Residency and service towards a standard for representing telecommunications and innovation open data

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Abstract: In order to compare and analyse open data across cities, standard representations or ontologies have to be created. This paper defines a innovation and telecommunications ontology that includes concepts of residency and services. The design of the ontology is based upon the data requirements of the ISO 37120:17 telecommunication and innovation indicators. ISO 37120 defines 100 indicators to measure and compare city performance. This ontology enables both the representation of ISO 37120:17 telecommunication and innovation indicators’ definitions, and a city’s indicator values and supporting data. This enables the analysis of city innovation and telecommunications

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1 Introduction

Governments need an effective way to measure and compare their city’s innovation capacity. In an increasingly interconnected global environment, cities are competing to establish world leading infrastructure to foster and support innovation. This is part of a broader move to build smart cities that enhance the quality of service provided to city residents. The capacities to share information, analyse city inefficiencies, improve innovation capacities, and to perform longitudinal/transversal analysis of city performance are prerequisites to building smarter cities. In order to analyse a city and compare it to other cities, a set of precisely defined metrics, consistently applied within and across cities is required.

To address the problem of imprecise and incomparable metrics, standard indicators of city performance were formalised by ISO 37120 (ISO, 2014). ISO 37120 is comprised of over 100 city indicators divided into 17 themes, including ‘telecommunications and innovation’ with a standard definition and methodology. ISO 37120 provides the definitions necessary to measure a city’s performance regardless of its geographic location or demographics. Never the less, there or many outstanding issues including:

- the publishing of a city’s ISO 37120 indicators do not include the data used to derive them[1]
- even though cities espouse the importance of open data, little if any of the data used to derive indicators is available on their open data websites (Fox and Pettit, 2015)
- cities that do publish data do not have a global data standard to follow, consequently cities use different data models and vocabularies for publishing related indicator data.

The primary goal of the PolisGnosis project (Fox, 2015a) is to automate the analysis of city performance using an intelligent agent that takes as input: an indicator definition and the data cities use to derive their indicator values. However before this analysis can be performed, that following standards must exist:

1 A representation of the meta data associated with a published indicator value.
   - For example, its units, scale, its provenance (when it was created, who created it, what process was used to create it), the degree of certainty in the value, and the degree to which the organisation that created it and/or the process used to derive it can be trusted?

2 A representation of the indicator definition. 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.

3 A representation of the data used to derive an indicator value.
   - An indicator is the apex of a tree of supporting data that is aggregated across place, time, organisations, etc. How is this represented?

4 A representation of an indicator's theme specific knowledge.

- Each theme, such as education, health, shelter, etc., has a core set of common sense knowledge that has to be represented for both the definition of an indicator and publishing an instance of an indicator and its supporting data.

5 A representation of 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 ontology for representing the definitions of the ISO 37120:17 telecommunications and innovation indicators (herein referred to as the innovation ontology). This ontology can be used by cities as a standard for the open publishing of telecommunication and innovation indicator data on the semantic web.

In the following we introduce the GCI innovation ontology, which contains two micro ontologies; residency and service. We then demonstrate how an Innovation indicator definition is represented using the ontology. Then, we verify the ontology by using competency questions (CQs) (Grüninger and Fox, 1995) to determine if the ontology satisfies its intended purpose of representing the ISO 37120 telecommunication and innovation indicators. Finally, we briefly discuss on how cities can use the ontology and future applications.

2 Background

2.1 ISO 37120

ISO 37120 defines a set of indicators for measuring city services and quality of life (Karayannis, 2014). ISO 37120 is composed 100 indicators divided into 17 themes, including education, transportation, shelter and telecommunications and innovation. Since its introduction in 2014, cities have begun to report their indicator values on the world council for city data website (http://www.dataforcities.org/). Yet, none of these indicators are available in semantic web form, nor is the data used to derive the indicator values available (Fox and Pettit, 2015).

2.2 ISO 37120 telecommunication and innovation indicators

The ISO 37120 telecommunication and innovation theme contains three indicators:

- (17.1) number of internet connections per 100,000 residents (core indicator)
- (17.2) number of cell phone connections per 100,000 population (core indicator)
- (17.3) number of landline phone connections per 100,000 population (supporting indicator).

Based on the analysis of the definitions of each of these indicators we define a set of CQs[2] that the ontology must be able to answer. CQs fall into the following categories:

- factual (F): questions that ask what the value of some property is.
- consistency-definitional (CD): determine whether the instantiation of an indicator by a city is consistent with the ISO 37120 definition
- consistency-internal (CI): determine whether different parts of the instantiation are consistent with each other
- deduced (D): a value or relationship can be deduced form the instantiation.

The definitions of the ISO 37120 telecommunication and innovation indicators, along with their CQs, can be found in Forde and Fox (2015). Following is a subset of CQs.

1 (F) what city is the indicator for?

2 (F) what is the population of the city?

3 (F) what organisations provide internet service?

4 (CI) for each internet service provider, how many subscribers are there?

5 (F) at what minimum price does the service provider provide service to the subscriber?

6 (D) did the subscriber purchase the service within the census year?

7 (D) is the reported number of subscribers (connections) certified by the government?

2.3 Existing innovation ontologies

In this section we review existing vocabularies and ontologies that focus on innovation.

- *Items ontology* (Ning et al., 2006): used to facilitate the collection, distribution and development of ideas by focusing on features that are people-centric
- *OntoGate ontology* (Bullinger, 2008): its purpose is to enable the understanding of the innovation process. It focuses on idea assessment and selection.
- *GI2MO ontology* (Westerski et al., 2010): enables IT systems to share information with each other, using semantic web technologies, by formalising metadata that describes innovations and related information.

These ontologies were found to not contain any concepts nor properties relevant to answering the CQs.

2.4 Existing telecommunication ontologies

The most comprehensive ontology found that deals with telecommunication were the telecommunications service domain ontology (TSDO). The TDSO enables the implementation of semantic web services within telecommunication service systems (Qiao et al., 2012). Below are the classes and properties from the TSDO that were found to be relevant.

- *ServiceRole:* describes the stakeholder's concepts of the service supply chain, for example: service provider, content provider, network operator, and service user.
- *ServiceCategory:* describes a telecommunication's service classification. This ontology defines the relationship between various telecommunications services, like: basic service, value-added service, voice service, data service, conference service, presence service, download service, browsing service, and messaging service.
- *Network:* specifies the network concepts, network category, network features, as well as the relationships of various networks such as, mobile network, internet and fixed network, GSM, CDMA, UMTS, WCDMA, and WLAN.

3 Innovation ontology

The following defines the two ontologies required to represent the definitions of the innovation indicators: residency and services.

3.1 Residency ontology

The telecommunication and innovation indicators rely upon the number of residents in the city. The question is: what is a resident? Depending on where people live in the world the definitions of what makes someone a resident of that city will vary. In Toronto, "you are identified as a resident if you reside in, own property, or own or operate a business in Toronto" (311 Toronto). In Beijing, they use the Hukou system which is a household registration program that results in a government issued permit. Beijing residents are "all individuals holding the nationality of the People's Republic of China who have a domicile in Beijing and nowhere else. If the individual maintains a regular dwelling somewhere else, the more regular dwelling is considered their place of residence" (Li, 1991).

Table 1 Resident class description

Class	*Property*	*Value*
Resident	owl:subClassOf	person OR organisation
	owl:subClassOf	Residency
	cityCurrentlyResiding In	Exactly 1 City
	reside in	Residence
	hasProof	AcceptedResidency-Document

As there exists no single standard definition or method with which a city's population is calculated the residency number cities report may be inconsistent thereby making comparisons difficult. If we are to use these values we must know how they were derived, hence the need for a residency ontology. Following are CQs for the residency ontology:

- (F) what proof of residency was used?
- (F) where does the resident reside?

- (F) does the resident reside in the city at the same time as the indicator measurement?
- (F) how long has a person resided in the city?

Table 2 Residence class description

Class	*Property*	*Value*
Residence	owl:subClassOf	BuildingClass
	owl:subClassOf	Residency
	hasUse	Human Habitation
	ic:hasAddress	Exactly 1 HomeAddress
	gci:for_city	Exactly 1 city
Human habitation	Is_used_by	min 1 person
	'for city'	Exactly 1 city
	owl:subClassOf	Residency

We start by defining the properties that a person must have to be considered a resident of a particular city.

Using the property 'HomeAddress' as defined by the icontacts ontology[3] we created a property called 'cityCurrentlyResidingIn' that is bound by an axiom to have the same geoname URI value as the gci:for City property. This ensures that the indicator is made up of people currently residing in the city being evaluated.

Residence is defined here as a physical structure that has an address, is considered residential by the city, and is used primarily for human habitation.

Table 3 ARD class description

Class	*Property*	*Value*
ARD	owl:subClassOf	Document
	owl:subClassOf	Residency
	forAddress	Exactly 1 'home address'
	Certification_Date	Exactly 1 dateTime
	Expiry_Date	Exactly 1 dateTime
	Is_issued_by	Exactly 1 'Government Organisation'
	gci:for_city	Exactly 1 city

The AcceptedResidencyDocument (ARD) class defines the necessary documents through which residency can be proved. For specific city resident classes the document type span: driver licenses, permit cards, residential tenant records, emergency records, and government census.

For consistency measures we employ the following axioms:

1. the value for the 'CityCurrentlyResidingIn' property must be the same as the 'gci:for City' value
2. the address provided by the government organisation's ARD must be the same address as the residence.

3.2 Service ontology

The ISO 37120 telecommunication and innovation indicators each measure a different ICT-based service. In particular, the number of connections a particular service has per capita. At its most basic level, a connection means that a resident has given money to a telecommunications service provider (TSP) in exchange for the ability to have access to a service. Regardless of the source providing the number of users on the particular telecommunication service we need to have the representational capability for a service provider to define how a connection with that service is made. To achieve this we created a service consumption ontology that utilises a purchase relationship to identify whether or not a service was purchased. The purchase indicates that a connection exits between the service provider and the consumer (user). Following are the CQs:

1 (F) what service is being provided?

2 (F) what service is being consumed?

3 (D) what service(s) does a particular resident consume?

4 (D) when is a service consumed?

5 (F) what is the purchase price for the service?

6 (F) how many consumers of a service are there?

7 (F) how many providers of a service are there?

8 (D) what service has the most subscribers?

9 (F) at what time was the service initiated?

10 (F) for what time period is the service available?

Our ontology extends the document service ontology (DSO) defined by Voss (2013) in Figure 1.

Figure 1 Classes and properties defined in the service ontology

```
  +-----------------+   provides     +---------------+   consumedBy   +-----------------+
  | ServiceProvider |--------------->|               |--------------->| ServiceConsumer |
  |                 |<---------------|               |<---------------|                 |
  +-----------------+   providedBy   |               |   consumes     +-----------------+
                                     |    Service    |
+-------------------+   limits       |               |   delay
| ServiceLimitation |--------------->|               |-------------> duration-or-time
|                   |<---------------|               |-------------> xsd:nonNegativeInteger
+-------------------+  limitedBy     |               |   queue
                                     +---------------+
```

Table 4 Service class description

Class	*Property*	*Value*
Service	providedBy	some ServiceProvider
	limitedBy	some ServiceLimitation
	consumedBy	some ServiceConsumer
	delay	some time
	queue	exactly 1 nonNegativeInteger

DSO defines a service as ‘some action that is done for someone’. In our case this ‘action’ is a telecommunication connection and the ‘someone’ is the user. Using the class ‘ServiceProvider’ we can represent the service provided by a telecommunications company using the property ‘provides’. A ’ServiceProvider’ ’provides’ a connection to a service, which is modelled by the ‘Service’ class. This ‘Service’ is then ‘consumedBy’ the ‘ServiceConsumer’. However, this is incomplete since services have to be purchased.

Table 5 ServiceProvider class description

Class	*Property*	*Value*
ServiceProvider	owl:subClassOf	Organisation
	sells	min 1 service
	provides	min 1 service
	has_ownership	exactly 1 Ownership
	consistsOf	Division
	hasGoal	only Goal
	hasLegalName	exactly 1 String

Table 6 Apurchase class description

Class	*Property*	*Value*
APurchase	owl:subClassOf	Offer
	consumedBy	exactly 1 ServiceConsumer
	providedBy	Exactly 1 serviceProvider
	service:type	Exactly 1 String
	‘price currency’	some decimal
	Certification_date	Exactly 1 dateTime
	expiry date	exactly 1 dateTime

Table 7 ServiceConsumer class description

Class	*Property*	*Value*
ServiceConsumer	residentOf	exactly 1 City
	purchases	min 1 Service
	consumes	min 1 Service
	CompletedActionStatus	APurchase
	owl:equivalentClass	ServiceUser

To represent this we created an ‘APurchase’ class that brings in properties from schema.org and DSO. From schema.org we use CompletedActionStatus for a purchase that has already taken place and the class ‘Offers’ in which ‘Apurchase’ is a subclass. An ‘offer’ is defined as, ‘the transfer of some rights to an item or to provide a service’. ‘Apurchase’ is a subclass of offer because it forms a transaction between the ‘ServiceProvider’ and ‘ServiceConsumer’, which is confirmed through ‘CompletedActionStatus’.

We also use the property ‘price’ to set the monetary amount exchanged from the consumer to the service provider for connection to the telecommunication service.

Finally, from DSO we use the property 'consumer' to point to the entity making the purchase, and the property 'provider' that points to the service provider. For consistency we add the following axiom:

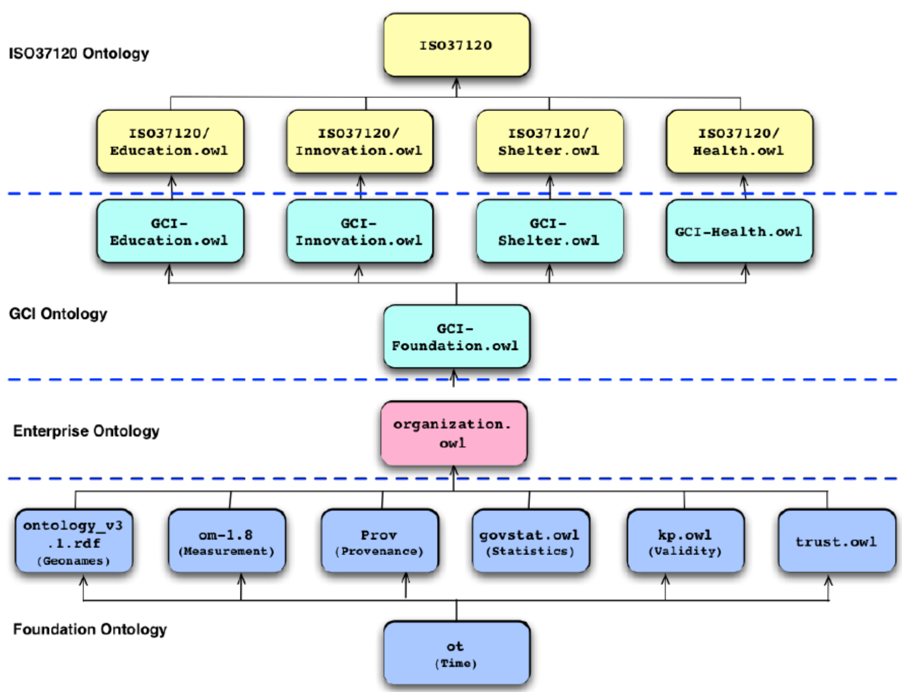
- The 'gci: for_City' value of the 'ServiceConsumer' must be the same as the 'gci:for_City' value of the indicators denominator.

This service ontology now provides the concepts necessary to represent the various services required to define the telecommunications and innovation indicators: internet services, mobile cellular services, and landline phone services.

4 Global city indicator ontology

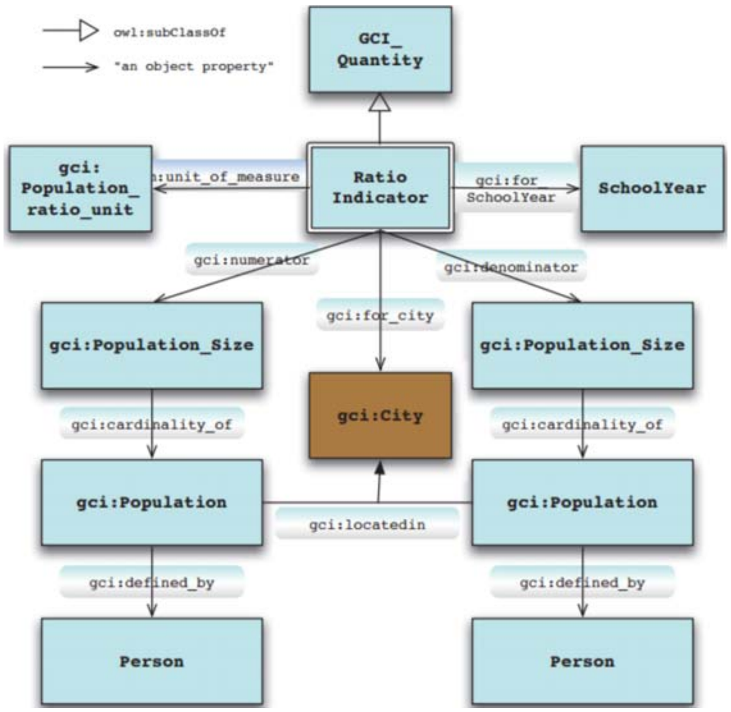
The ontology defined in the previous section is one of many required to represent both ISO 37120 indicator definitions and the data used to derive them. Figure 2 depicts the ontology hierarchy used to define the ISO 37120 indicators and their supporting data. Each innovation indicator is represented in the ISO37120/Innovation.owl file[4] which imports and uses the GCI-innovation.owl[5] file that contains the innovation ontology. The innovation ontology file imports the GCI-foundation.owl[6] file which contains classes that are generic across all themes of indicators (Fox, 2013). Finally, the foundation ontology imports more generic ontologies for time, provenance, measurement, etc.

Figure 2 ISO 37120 ontology modules (see online version for colours)



The GCI Foundation ontology provides the design pattern for most ISO 37120 indicators. Figure 3 defines one type of indicator that is a ratio of two population sizes. A ‘population size’ is the cardinaltity of a ‘population’ which is defined by a specific kind of person within a specific city. For example, a person who has an internet subscription in Toronto would form the numerator ‘population’.

Figure 3 A generic graph for representing indicators that are a ratio of two populations (see online version for colours)



5 Innovation indicator example

In this section we show how an innovation indicator is represented using the GCI innovation and foundation ontologies. Starting with the pattern defined in Figure 3, we specialise the numerator, i.e., ServiceUser size, to each indicator’s service. We define an internet connection as a type of service that has a provider (‘ServiceProvider’) and a resident user (‘ServiceUser’), and is established after a transaction has occurred (‘APurchase’).

To illustrate the representation of these definitions using our ontology we will model an internet user, internet service provider and an internet service. All of which are necessary to represent the number of internet connections within a cities population.

We start by defining a resident internet user with a ‘InternetUser’ class.

- *InternetUser:* 'person' or 'organisation' (as defined by the schema.org ontology) that consumes or purchases an internet service subscription from an internet subscription provider.
- *InternetServiceProvider (ISP):* an organisation that has the goal of providing internet service.
- *InternetService:* a service provided by an ISP enabling an InternetUser to connect to the WWW, the class that models the service as an internet connection being provided.

Table 8 InternetUser class description

Class	*Property*	*Value*
InternetUser	owl:subClassOf	organisation or person
	owl:subClassOf	ServiceConsumer
	owl:subClassOf	ServiceUser
	purchases	min 1 Service
	consumes	min 1 Service
	CompletedActionStatus	APurchase
	residentOf	Exactly 1 City

Table 9 ISP class description

Class	*Property*	*Value*
ISP	owl:subClassOf	organisation or person
	owl:subClassOf	ServiceProvider
	sells	min 1 Service
	provides	min 1 InternetService

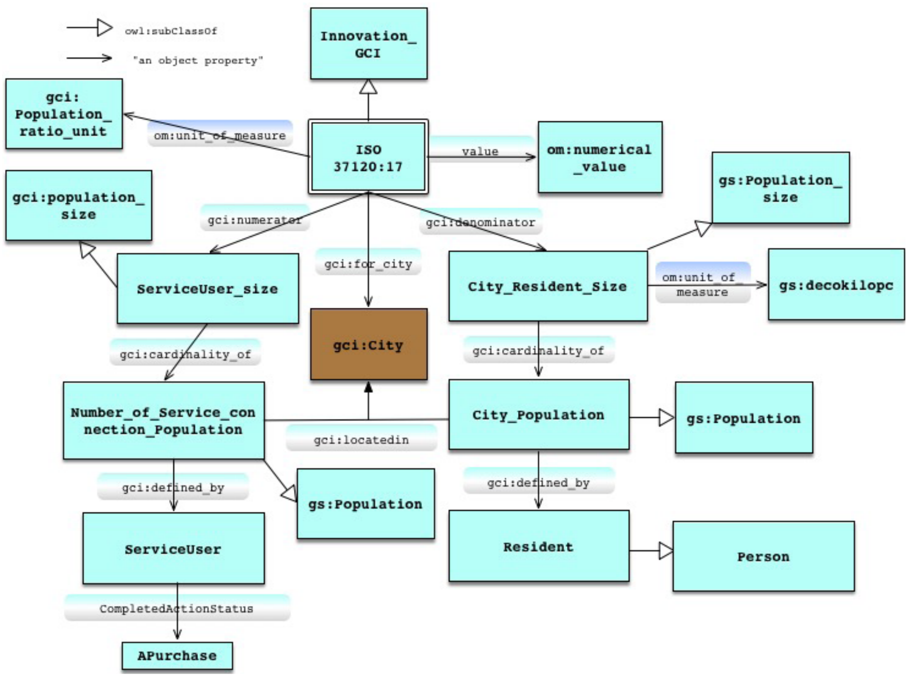
Table 10 InternetService class description

Class	*Property*	*Value*
InternetService	owl:subClassOf	Service
	providedBy	some InternetServiceProvider
	limitedBy	some ServiceLimitation
	consumedBy	some InternetUser

For all telecommunication and innovation indicators, the denominator is defined to be the population that resides in a city (i.e., 'CityResidentSize'). Similarly, the numerator is defined to be the population that consumes a designated service (i.e., 'ServiceUserSize').

A graphical depiction of this can be found in Figure 4. ISO37120/Innovation.owl[7] provides a complete OWL definition for the three ISO 37120 telecommunication and innovation theme indicators.

Figure 4 Ratio indicator defined by ISO 37120:17 (see online version for colours)



6 Verification

Verification in this context means that what we have implemented conforms to ontology specifications, we test this in two ways. The first is to determine whether the ontology is consistent. Using Protégé's Hermit reasoner, our ontologies were found to be consistent. The second approach is to use the CQs as requirements, implemented as SPARQL queries and applied to test data. The following depicts the SPARQL query, defined using the GCI innovation ontology, for the 5th CQ of indicator 17.1 'number of internet connections per 100,000 residents'.

- (CI) For each internet service provider, how many subscribers are there?

To test the query we created the instances found in Table 11.

```
(CI) For each internet service provider,
    how many subscribers are there?
SELECT DISTINCT (COUNT (?internetUser) as
    ?count) ?internetProvider
WHERE {?internetProvider a
    isoi:InternetServiceProvider.
?internetProvider service:provides
```

```
    ?internetService.
?internetUser service:consumes
    ?internetService.
?internetService a isoi:InternetService}
GROUP BY ?internetProvider
```

SPARQL returned a count of Rogers 3 and Bell 1 which is correct.

Table 11 Test instances for ISO 37120:17.1 CQ 5

Class	*Property*	*Value*
InternetUser1 InternetUser2 InternetUser3	rdfs:type	isoi:InternetUser
	service:consumes	rogersInternetService1
	internetUser4	isoi:InternetUser
	service:consumes	bellInternetService2
bell	rdfs:type	isoi:InternetServiceProvider
	service:provides	bellInternetService2
rogers	rdfs:type	isoi:InternetServiceProvider
	service:provides	rogersInternetService1
rogersInternetService1	rdfs:type	isoi:InternetService
	gci-i:providedBy	rogers
	gci-i:consumedBy	InternetUser1 InternetUser2 InternetUser3
bellInternetService2	rdfs:type	isoi:InternetService
	gci-i:providedBy	bell
	gci-i:consumedBy	InternetUser4

The implementation of this ontology using Toronto's 2013 ISO 37120 innovation indicators values can be downloaded from the Enterprise Integration Laboratory website[8].

7 Discussion

7.1 How cities can use our innovation ontology

Cities have the necessary elements to provide an effective environment for innovation. They offer infrastructure, organisation, people, density, proximity and variety. Further, urban factors assist the formation and development of networks (both social and technical). These networks are vital for sharing ideas, producing innovative products and services, as well as their transfer to markets (Athey et al., 2008). With such a strong reliance on communication networks, it is necessary that cities have the capacity to identically interpret shared information (Fox, 2015). Government legislation set by city councils also directly or indirectly shapes the innovative capacity of their cities (Athey et al., 2008). When we consider how uneven innovation can be between cities it is clear that sharing best practices can profoundly improve one cities performance in comparison to another.

As cities realise the necessity to become innovation hubs, there is a pressing need for smarter resource and infrastructure management (Naphade et al., 2011). Not only is this important to nucleate innovative businesses, it is vital for meeting and exceeding the future needs of their citizens (Naphade et al., 2011). Concurrent trends in:

- urbanisation
- economic growth
- technological progress
- environmental sustainability.

are some of the foremost drivers behind the urgency to form smart cities (Naphade et al., 2011).

ISO37120's is a first step. It identifies indicators for measuring innovativeness[9] and provides a precise definition for each. If cities were to simply report their indicator values, and use them as a basis of comparison with other cities, it would be little more than a beauty contest, i.e., which city 'looks better'! In order for a city to improve, it needs to understand the root cause of its performance, and in order to discover root causes, access to the data used to derive an indicator's value is needed. Therein lies the challenge. Cities need to make the data used to derive their indicator values openly available using global standards.

The GCI innovation ontology provides the first step towards a global standard for representing and publishing telecommunications and innovation data used to derive indicator values. It enables cities to adopt a common data structure and vocabulary/ontology for the representation of their data, and share this data over the internet. By doing so it makes it possible to build generic applications that can access, merge and analyse data from cities across the world.

The GCI innovation ontology is not limited to representing the ISO37120 indicators. It can be easily extended to measure other types of services. For example, Bornholm, Denmark, is a small island and home to 40,000 people. They have been working on a system to integrate the electric vehicles (ev) of residents into their power grid for additional power storage (Binding et al., 2010). The GCI innovation ontology can be easily extended to measure number of ev's, charging stations, etc. Cities like Rio de Janeiro who suffer from reoccurring natural disasters (mudslides) (Vieira and Fernandes, 2004) can extend the use of the *residency* and *service* micro-ontologies to account for and/or track the number of services that have been deployed. Each agency that performs a service can be modelled using the ServiceProvider class and cities can ensure that the correct amount of relief is being deployed.

A city like Helsinki can benefit from our ontology by using it to measure and benchmark its performance year over year. Our ontology allows for reliable and consistent standards for measurement. By creating an innovation index based on our ontology, Helsinki and others can conduct longitudinal studies that will be able to identify if they are becoming less or more innovative over time. Having this knowledge is useful for governments forming city-based innovation strategies.

Metropolitan areas must be able to create and increase innovative ecosystems in order to give citizens and corporations a better chance at innovating (Schaffers et al., 2012). By adopting our ontology and others like it, cities will be able to compare their performance based on metrics that are consistently interpreted and applied globally. Thereby increasing the use of established practices to increase their innovative capacity and to foster economic development for its residents.

7.2 Future applications

Most cities across the world have aspirations to provide their residents with the highest quality of life. This requires cities to create unique economic, social, technical, and educational opportunities. Over the last few years we have seen an increase in systems geared towards making cities smarter (Budde, 2014). However, the data produced remains heterogeneous both in terms of its semantic representation and interaction with other systems. Extracting meaningful information from the variety and volume of data generated in a smart city is very complex. By using the semantic web and ontological engineering in the future, we can increase the interoperability and integration of the data, eventually leading to an automated analysis process (Fox, 2015).

In the future this sort of ability will have many positive implications. City governments can create environmentally sustainable, interconnected, open and intelligent societies that generate economic opportunities and increase the quality of life (Zygiaris, 2013). ‘Smart’ policy that investigates a cities potential to be innovative using our ontology will seek to increase broadband and telecommunication access for its citizens. Investment in these areas is the first step for planners to define a reference model that can conceptually be used to track the innovative output of residents to the ISO 37120:17 standards.

In terms of extending our innovation ontology, as the ISO adds indicators to measure the innovative capacity of a city, members of the global community can extend upon the concepts found in our ontology to ensure that it is kept up to date. The ultimate goal of this work is to automate the performance of longitudinal and transversal analysis in order to discover the root causes of differences (Fox, 2015a). Understanding these causes will allow for the creation of smarter cities that can identify and solve problems before they occur.

8 Conclusions

The process of building smarter cities depends upon our ability to measure their performance. Measurement standards such as ISO 37120 are important to this process. If we are to learn from other cities, we must understand what they do. Open data provides a path to this understanding. Cities are openly publishing vast amounts of data but like the Tower of Babel, they each speak their own language of data models, making interpretation and comparisons at best difficult if not impossible. The ontology presented in this paper makes it possible for cities to ‘speak; the same language. It provides a standard for representing and community innovation-related data.

The research presented in this paper is part of a larger effort to create an intelligent agent that can analyse and determine the root causes of variations in performances among cities. A prerequisite to creating such an agent is the availability of ontologies that can represent both the definitions of indicators and the data used to derive their values. Towards this end we introduced the GCI innovation ontology which is composed of two sub-ontologies: residency and service. With these ontologies, along with the GCI Foundation ontology, we were able to represent the definitions of the ISO 37120 telecommunication and innovation indicators, their instantiation by cities, and the supporting data used to derive them, thereby enabling their publishing over the internet and their analysis by systems like PolisGnosis.

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Notes

1 The World Council for City Data (http://www.dataforcities.org/) publishes indicators for several cities but does not publish the data used to derive them.

2 See Gruninger and Fox (1995) for a definition of the methodology.

3 http://ontology.eil.utoronto.ca/icontact.owl.

4 http://ontology.eil.utoronto.ca/GCI/ISO37120/Innovation.owl.

5 fttp://ontology.eil.utoronto.ca/GCI/Innovation/GCI-Innovation.owl.

6 http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl.

7 http://ontology.eil.utoronto.ca/GCI/ISO37120/Innovation.owl.

8 http://ontology.eil.utoronto.ca/ISO37120/Toronto/2013/ISO37120 17 2013 TO.owl.

9 Whether the reader believes the ISO37120 indicators are the 'right' indicators for measuring the innovativeness of a city is a separate issue.