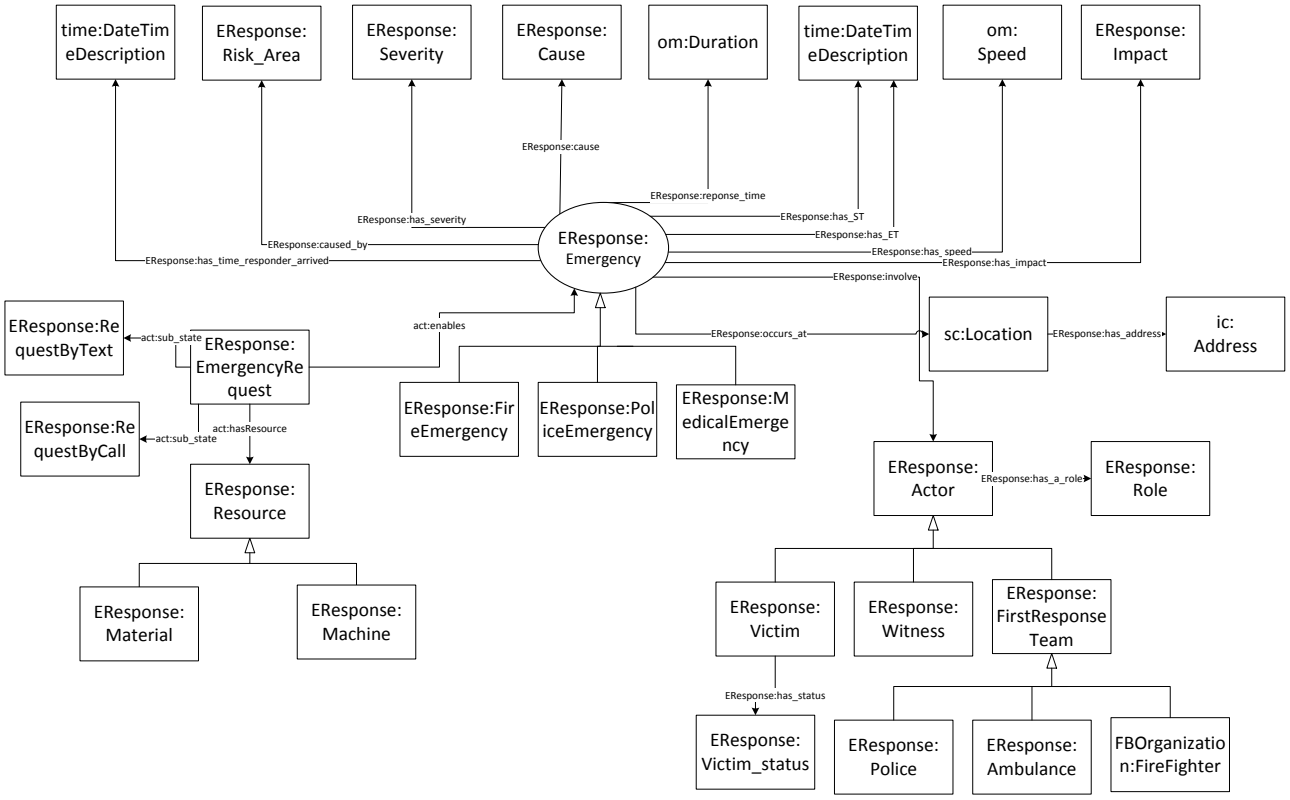

Figure 10 – Emergency Response Ontology

The main class of this ontology, located at the center of Figure 10, is the Emergency class which has three subclasses: Fire_Emergency, Police_Emergency, and Medical_Emergency classes. The Emergency class has been also defined as a subclass of the Activity concept presented in the TOVE ontology (Fox, 1992): this means that this activity can be enabled from a certain state represented by the EmergencyRequest class. An emergency request can be received by text or by call and the classes refer to this two method have been defined as sub-state of the primary request. A resource can also be assigned to an EmergencyRequest and it can belong to one of the following specification classes: Material and Machine classes. The definition of the EResponse:Emergency class correspond to an extended and reviewed version of the Fire-Emergency concept that is possible to find in the BFER domain model (Nunavath et al., 2016). As this latter model, the Emergency class has properties that define the type of emergency: for example, the degree of its severity, the escalation of the

emergency speed, the date and time in which the emergency has started, the cause of the emergency. The Emergency class also has a property to help to define the ISO 37120 indicators that are the Responder_TimeArrive class which represents the date and time in which the assigned First Response Team arrives at the emergency location (represented by the Location and Address classes).

Another property of an Emergency is the response_time. This is the difference between the start time of the emergency (has_ST) and the arrival time of the responder (has_time_responder_arrived). It is a om:Duration quantity whose unit of measure is om:minute-time. Note that the specification of the arithmetic difference cannot be specified in OWL-DL.

Another important class of the Emergency Response ontology is the Actor class, which is connected to the role this person had during the emergency. An actor can be a victim, a witness, and a first response team and in this latter case, the ontology allows to specify the type of team has participated to the considered emergency.

EResponse:Emergency	owl:subClassOf	act:Activity
	EResponse:has_time_responder_arrived	only 1 time:DateTimeDescription
	EResponse:caused_by	only EResponse:Risk_Area
	EResponse:has_severity	only 1 EResponse:Severity
	EResponse:cause	only EResponse:Cause
	EResponse:has_ST	only 1 time:DateTimeDescription
	EResponse:has_ET	only 1 time:DateTimeDescription
	erresonse:response_time	only 1 (om:Duration and (om:unit_of_measure om:minute-time))
	EResponse:has_Speed	om:Speed
	EResponse:has_impact	EResponse:Impact
	EResponse:occurs_at	sc:Location
	EResponse:involve	EResponse:Actor
eresponse:FireEmergency	owl:subClassOf	eresponse:Emergency
	eresponse:involve	eresponse:Firefighters
	owl:disjointWith	eresponse:PoliceEmergency eresponse:MedicalEmergency
eresponse:PoliceEmergency	owl:subClassOf	eresponse:Emergency
	eresponse:involve	eresponse:Police
	owl:disjointWith	eresponse:FireEmergency eresonse:MedicalEmergency
eresponse:MedicalEmergency	owl:subClassOf	eresponse:Emergency
	eresponse:involve	eresponse:Ambulance
	owl:disjointWith	eresponse:PoliceEmergency eresponse:FireEmergency
EResponse:EmergencyRequest	owl:subClassOf	act:State
	act:enables	EResponse:Emergency
	act:has_substates	EResponse:RequestByText, EResponse EResponse:RequestByCall
	act:has_resource	EResponse:Resource
EResponse:Material	owl:subClassOf	EResponse:Resource
EResponse:Machine	owl:subClassOf	EResponse:Resource

EResponse:Police	owl:subclassOf	EResponse:FirstResponseTeam
FBOrganization:FireFighters	owl:subclassOf	EResponse:FirstResponseTeam
EResponse:Ambulance	owl:subclassOf	EResponse:FirstResponseTeam
EResponse:RequestByText	owl:subclassOf	act:State
EResponse:RequestByCall	owl:subclassOf	act:State
EResponse:Victim	owl:subclassOf	EResponse:Actor
	EResponse:has_status	EResponse:Victim_status
EResponse:Witness	owl:subclassOf	EResponse:Actor
EResponse:FirstResponseTeam	owl:subclassOf	EResponse:Actor
EResponse:Location	EResponse:has_address	ic:address

Table 3 - Classes and properties defined in the Emergency Response ontology

6 GCI Foundation Ontology Infrastructure

Most of the indicators included in the Fire and Emergency Response Ontology, which is presented in the next session, are ratio indicators; therefore, this section will show the basic structure of a ratio indicator using the GCI Foundation Ontology.

The OM Measurement Ontology (Rijgersberg at al., 2011), used by the GCI Foundation Ontology, has been created to improve the annotation and interpretation of quantitative research data and defines the underlying semantic of a number, such as what is being measured and the unit of measurement. OM ontology makes it possible to ensure the comparability and compatibility of the number, e.g. the total number of fire-related deaths and the total number of firefighters are expressed with the same measurement unit and use the same conversion standard.

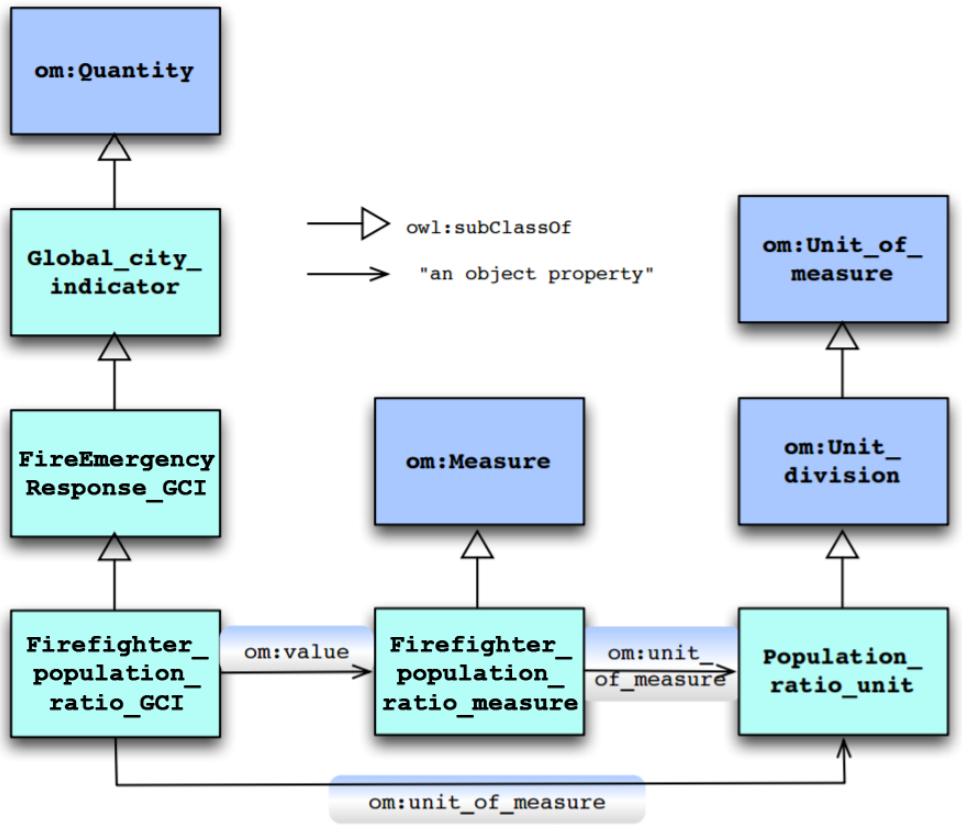

Figure 11 - Measurement Ontology

The OM ontology shown in Figure 11, presents three main classes: the *Quantity* class that denote what is being measured, e.g. the total number of firefighters in a fire brigade; the *Unit_of_Measure* class that denotes how the quantity is measured, e.g. in units; and the *Measure* class that denotes the value of the measurement and it is linked to both *Quantity* and *Unit_of_Measure* classes. For example, the firefighters' population ratio is a subclass of *Quantity* and its value is an instance of *Measure* whose units are a *Population_ratio_unit* that is a subclass of *Unit_of_Measure*. The value measured is a property of *Firefighter_population_ratio_measure*, that is a *Measure* subclass.

The firefighter population ratio indicator is based on a measure of the number of firefighters and people resident in the same city. Both numbers can be viewed as a statistical measurement. In fact, there is the need to perform a measurement of a population and this measurement corresponds to a count of the number of members that satisfy the description of firefighter and city population, respectively. Most of the indicators require a count of a member of a population, but there are other indicators that require some statistics or mathematical operation like mean, subtraction, standard deviation, sum, etc. For this reason, an extension of the GovStat general statistics ontology (Pattuelli, 2009) has been included in the core ontology.

The Fire and Emergency Response indicators defined as a ratio of a certain numerator to a certain denominator may be defined by some indicator-related classes. The core class is a *Population* to be measured. *Population* is linked to a parameter (mean, sum, etc.) by the *is_described_by* property and the parameter is a subclass of *Parameter*. In order to define what portion of a city we need to determine the size of, the GovStat ontology has been extended with the *locate_in* property, that identifies the area (i.e. city) that the *Population* is drawn from, and the *defined_by* property, that identifies the class that all members of the population are subsumed by. For example, the Fire and Emergency Response indicators are all ratios. In Figure 12 it is possible to observe the Foundation Ontology Ratio definition. Each ratio indicator has a unit of measure defined as a Population_ratio_unit, that specifies that the indicator is the ratio sizes (cardinalities) of two populations. One population size is the numerator and the other one the dominator. A Population_size is defined as the cardinality of a Population, and the Population is defined by a City where the population is located in, and by a description of Population_size could be the number of full-time firefighters in a particular city.

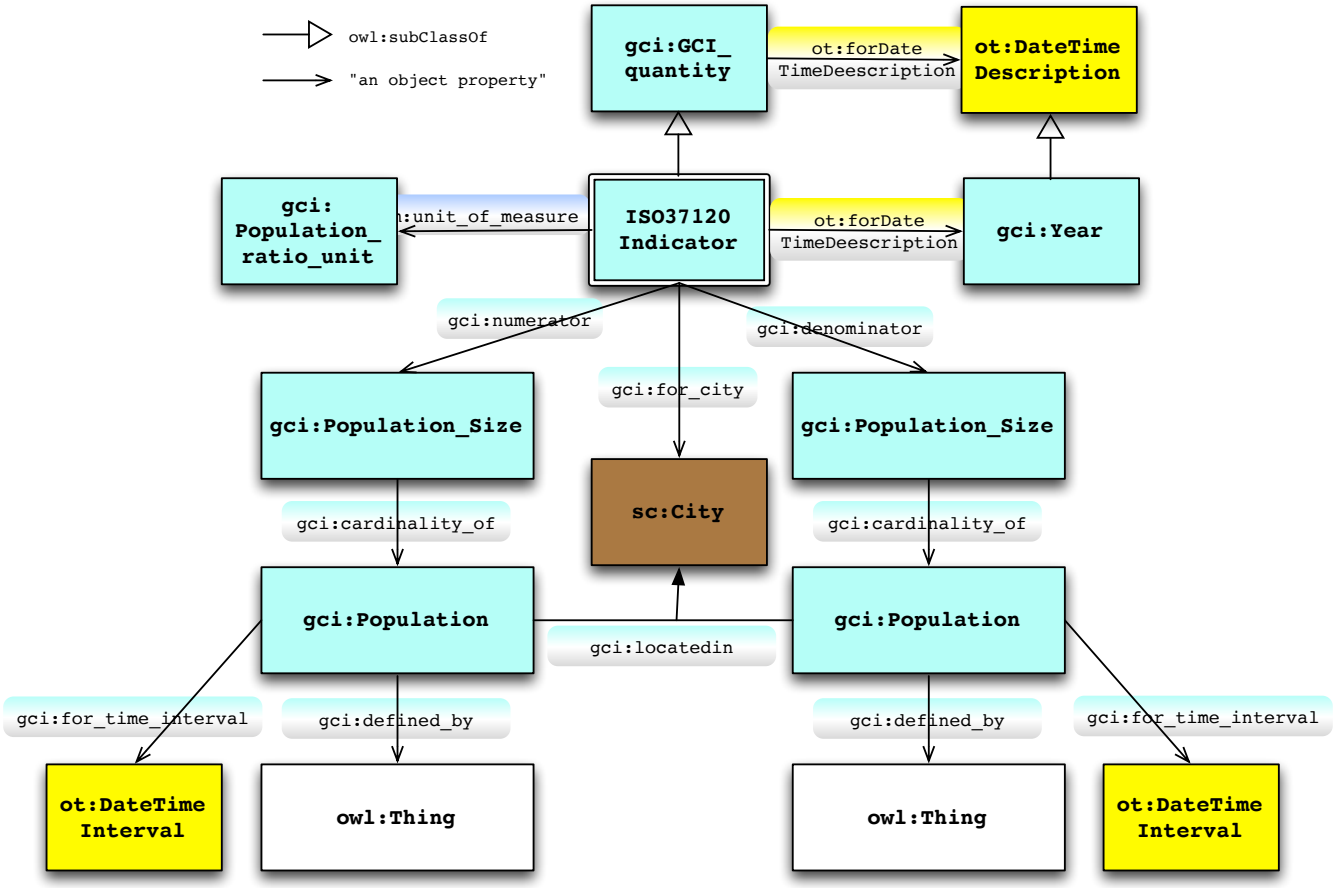

Figure 12 - Foundation Ontology Indicator Pattern

7 ISO 37120 Fire and Emergency Response Indicators Ontology

Using the three ontologies presented in Section 5, it is now possible to define each Fire and Emergency Response indicators.

There are concepts common to more than one indicator which we will present here. The first concept is the city population size that is used to define the dominator of the first four indicators.

The City Population Size is a sub-class of the City Population class and it represents the cardinality of this latter. The City Population is, in turn, a subclass of the Population class and it is defined by one person who is located in one city. Table 4 contains the full definition of these concepts.

CLASS	PROPERTY	VALUE RESTRICTION
gci:City_Population	owl:subClassOf	gci:Population
	gci:located_in	Exactly 1 gci:City
	gci:defined_by	Exactly 1 gci:Resident
gci:City_Population_Size	owl:subClassOf	gci:Population_Size
	gci:cardinality_of	Exactly 1 City_Population
gci:City	owl:subClassOf	geo:Feature

	hasFireBrigade	Some FBOrganization:FireBrigade

Table 4 - City_Population and City_Population_Size definitions

7.1 #10.1 - Number of firefighters per 100,000 population (core indicator)

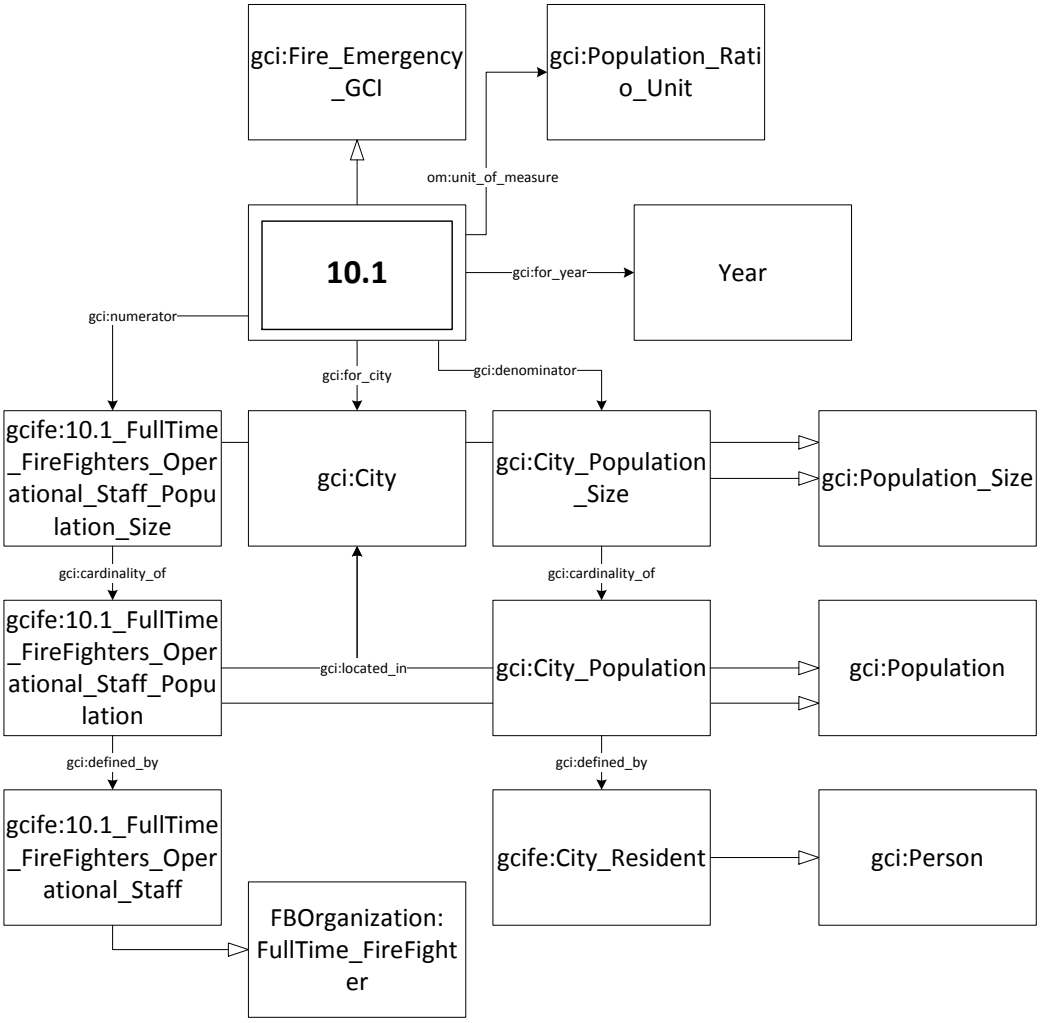

Figure 13 - Indicator 10.1 definition

As already shown in Section 2, the first indicator is a ratio defined as the number of firefighters working in a city divided the population of the same city. The resulting number is represented per 100,000 population. Figure 13 shows a partial definition of the ISO37120:10.1 and the full definition can be found in the owl file that defines this specific core indicator. Table 5, instead, contains the definitions of the main classes and properties represented in Figure 13.

gcife:ISO37120:10.1	om:numerator	gcife:10.1_FullTime_FireFighter_OperationalStaff_population_size
	om:denominator	gci:City_Population_Size
gcife:10.1_FullTime_FireFighter_	owl:subClassOf	gs:Population_Size

OperationalStaff_population_size	gci:cardinality_Of	gcife:10.1_ FullTime_FireFighter_ OperationalStaff_population
gcife:10.1_ FullTime_FireFighter_ OperationalStaff_population	owl:subClassOf	gci:Population
	gci:located_in	gci:City
	gci:defined_By	gcife:10.1_FullTime_FireFighter_ OperationalStaff
	gci:hasPrimaryResidence	Exactly 1 City
gcife:10.1_FullTime_FireFighter_ OperationalStaff	owl:subClassOf	FBOrganization:FireFighter
	gci:hasPlacement	FBOrganization:EmergencyOperation
	gci:hasPrimaryResidence	Exactly 1 City
	owl:subClassOf	FBOrganization:FullTime_FireFighter

Table 5 - ISO37120 10.1 indicator: main classes and properties

The 10.1_FullTime_FireFighter_OperationalStaff_population_size class is defined as the cardinality of the class 10.1_ FullTime_FireFighter_OperationalStaff_population. This latter can be defined as the total number of full-time firefighters placed in the Emergency Operation division of a fire brigade located in the same city in which they are resident (see Section 5.1 and the related ontology shown in Figure 8).

7.2 #10.2 - Number of fire-related deaths per 100,000 population (core indicator)

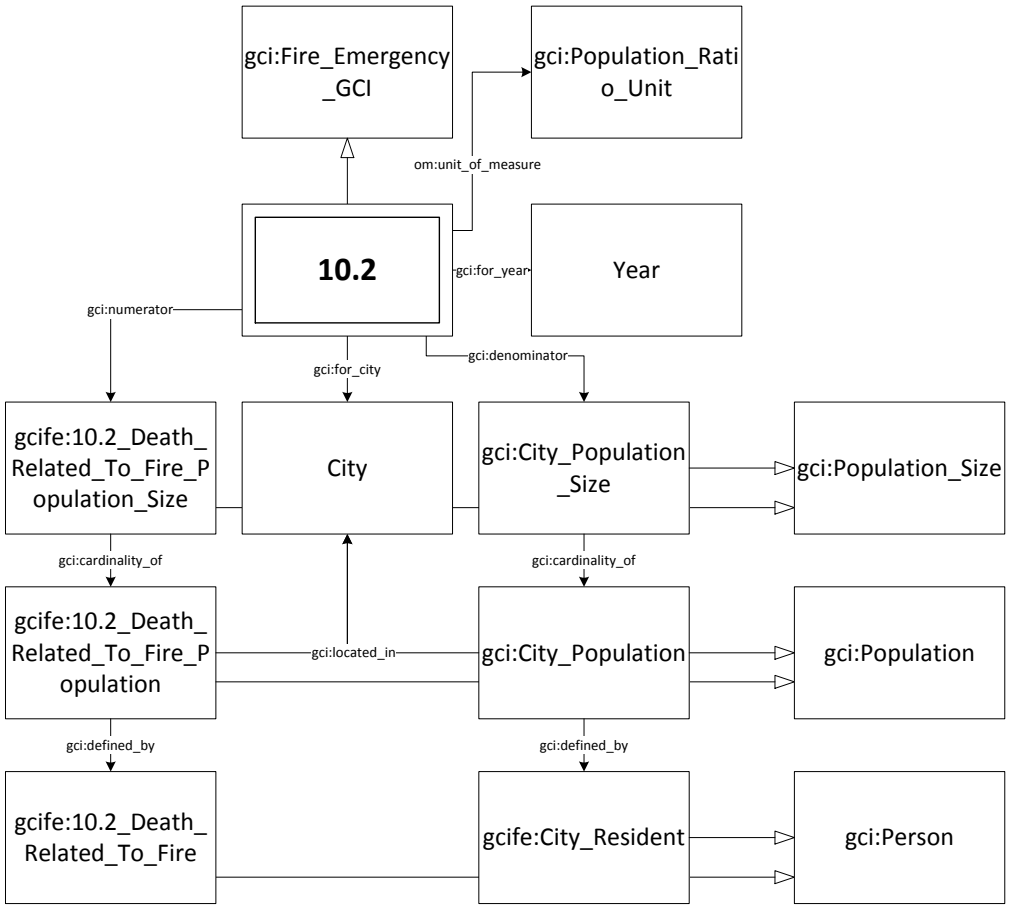

Figure 14 - Indicator 10.2 definition

The ISO37120:10.2 indicator is defined as a ratio having the total number of fire-related deaths occurred in 12 months in a city as the numerator, and the total number of population of the same city, as the denominator (Figure 14). This core indicator must be expressed per 100,000 population.

CLASS	PROPERTY	VALUE RESTRICTION
gcife:ISO37120:10.2	om:numerator	gcife:10.2_Death_Related_To_Fire_Population_Size
	om:denominator	gci:City_Population_Size
gcife:10.2_Death_Related_To_Fire_Population_Size	owl:subClassOf	gci:Population_Size
	gci:cardinality_Of	gcife:10.2_Death_Related_To_Fire_Population
gcife:10.2_Death_Related_To_Fire_Population	owl:subClassOf	gci:Population
	gci:located_in	gci:City
	gci:defined_By	gcife:10.2_Death_Related_To_Fire
	gci:hasPrimaryResidence	Exactly 1 gci:City
gcife:10.2_Death_Related_To_Fire	owl:subClassOf	gci:Person
	FDRDeath:hasHealthState	value "Death"^^ xsd:string
	FDRDeath:isSubjectedTo	Exactly 1 (FDRDeath:burn_by_fire OR FDRDeath:smoke_inhalation OR FDRDeath:panic OR FDRDeath:mechanical_trauma)

Table 6 - ISO37120 10.2 indicator: main classes and properties

The total number of fire-related deaths, represented by the 10.2_Death_Related_To_Fire class, is a subclass of the Person class and it can be obtained looking for people having a health state equal to "death" and one of the following causes of change: burn_by_fire, smoke_inhslstion, panic, mechanical_trauma. In order to work properly, the considered city must be the same in which death people are resident.

7.3 #10.3 - Number of disaster-related deaths per 100,000 population (core indicator)

The definition of this indicator is very similar to the previous one, except for the type of death considered. In fact, the ISO37120:10.3 indicator involves the number of natural-disaster-related death as the numerator and the population of the city as the denominator.

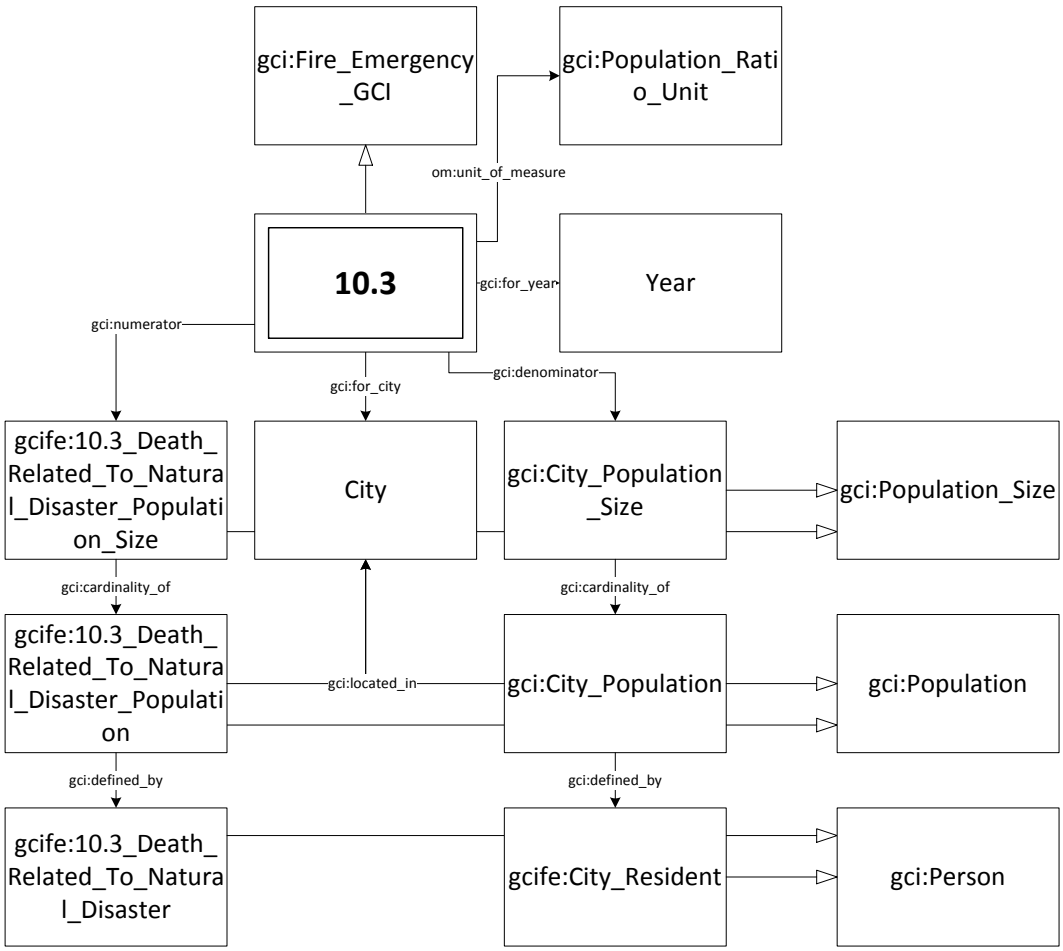

Figure 15 - Indicator 10.3 definition

The 10.3_Death_Related_To_Natural_Disaster_Population_Size class represents the cardinality of the 10.3_Death_Related_To_Natural_Disaster_Population class, which is defined as the 10.3_Death_Related_To_Natural_Disaster population. A natural-disaster-related death can be represented as a person who has a health state equal to “death” and one of the following as a cause of death: heart attack, shaking, drowning, mud, collapse, poisoning, epidemic, panic, and mechanical trauma. Finally, the population of the considered city represents the denominator of this indicator.

CLASS	PROPERTY	VALUE RESTRICTION
ISO37120:10.3	om:numerator	gcife:10.3_Death_Related_TO_ Natural_Disaster_Population_Size
	om:denominator	gci:City_Population_Size
gcife:10.3_Death_Related_ To_Natural_Disaster_Population_Size	owl:subClassOf	gci:Population_Size
	gci:cardinality_Of	gcife:10.3_Death_Related_To_ Natural_Disaster_Population
gcife:10.3_Death_Related_To _Natural_ Disaster_Population	owl:subClassOf	gci:Population
	gci:located_in	gci:City
	gci:defined_By	gcife:10.3_Death_Related_To_ Natural_Disaster
	gci:hasPrimaryResidence	Exactly 1 gci:City
gcife:10.3_Death_Related_To_	owl:subClassOf	gci:Person

Natural_Disaster	FDRDeath:hasHealthState	value “Death”^^xsd:string
	FDRDeath:isSubjectedTo	exactly 1 (FDRDeath:Heart_attack OR FDRDeath:shaking OR FDRDeath:drowning OR FDRDeath:mud OR FDRDeath:collapse OR FDRDeath:poisoning OR FDRDeath:epidemic OR FDRDeath:mechanical_trauma)

Table 7 - ISO37120 10.3 indicator: main classes and properties

7.4 #10.4 - Number of volunteer and part-time firefighters per 100,000 population (supporting indicator)

The ISO37120:10.4 is a supporting indicator and it is calculated as the ratio between the total number of part-time and volunteer firefighters working as operational staff, and the total population of the city.

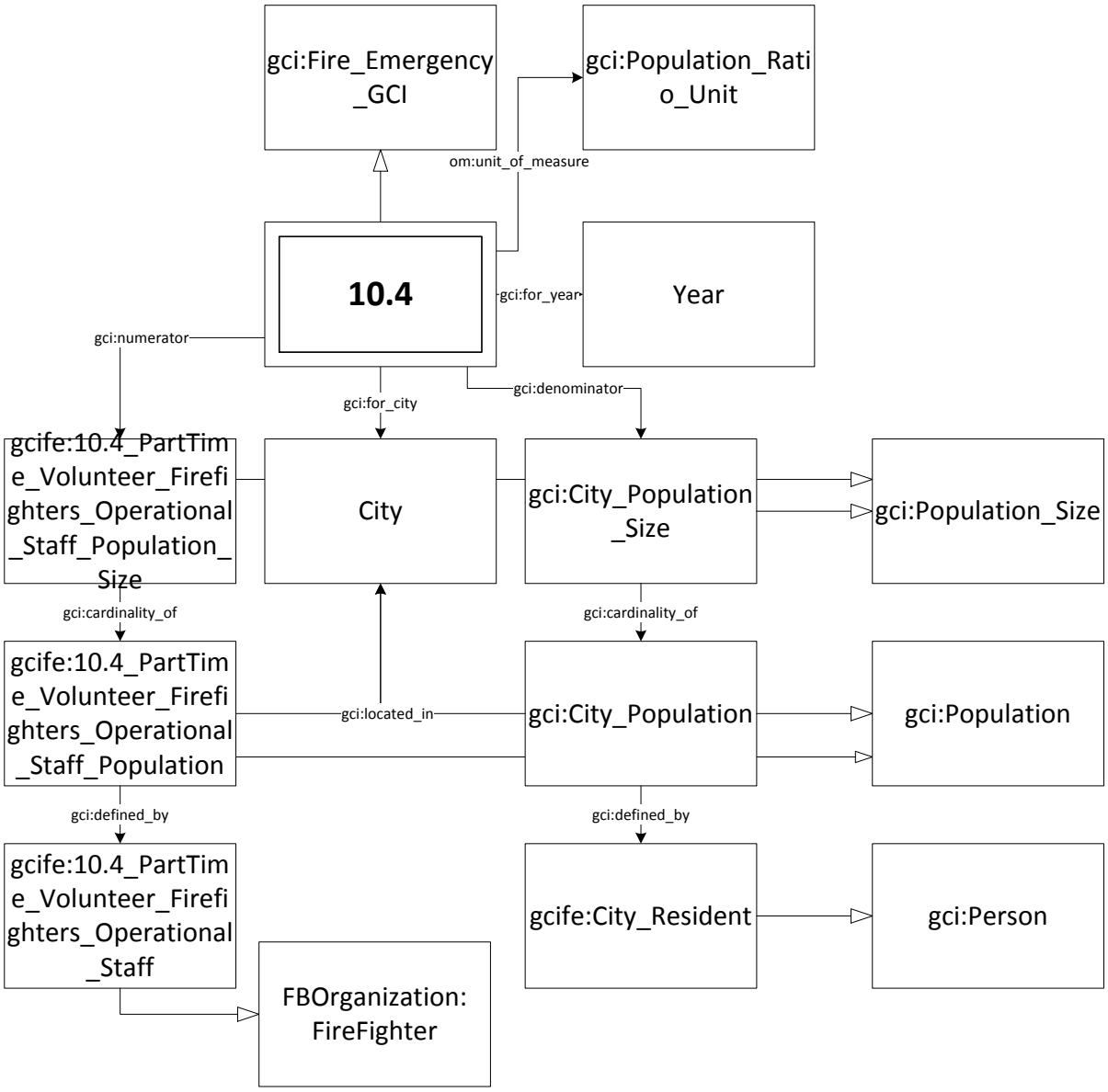

Figure 16 - Indicator 10.4 definition

The 10.4_PartTime_Volunteer_FireFighter_OperationalStaff_population_size class represent the cardinality of the population 10.4_ PartTime_Volunteer_FireFighter_OperationalStaff_population which is then defined as the PartTime_Volunteer_FireFighter_OperationalStaff class.

CLASS	PROPERTY	VALUE RESTRICTION
gcife:ISO37120:10.4	om:numerator	gcife:10.4_ PartTime_Volunteer_FireFighter_ OperationalStaff_population_size
	om:denominator	gci:City_Population_Size
gcife:10.4_PartTime_Volunteer_Fire Fighter_OperationalStaff_population_size	owl:subClassOf	gci:Population_Size
	gci:cardinality_Of	gcife:10.4_PartTime_Volunteer_ FireFighter_OperationalStaff_populatio n
gcife:10.4_	owl:subClassOf	gci:Population

PartTime_Volunteer_FireFighter_ OperationalStaff_population	gci:located_in	gci:City
	gci:defined_By	gcife:PartTime_Volunteer_ FireFighter_OperationalStaff
gcife:PartTime_Volunteer_Fire Fighter_OperationalStaff	owl:subClassOf	FBOrganization:PartTime_FireFighter
	owl:subClassOf	FBOrganization:Volunteer _FireFighter
	gcife:hasPlacement	FBOrganization:Division
	gci:hasPrimaryResidenc e	exactly 1 gci:City

Table 8 - ISO37120 10.4 indicator: main classes and properties

7.5 #10.5 - Response time for emergency response service from initial call (supporting indicator)

The ISO37120:10.5 indicator is the ratio between the 10.5_ Initial_Distress_Call_Time_FRT_Population_Sum and the total number of emergency responded by a first responder team. The initial distress call time of a first response team can be calculated as the difference between the gcife:Responder_TimeArrive and the gcife:StartTime, that represent the time between the emergency starting and the arrival time of the first response team at the emergency location.

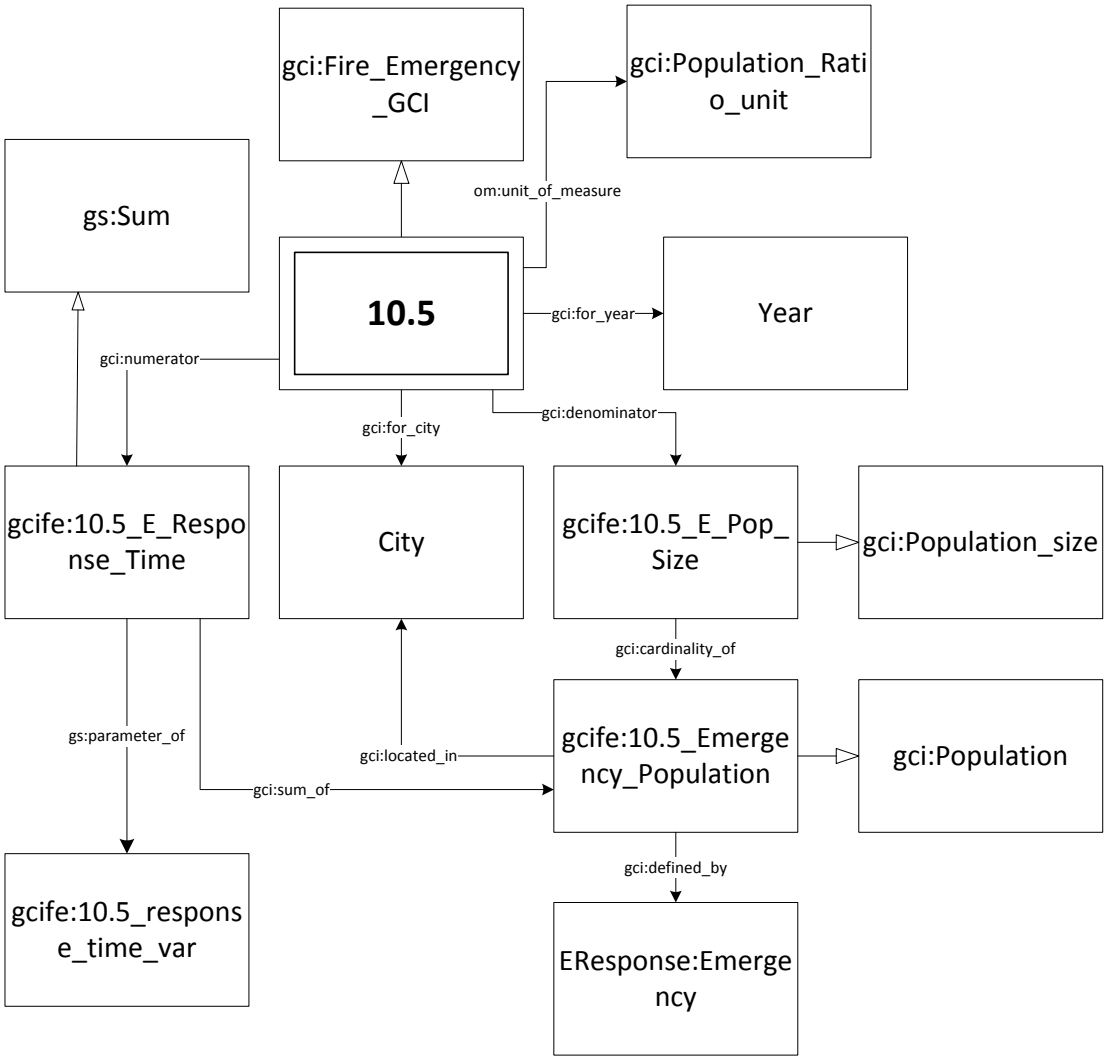

Figure 17 - Indicator 10.5 definition

CLASS	PROPERTY	VALUE RESTRICTION
ISO37120:10.5	om:numerator	gcife:10.5_ E_Response_Time
	om:denominator	gcife:10.5_E_Pop_Size
gcife:10.5_ E_Response_Time	owl:subClassOf	gs:Sum
	owl:subClassOf	om:Duration
	om:unit_of_measure	om:minute-time
	gs:sum_of	gcife:10.5_Emergency_Population
	gs:parameter_of	only 1 10.5_response_time_var
gcife:10.5_response_time_var	rdfs:type	gs:Variable
	gs:has_name	"response_time"
gcife:10.5_E_Pop_Size	owl:subClassOf	gci:Population_Size
	gs:cardinality_of	gcife:10.5_Emergency_Population
gcife:10.5_Emergency_Population	owl:subClassOf	gci:Population
	gci:defined_by	eresponse:Emergency

Table 9 - ISO37120 10.5 indicator: main classes and properties

7.6 #10.6 - Response time for fire department from initial call (supporting indicator)

This indicator is very similar to the one showed in the previous section, in fact, it has the total response time calculated on emergencies to which responded a fire department, as a numerator and the total number of emergenies for the fire department as a denominator. This is another support indicator.

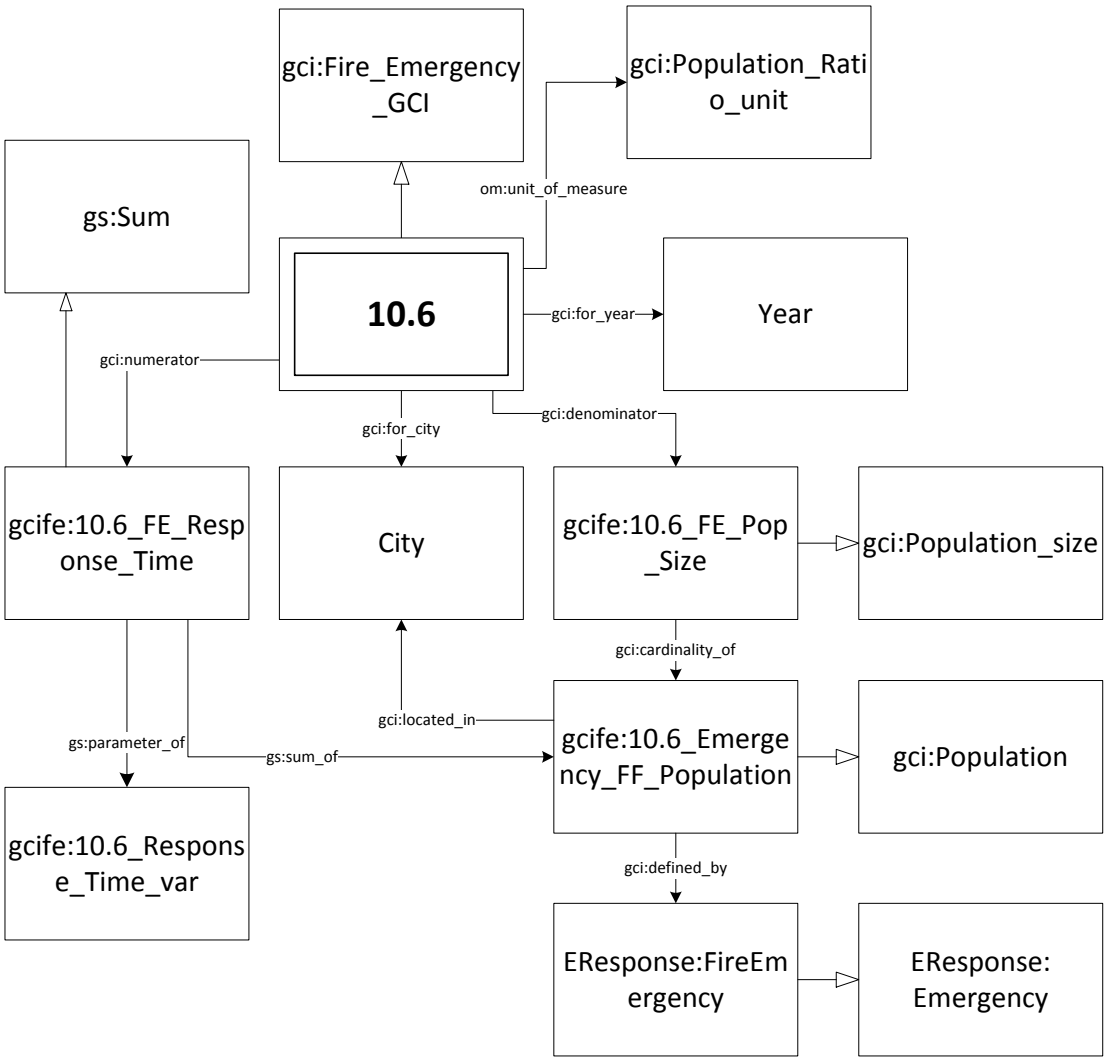

Figure 18 - Indicator 10.6 definition

CLASS	PROPERTY	VALUE RESTRICTION
ISO37120:10.6	om:numerator	gcife:10.6_ FE_Response_Time
	om:denominator	gcife:10.6_FE_Pop_Size
gcife:10.6_ FE_Response_Time	owl:subClassOf	gs:Sum
	owl:subClassOf	om:Duration
	om:unit_of_measure	om:minute-time
	gs:sum_of	gcife:10.6_Emergency_FF_Population
	gs:parameter_of	only 1 10.6_response_time_var
10.6_response_time_var	rdfs:type	gs:Variable

	gs:has_name	“response_time”
gcife:10.6_FE_Pop_Size	owl:subClassOf	gci:Population_Size
	gs:cardinality_of	gcife:10.6_Emergency_FF_Population
gcife:10.6_Emergency_FF_Population	owl:subClassOf	gci:Population
	gci:defined_by	eresponse:FireEmergency

Table 10 - ISO37120 10.6 indicator: main classes and properties

8 Evaluation

Among the several issues, the most critical aspects related to an ontology construction that enables deduction and reasoning, are connected to the verification and validation of the obtained model and knowledge base.

In fact, a verification and validation process can be performed by defining a set of SPARQL queries on the knowledge base with the aim of detecting inconsistencies and incompleteness, and verifying the correct status of the model [Bellini at al., 2014b]. In this case, the SPARQL queries useful for the validation process correspond to the CQs defined in Section 2.

This evaluation uses data for the year 2013 for the city of Toronto in Ontario, Canada and it presents an example of the process related to the ISP37120:10.1 indicator, that is the core indicator for the number of firefighters per 100,000 population.

Prefix are defined as follow:

- gn: http://sws.geonames.org/
- gci: http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl#
- gcife: http://ontology.eil.utoronto.ca/GCI/FireEmergency/GCI-FireEmergency.owl#
- FBOrganization: http://ontology.eil.utoronto.ca/GCI/FireEmergency/FBOrganization.owl#
- FDRDeath: http://ontology.eil.utoronto.ca/GCI/FireEmergency/FDRDeath.owl#
- EResponse: http://ontology.eil.utoronto.ca/GCI/FireEmergency/EResponse.owl#
- gs: http://ontology.eil.utoronto.ca/govstat.owl#
- om: http://www.wurvoc.org/vocabularies/om-1.8/
- owl: http://www.w3.org/2002/07/owl#
- ic: http://ontology.eil.utoronto.ca/icontact.owl#
- iso: http://ontology.eil.utoronto.ca/ISO37120.owl#
- act: http://ontology.eil.utoronto.ca/tove/activity.owl#
- time: http://www.w3.org/2006/time#
- sc: http://schema.org/

Instance	Property	Value
gn:6251999	rdfs:label	“Canada”
	rdfs:type	gn:Feature
	rdfs:type	sc:Country
gn:6093943	rdfs:label	“Ontario”
	rdfs:type	gn:Feature
	rdfs:type	sc:Province
gn:6167865	rdfs:label	“Toronto”
	rdfs:type	gn:Feature
	rdfs:type	gci:City

Instance	Property	Value
10.1_ex (instance of 10.1)	rdfs:type	iso:10.1
	gci:numerator	10.1_FT_FF_size
	gci:denumerator	10.1_P_size
	gci:for_year	2013
	gci:for_city	gn:6167865
	om:unit_of_measure	gci:Population_ratio_unit
	om:value	10.1_ex_value
10.1_ex_value (the value of 10.1)	rdfs:type	om:measure
	om:numerical_value	100.4
	om:unit	gci:Population_Ratio_Unit (change to instance)
10.1_FT_FF_size (numerator of 10.1)	rdfs:type	gcife:10.1_FullTime_FireFighter_ OperationalStaff_population_size
	gci:cardinality_of	10.1_FT_FF_pop
	om:phenomenon	10.1_FT_FF_pop
	om:value	10.1_FT_FF_size_value
10.1_P_size (denominator of 10.1)	rdfs:type	10.1_City_Population_Size
	gci:cardinality_of	10.1_P_pop
	om:phenomenon	10.1_P_pop
	om:value	10.1_P_size_value
10.1_FT_FF_size_value (value of the numerator of 10.1)	rdfs:type	om:measure
	om:numerical_value	2782
	om:unit	gci:Population_Size (change to instance)
10.1_P_size_value (value of the denominator of 10.1)	rdfs:type	om:measure
	om:numerical_value	27.71
	om:unit	gci:Population_Size (change to instance)
10.1_FT_FF_pop (numerator population)	rdfs:type	gcife: 10.1_ FullTime_FireFighter_ OperationalStaff_population
	gci:locatedIn	gn:6167865
	gci:defined_by	10.1_FT_FF_person
10.1_P_pop (denominator population)	rdfs:type	gcife:10.1_City_Population
	gci:locatedIn	gn:6167865
	gci:defined_by	10.1_P_person
10.1_FT_FF_person	rdfs:type	gcife:10.1_FullTime_FireFighter_ OperationalStaff
10.1_P_person	rdfs:type	10.1_City_Resident

Instance	Property	Value
john_smith	rdfs:type	gci:Person
	org:memberOf	10.1_P_pop
	org:memberOf	10.1_FT_FF_pop
	ic:hasAddress	js_address
js_address	rdfs:type	Ic:Address
	ic:hasCity	gn:6167865

	ic:hasState	gn:6093943
	ic:hasCountry	gn:6251999

8.1 Verification

In this section we verify a portion of the ontology by showing how the CQs for the indicator: *Number of firefighters per 100,000 population (core indicator)* can be specified as SPARQL queries.

(F) What city is the indicator for?

```
SELECT ?city WHERE {
        10.1_ex         gci:for_city      ?city
}
```

(F) What is the population of the city?

```
SELECT ?Population WHERE {

        10.1_ex gci:dominator   ?Pop
        ?Pop    om:value ?Meas
        ?Meas   om:numerical_value ?Population
}
```

(F) In which division can a full-time firefighter work?

```
SELECT DISTINCT(?division) WHERE {
        ?firefighter      a FBOrganization:FullTime_FireFighter
        ?firefighter      FBOrganization:hasPlacement   ?division
}
```

(CD) Is the full-time firefighter X resident of the city in which his fire brigade is located?

```
SELECT ?firefighter WHERE {
        ?firefighter      a FBOrganization:FullTime_FireFighter
        ?firefighter      a gci:Person
        ?city             a gci:City
        ?firefighter      gci:hasPrimaryResidence         “city”
        ?firefighter      FBOrganization:hasPlacement   ?division
        ?brigade          org:consistOf    ?division
        ?brigade          FBOrganization:isPartOfCity     ?city
}
```

(D) What category of firefighter does the city X have?

```
SELECT DISTINCT(?typeFF) WHERE {
        ?city             rdfs:label        “X”
        ?brigade          FBOrganization:isPartOfCity     ?city
        ?city             a gci:City
```

```
        ?division       a FBOrganization:Division
        ?brigade        org:consistOf   ?division
        ?firefighter    FBOrganization:hasPlacement   ?division
        ?firefighter    rdfs:type       ?typeFF
}
```

(D) Is the firefighter X a full-time firefighter? (F) Is the firefighter X full-time, part-time, or volunteer?

```
SELECT ?typeFF WHERE {
        ?firefighter    rdfs:label      "X"
        ?firefighter    rdfs:type       ?typeFF
}
```

(D) Is the full-time firefighter X part of the emergency operational staff?

```
SELECT ?firefighter WHERE {
        ?firefighter    a FBOrganization:FullTime_FireFighter
        ?firefighter    FBOrganization:hasPlacement   ?division
        ?division       a FBOrganization:Division
        ?division       rdfs:label      "Emergency Operational"
}
```

(F) What divisions is the fire brigade X of the city Y composed of?

```
SELECT ?division WHERE {
        ?brigade        a FBOrganization:FireBrigade
        ?brigade        rdfs:label              "X"
        ?brigade        FBOrganization:isPartOfCity   ?city
        ?city           a gci:City
        ?city           rdfs:label              "Y"
        ?division       a FBOrganization:Division
        ?brigade        org:consistOf   ?division
}
```

(D) Which type of firefighter works in division X?

```
SELECT ?typeFF WHERE {
        ?firefighter    a ?typeFF
        ?firefighter    FBOrganization:hasPlacement   ?division
        ?division       a FBOrganization:Division
        ?division       rdfs:label      "X"
}
```

(CI) Can a firefighter work in a fire brigade located in a city that is not his resident city?

```
SELECT ?firefighter ?cityR ?cityW WHERE {
        ?firefighter    a gcife:FireFighter
        ?firefighter    a gci:Person
```

```
        ?brigade        a FBOrganization:FireBrigade
        ?firefighter    gci:hasPrimaryResidence        ?cityR
        ?firefighter    gcife:hasPlacement      ?division
        ?brigade        org:consistOf   ?division
        ?brigade        gcife:isPartOfCity      ?cityW
}
```

8.2 Validation

The research presented in this paper has two goals:

1. To determine that the data provided by a city is consistent with the definitions provided in ISO37120, and
2. To determine the root causes for why a city's indicator changes over time (i.e. longitudinal analysis), or why it differs from another city (i.e. transversal analysis).

This section focusses on using the Fire and Emergency Response ontology for consistency analysis. Root case analysis will be addressed in future research.

There are two types of consistency we are concerned with:

1. Is the data submitted by a city for a specific indicator in the form of OWL.
    a. Does each individual contain all the necessary properties and satisfy the property restrictions defined in the class it is a member of?
2. How to manage definitional constraints that cannot be represented in OWL?

To resolve the first type of consistency, a set of Prolog rules has been implemented to determine whether an individual is consistent with the class it is a member of. Given an individual and its corresponding class, the rules determine whether:

- The individual contains all of the necessary properties as defined by the class it is a member of, and
- The corresponding value for the individual's property is consistent with the restrictions defined by the class for that property.

To handle the second type of consistency, each constraint has been represented as a Prolog rule that can be applied to any individuals/instances of 10.1 indicator data. This is because the second type of consistency is represented in this paper by axioms (definitional constraints) that cannot be represented in OWL.

The validation of the Fire and Emergency Response Ontology has been performed by representing the City of Toronto's Fire and Emergency Response indicators using the ontology.

9 Conclusions

This research defines an ontology that represents the ISO37120 Fire and Emergency Response theme indicator definitions. To do so, three other ontologies have been defined to represent all the relevant information related to an emergency call, a fire brigade and a death related to fire or natural disaster. Thanks to these ontologies, the analysis of a city's performance represented by the indicators, can be performed, in order to compare cities and identify differences between their values.

In summary, this research makes the following contributions:

- Defines a Fire Brigade organization ontology that represents this specific organization using the Organization ontology;

- Defines an Emergency Response ontology that models the 911 process to answer to an emergency call;
- Defines a Fire Related and Disaster Relate Death ontology;
- Defines each ISO37120 Fire and Emergency Response indicator using the foundation and the Fire and Emergency Response Ontology;
- Enables the publishing of a city's ISO37120 Fire Emergency Response indicators' values along with supporting data used to derive them using Semantic Web standards.
- Demonstrates that the ontology-based definitions of indicators can be used to automatically validate that indicator data supplied by cities conforms (or not) to the indicator definitions.

10 References

Bellini, P., Benigni, M., Billero, R., Nesi, P., & Rauch, N. (2014). "Km4City ontology building vs data harvesting and cleaning for smart-city services". *Journal of Visual Languages & Computing*, Vol. *25*, No. 6, pp. 827-839.

Bellini, P., Nesi, P., & Rauch, N. (2014). Knowledge Base Construction Process for Smart-City Services. In *19th International Conference on Engineering of Complex Computer Systems (ICECCS)*, pp. 186-189, IEEE.

Clark, T., Sammut, P., & Willans, J. (2008). Applied metamodelling: a foundation for language driven development.

Comes, T., Hiete, M., & Schultmann, F. (2013). An Approach to Multi-Criteria Decision Problems Under Severe Uncertainty. *Journal of Multi-Criteria Decision Analysis*, *20*(1-2), 29-48.

Fadel, F. G., Fox, M. S., & Gruninger, M. (1994). A generic enterprise resource ontology. In Enabling Technologies: Infrastructure for Collaborative Enterprises, 1994. Proceedings., Third Workshop on (pp. 117-128). IEEE.

Fadel, F. G. (1994). A Resource Ontology for Enterprise Modelling. M.A. Sc. Thesis, Enterprise Integration Laboratory, University of Toronto.

Fazel-Zarandi, M., & Fox, M. S. (2012). "An Ontology for Skill and Competency Management", In *Formal Ontologies in Information Systems*, pp. 89-102.

Fox, M. S. (1992). The tove project towards a common-sense model of the enterprise. In *International Conference on Industrial, Engineering and Other Applications of Applied Intelligent Systems* (pp. 25-34). Springer Berlin Heidelberg.

Fox, M. S. (2013). A foundation ontology for global city indicators. *University of Toronto, Toronto, Global Cities Institute*.

Fox, M. S. (2014), "An Education Ontology for Global City Indicators (ISO 37120)", In *Working Paper, Enterprise Integration Laboratory, University of Toronto* (Vol. 2014, No. 2014).

Fox, M. S. (2017). "The PolisGnosis Project: Enabling the Computational Analysis of City Performance", *Proceedings of the 2017 Industrial and Systems Engineering Conference*, K. Coperich, E. Cudney, H. Nembhard, eds., Institute for Industrial and Systems Engineering.

Fox, M. S., Barbuceanu, M., & Gruninger, M. (1996). An organisation ontology for enterprise modeling: Preliminary concepts for linking structure and behaviour. *Computers in industry*, *29*(1), 123-134.

Fox, M.S., Chionglo, J., Fadel, F. A, (1993), Common-Sense Model of the Enterprise, Proceedings of the Industrial Engineering Research Conference.

Fox, M. S., & Grüninger, M. (1994). Ontologies for Enterprise Integration. In *CoopIS* (pp. 82-89).

Fox, M. S., & Gruninger, M. (1998). Enterprise modeling. *AI magazine*, *19*(3), 109.

Fox, M. S., & Huang, J. (2005). Knowledge provenance in enterprise information. *International Journal of Production Research*, *43*(20), 4471-4492.

Gangemi, A. (2005, November). Ontology design patterns for semantic web content. In *International semantic web conference* (pp. 262-276). Springer Berlin Heidelberg.

[Geonames] - www.geonames.org

Gruber, T. R. (1993). A translation approach to portable ontology specifications. *Knowledge acquisition*, *5*(2), 199-220.

Grüninger, M., & Fox, M. S. (1995). Methodology for the Design and Evaluation of Ontologies.

Hobbs, J. R., & Pan, F. (2006). Time ontology in OWL. W3C working draft, 27 September 2006. *W3C Working Draft*, *27*.

Huang, J., & Fox, M. S. (2006, August). An ontology of trust: formal semantics and transitivity. In *Proceedings of the 8th international conference on Electronic commerce: The new e-commerce: innovations for conquering current barriers, obstacles and limitations to conducting successful business on the internet* (pp. 259-270). ACM.

[iContact] - International Contact Ontology http://ontology.eil.utoronto.ca/icontact.html

Megan Katsumi and Mark Fox (2017, January). iCity Ontology Initial Release. http://ontology.eil.utoronto.ca/icity/iCityOntology_v1%20Report.pdf

Kim, H. M., & Fox, M. S. (1994). Formal Models of Quality and ISO 9000 Compliance. In *ANNUAL QUALITY CONGRESS PROCEEDINGS-AMERICAN SOCIETY FOR QUALITY CONTROL* (pp. 17-17).

Lebo, T., Sahoo, S., McGuinness, D., Belhajjame, K., Cheney, J., Corsar, D., ... & Zhao, J. (2013). Prov-o: The prov ontology. *W3C recommendation*, *30*.

Lin, J., Fox, M. S., & Bilgic, T. (1996). A requirement ontology for engineering design. *Concurrent Engineering*, *4*(3), 279-291.

Lin, J., Fox, M. S., & Bilgic, T. (1997). A product ontology. *Enterprise Integration*.

NFPA 1710 - Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments Scope. 2016

Niles, I., & Pease, A. (2001, October). Towards a standard upper ontology. In *Proceedings of the international conference on Formal Ontology in Information Systems-Volume 2001* (pp. 2-9). ACM.

Nunavath, V., Radianti, J., Comes, T., & Prinz, A. (2015). Visualization of information flows and exchanged information: evidence from an indoor fire game.

Nunavath, V., Prinz, A., Comes, T., & Radianti, J. (2016). Representing fire emergency response knowledge through a domain modelling approach.

NFPA (2015)- A Reporter's Guide to Fire and the NFPA (2015).

Pattuelli, M. C. (2003). The GovStat Ontology: Technical Report. *The GovStat Project, Integration Design Laboratory, School of Information and Library Science, University of North Carolina at Chapel Hill, http://ils. unc. edu/govstat/papers/govstatontology. doc*.

Rijgersberg, H., Wigham, M., & Top, J. L. (2011). How semantics can improve engineering processes: A case of units of measure and quantities. *Advanced Engineering Informatics*, *25*(2), 276-287.

Wang, Y. & Fox, M.S. (2015). A Shelter Ontology for Global City. Indicators (ISO+37120)

SSN, (2017), Semantic Sensor Net Ontology, https://www.w3.org/TR/vocab-ssn/

Tham, K. D., Fox, M. S., & Gruninger, M. (1994, April). A cost ontology for enterprise modelling. In *Enabling Technologies: Infrastructure for Collaborative Enterprises, 1994. Proceedings., Third Workshop on* (pp. 197-210). IEEE.

Van de Walle, B., & Turoff, M. (2008). Decision support for emergency situations. *Information Systems and E-Business Management*, *6*(3), 295-316.

12 Appendix

The Global City Indicator Foundation ontology can be found in:
http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Founation-v2.owl.

The Global City Indicator Fire & Emergency ontology can be found in:
http://ontology.eil.utoronto.ca/GCI/FireEmergency/GCI-FireEmergency.owl.

URIs for all of the ISO37120 indicators can be found in:
http://ontology.eil.utoronto.ca/ISO37120.owl.

Definitions of the ISO37120 Fire & Emergency indicators, using the GCI Foundation and FireEmergency ontologies can be found in:
http://ontology.eil.utoronto.ca/GCI/ISO37120/FireEmergency.owl.

Representation of the City of Toronto 2013 ISO 37120 Fire & Emergency values can be found in: http://ontology.eil.utoronto.ca/ISO37120/Toronto/2013/ISO37120_10_2013_TO.ttl.