A Telecommunication & Innovation Ontology for Global City Indicators (ISO 37120)

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Abstract
This paper defines an ontology for representing the definitions of the ISO 37120 Telecommunication & Innovation theme indicators. In order to represent these indicators, two ontologies had to be created: Residency and Service. Using these two ontologies along with the Global City Indicator Foundation Ontology we are able to represent on the Semantic Web:

1. the ISO 37120 definition of Telecommunication & Innovation indicators,
2. their instantiation by cities, and
3. the supporting data use to derive them.

As a result we have enabled the automated analysis of city performance by systems such as PolisGnosis.

1. Introduction
Cities use a variety of metrics to evaluate themselves. With the introduction of ISO 37120, which contains over 100 indicators for measuring a city's quality of life and sustainability, it is now possible to consistently measure and compare cities, assuming they adhere to the standard. With the growing adoption of Open Data principles by cities, it is becoming possible (in theory at least) to automate this analysis process. One major impediment to the open publishing of indicator data is the lack of standards.

The goal of the PolisGnosis project (Fox, 2015) is to automate the longitudinal analysis (i.e., how and why a city's indicators change over time) and transversal analysis (i.e., how and why cities differ from each other at the same time), in order to discover the root causes of differences. Our approach is to develop a theory that takes as input:

- All of the information and knowledge with respect to an indicator,
- A set of consistency axioms,
- A set of diagnosis axioms, and

apply the axioms to determine why indicators change.

We have identified five categories of knowledge that have to be represented in order to analyze city performance based on ISO37120:

1. How do we represent the (ISO 37120) 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 the definition of an indicator and in publishing an instance of an indicator and its supporting data.
3. 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.
4. How do we represent the meta data associated with a published indicator value? For example, its units, scale, 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 we trust the organization that created it?
5. 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?

The primary goal of this paper is on the development of an ontology for representing items 1, 2, 3 and 5, namely the representation of the definition of an indicator, general knowledge of the indicators theme, representation of city specific theme knowledge, and a city's supporting data used to derive an indicator value. The representation of an indicator's meta data is defined in Fox (2013). A secondary goal of this work is for the ontology to be used as a standard for the open publishing of Telecommunication & Innovation indicator information and knowledge by cities on the Semantic Web.

In the remainder of this paper we first describe the architecture of the ontologies being developed to represent ISO 37120 indicators. Adopting the ontology engineering methodology of Gruninger & Fox (1995), for each indicator we then define a set of competency questions the Telecommunication & Innovation ontology must be able to answer. We then review how existing vocabularies and ontologies represent Telecommunication & Innovation related concepts to determine whether they satisfy our competency requirements. The next section introduces our Telecommunication & Innovation ontology, followed by a demonstration of how the ISO 37120 Telecommunication & Innovation indicators are represented using it. Finally, we evaluate the ontology from a competency perspective.

2. Architecture of the ISO37120 Ontology

The following diagram (Figure 1) depicts the organization of files used to define the ISO 37120 ontology we are developing. At the highest level, i.e., ISO 37120 Ontology level, the ISO 37120 module[1] contains the globally unique identifier (IRI) for each ISO 37120 indicator. For example, the IRI for the Student/Teacher Ratio indicator is: "http://ontology.eil.utoronto.ca/ISO37120.owl#6.5".

[1] http://ontology.eil.utoronto.ca/GCI/37120.owl.

For each category of indicators in the ISO 37120 specification, for example Telecommunication & Innovation, there is a separate file that provides the definition of each indicator in that category. For example, ISO37120/Innovation.owl[2] provides a complete OWL definition for all three of the indicators in the ISO 37120 Telecommunication & Innovation theme.

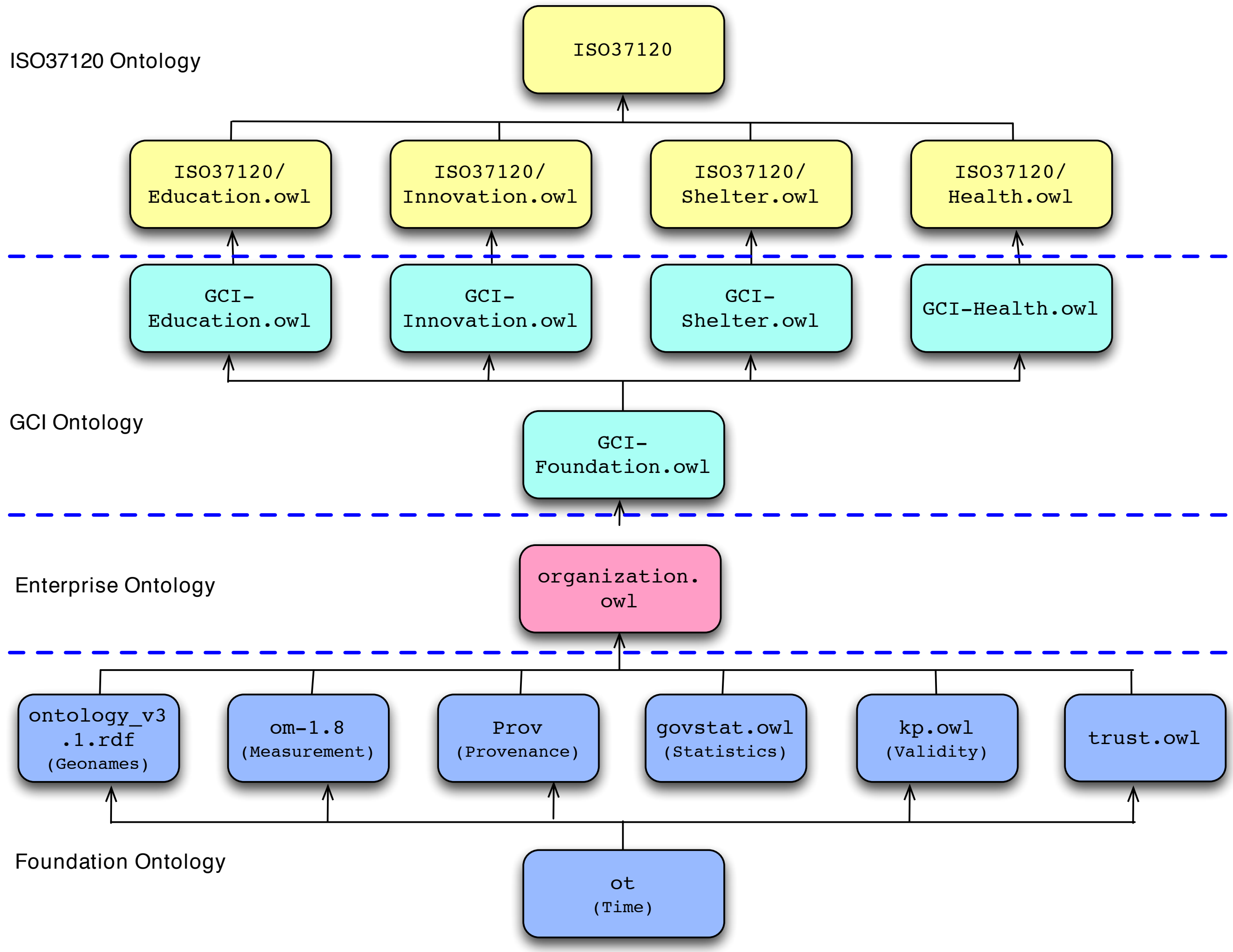

Figure 1: ISO 37120 Ontology Modules

The GCI Ontology level provides the theme specific ontologies required to define each theme's indicators. For example, to define the ISO 37120 Telecommunication & Innovation indicators, we need an Telecommunication & Innovation ontology covering concepts such as residency, services, etc. GCI-Innovation.owl[3] provides the classes used by ISO37120/Innovation.owl.

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[2] http://ontology.eil.utoronto.ca/GCI/ISO37120/Education.owl.

[3] The GCI Education ontology can be found at http://ontology.eil.utoronto.ca/GCI/Innovation/GCI-Innovation.owl along with its documentation at http://ontology.eil.utoronto.ca/GCI/Innovation/index.html. We will use the prefix "gcii" where needed.

All of the category specific indicator ontologies rely about the GCI Foundation ontology[4] for more generic concepts such as population counts and ratios, meta-information, etc.

The Enterprise Ontology level contains Enterprise Modelling ontologies. In this figure we only show the Organization Ontology file[5] (Fox et al., 1998), which is one of the TOVE Enterprise Modelling ontologies (Fox & Grüninger, 1998). In addition to the Organization ontology, TOVE has ontologies spanning:

- Activities and States (Gruninger & 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.

3. Indicators and their Competency Requirements

In this section we describe the three Telecommunication & Innovation theme indicators defined in ISO 37120.
Using the ontology engineering methodology set out by Grüninger and Fox (1995), a set of competency questions will be defined for each indicator. Competency questions define the representational requirements of an ontology. Each indicator can be viewed as a usage scenario that motivates the competency questions that our Telecommunication & Innovation ontology must be able to answer. There are four categories of competency questions that will be defined:

- **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.

Before we review the Telecommunication & Innovation indicators, there is a set of competency questions that focus on meta-information associated with an indicator value. For example:

1. (F) What are the units of measure for the numerical value?
2. (F) When was the numerical value measured?
3. (F) Who or what agency measured the numerical value?
4. (F) What process was used to measure the value?

[4] The GCI Foundation ontology can be found at http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl along with its documentation at http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.html. We will use the prefix "gci" where needed.

[5] The Organization ontology can be found at http://ontology.eil.utoronto.ca/organization.owl along with its documentation at http://ontology.eil.utoronto.ca/organization.html. We will use the prefix "org" where needed.

5. (CD) Is the indicator's supporting data consistent with the ISO37120 definition?

The questions are the subject of the Global City Indicator Foundation ontology defined in Fox (2013).

3.1. Number of internet connections per 100 000 population (ISO37120-17.1)

Indicator: "The number of internet connections per 100 000 population shall be calculated as the number of internet connections in the city (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of internet connections per 100 000 population." (ISO37120, 2014)

1. (F) What city is the indicator for?
2. (F) What is the population of the city?
3. (D) Who are the service providers that 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) Was the number of internet subscribers (connections) provided by government censuses?
8. (D) Is the reported number of internet subscribers (connections) certified by the government?

3.2. Number of cell phone connections per 100 000 population (ISO37120-17.2)

Indicator: "The number of cell phone connections per 100 000 shall be calculated as the total number of cell phone connections in the city (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of cell phone connections per 100 000 population" (ISO37120, 2014).

The competency questions for indicator 17.1 equally apply to this indicator, substituting cell phone for internet. Following are additional questions unique to cell phones.

Competency*Questions*

1. (D) Are cell phones used more than landline phones for telecommunication services?
2. (D) How many residents have both a cell phone and a landline connection?
3. (F) How many residents have more than one cell phone connection?
4. (D) Does a majority of the city's residents have access to cell phone connections?

3.3. Number of landline phone connections per 100 000 population (ISO37120-17.3)

Indicator: Number of landline phone connections per 100 000 population (supporting indicator) Definition: "The number of landline phone connections per 100 000 shall be calculated as the total number of landline telephone connections in the city (numerator) divided by one 100 000th of the city's total population (denominator). This result shall be expressed as the number of landline connections per 100 000 population" (ISO37120, 2014).

Competency*Questions*

1. (F) How many landline connections are domestic, business or other, respectively?
2. (D) Are the majority of the city's residents landline subscribers?

3. (D) What is the total number of phones (mobile and landline) per 100 000 population?

4. Background

In this section we will review non-ISO37120 Telecommunication & Innovation city indicators, and existing Telecommunication & Innovation ontologies and the extent to which they satisfy our competency questions.

4.1. Innovation-related City Indicators

The World Bank's primary collection of development indicators was taken from what they consider to be, "officially-recognized international sources" to display global development data (World Bank, 2013). Their goal is to create benchmarks against which development progress can be measured. The innovation related indicators are categorized as (World Bank, 2013):

- Telecommunications—access and use of telephones. The number of people connected to telecommunication services is highly correlated to the affordability of the service. If the service is not at a sustainable price point, the majority of the population will remain disconnected. As such, World Development Indicators (WDI) focus on affordability as the measured value. The two indicators used are:

    1. Fixed-line telephone service tariff and prepaid mobile cellular service tariff
    2. Telecommunications efficiency (total telecommunications revenue divided by GDP and by mobile cellular and fixed-line telephone subscribers per employee)

- Information technology and communications. This category is comprised of 3 indicators that reflect how the digital and information age has impacted the way humans go about daily life. Accessibility of these new technologies and the corresponding access to information reflect the opportunity for communities to raise their standard of living.

    1. **Newspapers and television:** The number of newspapers in circulation and the number of televisions per household
    2. **Personal computers and the Internet:** Due to the difficulty of surveying all of the places personal computers are found (libraries, businesses, schools, households, etc.) shipment data multiplied by the average life span of a personal computer is used as an indicator of personal computer availability within the population. Broadband and bandwidth measures for the internet are used to estimate the number of people with online access within the city. Broadband refers to technologies that provide internet speeds with a minimum of 256 kilo-bits a second.
    3. **Information and communications technology trade**: The importing and exporting of information and communication-based technology is a measure of a country's performance indicator, it is not used on the city level.

The International Telecommunication Union (ITU) aims to, "foster international cooperation and solidarity in the delivery of technical assistance to the developing countries and the creation, development and improvement of telecommunication equipment and networks in developing countries..." (ITU, 1992). Since 1960, the ITU has focused on collecting data on traffic, staff, prices, revenue, investment, and ITU access and use by households and individuals. The data covers 150 telecommunication/information communication technologies, including fixed telephone and mobile networks, and telecommunication service subscriptions (telephone and internet). They are the group tasked with measuring and collecting information and telecommunication performance through the use of indicators for the United Nations. Following are their indicators: (ITU's ICT-Eye, 2013)

1. Fixed telephone subscriptions per 100 inhabitants
2. Mobile-cellular telephone subscriptions per 100 inhabitants
3. Fixed (wired)-broadband Internet subscriptions per 100 inhabitants categorized by speed
4. Wireless-broadband subscriptions per 100 inhabitants
5. International Internet bandwidth per inhabitant (bits/second/inhabitant)
6. Percentage of the population covered by a at least a 3G mobile network
7. Fixed broadband Internet prices per month
8. Mobile cellular telephone prepaid prices per month
9. Mobile broadband Internet prices per month (new)
10. TV broadcasting subscriptions per 100 inhabitants

2ThinkNow is an agency that started the Innovation Cities program in 2006. It uses 162 indicators across 31 segments ranging from "Architecture History & Planning" to "Technology & Communications" (2ThinkNow, 2013). Within the Technology & Communications indicators they measure:

1. **Broadband Internet**: Measuring estimated broadband internet penetration the city's economy relative to competing cities
2. **Fixed Phone Network:** Measuring the presence of a fixed phone network can be valuable in a crisis, and is still part of global business, even in a mobile world
3. **Government IT Policy**: Is government supporting IT development?
4. **Internet Users:** How many internet users are there in the city relative to competing cities?
5. **Mobile Phone Networks:** Measuring how many mobile phone users there are relative to competing cities
6. **Social Web 2.0 Media**: Measuring social media communication from businesses
7. **Wireless Internet:** Measuring business grade wireless connections (2ThinkNow, 2013)

The measurement of ICT-related indicators has been a focus of organizations like the World Bank and ITU for many years. Yet non have evolved to the point of creating an ontology to represent the information nor publishing them on the Semantic Web.

4.2. Innovation Ontologies

The innovation ontologies we found were organized into very niche verticals that are irrelevant to our domain.

- **Iteams Ontology (Ning & al., 2006):** Used to facilitate the collection, distribution and development of ideas by focusing on features that are people-centric. Contains classes such as:
    - Teams
    - Actions
    - Goals

    - Community
    - Results

- **OntoGate Ontology (Bullinger, 2008):** Described as a Domain Ontology whose purpose is to allow company's access in understanding the innovation process. It deals with idea assessment and selection. It has a very large number of modules and some classes are:
    - Technological_feasibility
    - Resources_money
    - Customer_potential
    - Competition

- **Idea Ontology (Riedl & al., 2009):** Created as an Application Ontology it provides a common language for the dissemination of ideas, but fails to provide a model for the actual representation of an idea. Instead it uses established idea evaluations and provides the means to represent them. It contains classes such as:
    - CoreIdea
    - IdeaRealization
    - Origin
    - Status

- **GI2MO Ontology (Westerski & al., 2010):** As a Domain Ontology it works towards allowing IT systems to share information with each other through semantic web technologies. It aims to formalize metadata that describes innovations and related information. Contains classes such as:
    - AccessControlList
    - AccessType
    - Description
    - Metric

4.3. Telecommunication Ontologies

The ISO37120 Telecommunication & Innovation indicators are all based on measuring different ICT connections found within a city. This means that a large portion of our ontology will have to model telecommunication services and their associated properties. The following reviews existing telecommunication ontologies.

Telecommunications Service Domain Ontology: Semantic Interoperation Foundation of Intelligent Integrated Services

The Telecommunications Service Domain Ontology (TSDO) was constructed as a necessary component for the implementation of semantic web services within telecommunication service systems (Qiao et al, 2012). Due to the extensive number of concepts and technologies found in the telecommunication service industry, the network acts as the gateway to which these concepts and technologies interact and relate to each other. Services created from these interactions and technology become difficult to organize and consequently model. Qiao et al present a modelling approach for the telecommunications service field in a pragmatic domain ontology model. The associated knowledge repository consists of approximately 430 concepts/terminologies and 245 properties. This ontology describes the capabilities of telecommunication network services and satisfies the semantic interoperability issue.

The scope of the TSDO extends from domain specific vocabularies and knowledge found in telecommunications to more general concepts such as time. Telecommunication services range from network descriptions, carriers, quality, billing, service customers etc. Within the telecommunication service domain some concepts have higher sharing capabilities while others are specific to a single application, an application that makes abstracting this domain difficult. However, Qiao et al implemented a layered ontology that allows for domain concepts to be reused. Common ontologies like time and geography are transferable to other domains, while domain specific ontologies can be used in various telecommunication contexts. TSDO has six sub-ontologies shown below (Quid et al, 2012):

- **ServiceQuality**: A telecommunication network must provide services that have an end-to-end Quality of service (QoS) guarantee. Depending on the technical characteristics, the QoS provided by different networks varies. Service Quality Ontology mainly defines the QoS-related concepts about telecommunications service including, access network QoS, core network QoS, user's QoE, and such as call delay, message size, call through rate, positioning accuracy, and network bandwidth.
- **TerminalCapability**: Defines main concepts about terminal software, terminal hardware, terminal browser, and network characteristics supported by terminal.
- **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.
- **Charging**: Defines the charging-related concepts and rules about telecommunications services including: payment methods (such as prepaid and postpaid), charging types (such as time-based, volume-based, event-based, and content based), billing rates, as well as account balances.

For the ISO37120 Telecommunication & Innovation indicators, the network, service role and service category ontologies created by TSDO are relevant. The indicators will need to be described as specific telecommunication services, with consumers and providers, which is done in TSDO. The relevant classes are:

Table 1: TSDO Classes of Interest

Class	**Property**	**Values**
ServiceRole	operatedBy	Network
Network	provides	ServiceCategory
	consistsOf	NetworkElement
NetworkElement	supports	NetworkProtocol
TelecomNetwork	owl:subClassOf	Network
WirelessNetwork	owl:subClassOf	TelecomNetwork
	owl:disjointWith	WiredNetwork
FixedNetwork	owl:subClassOf	TelecomNetwork

	owl:disjointWith	MobileNetwork

The ranges of object property “operatedBy” and “provides” are taken from the ServiceRole and ServiceCategory ontologies, and carry with it definitions that we will need in our Telecommunication & Innovation ontology. The TSDO identified that modeling the operating capacity of the network operator was important as there are restrictions both in services provided and geographical areas served.

Internet Ontology V 1.0

The Internet ontology was created to model the “context” of the Internet (CASEI, 2010). Though this is not of any direct relevance to us, the elements of the Internet Ontology service context provide value. The service context was separated into two classes: objects and events. The objects class is used to describe the various entities within the environment related to a service entity. This means that networks, platforms, properties and the service entity itself are contained in the objects class. The events class is used to model processes initiated by the objects class. Focusing on the objects class, the service entity class offers a service or multiple services. The service offered has a functional property that includes (CASEI, 2010):

- service type
- service description
- service state
- protocol
- interface

The GCI Telecommunication & Innovation ontology can benefit from this model by representing a connection and deducing if a resident is connected to the indicated service. The state of the service can either be enabled or disabled. If it is disabled, then it is not considered when selecting active connections. This is useful because it allows us to create a sub-ontology that can track connection statuses of residents.

Table 2: Internet Ontology Service Class Description

Class	Property	Values
Service	has	Functionality
	has	Interface
	has	Service State
ServiceState	is	On OR Off

The service class also has non-functional properties, however, the only interesting property is cost.

4.4. Service Ontology

We will be extending the Service Ontology (Voß, 2013) in order to define the services used to measure a cities innovative capacity. The Service Ontology was established as a micro-ontology to define the semantics of a service. This micro-ontology borrows vocabulary from Schema.org, FOAF, GoodRelations and DCMI Metadata Terms. Figure 2 describes the relationships between the 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
                                     +---------------+
```

Figure 2 Classes and properties defined in the Service Ontology

There are three classes that will be important in the creation of our Service micro-ontology.

- Service
- ServiceProvider
- ServiceConsumer

A Service is defined as some action that is provided by a ServiceProvider and consumed by a ServiceConsumer. We will use these concepts to establish the usage of telecommunication services.

The relationships between the classes are described with four properties that will also use.

- provides and its inverse providedBy
- consumes and its inverse consumedBy

In order to relate a ServiceProvider instance to a Service, the ServiceProvider provides the Service. Consequently, a Service is providedBy a ServiceProvider. Following this description a Service instance is consumedBy a ServiceConsumer, and a ServiceConsumer consumes a Service.

These classes and properties will provided the basis to our micro-ontology that defines how a connection to a service is made by a resident.

4.5. Provisioning Ontologies

The GCI Telecommunication & Innovation indicators are all based on measuring the number of telecomm services to which residents in a city are connected. Thus, provisioning becomes an important concept. By accounting for the preparation process necessary to develop a network to provide services the GCI Telecommunication & Innovation ontology will be able to account for new network services introduced over time.

An Ontology-Based Service Discovery Approach for the Provisioning of Product-Service Bundles

This ontology models services based on human requirements (Knackstedt et al, 2008). The context in which these requirements are formed will change over time and in order for service providers to keep up they too will have to offer new services. This paper consolidates contextual knowledge that is modelled on an upper ontology for the service-centered perspective. Software services are used as the example to represent this ontology. Even though the service domain is different than that of the GCI Telecommunication & Innovation ontology the concepts still apply. A key component of this ontology is that a consumer can generate and consume their own service. Currently, the GCI Telecommunication & Innovation ontology does not investigate people who create their own telecommunication services. If self-generation becomes a significant portion of telecommunication service access it could be explored at a later time to model how to capture residents who generate their own connections to telecommunication services.

Context has a wide range of meanings. The definition used by Dey (2000) is that, “context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves”. The end goal of this work is to provide an ontology that forms a consolidated infrastructure of context information that can be represented as general knowledge and instantiated across multiple domains (Cabrera et al, 2014).

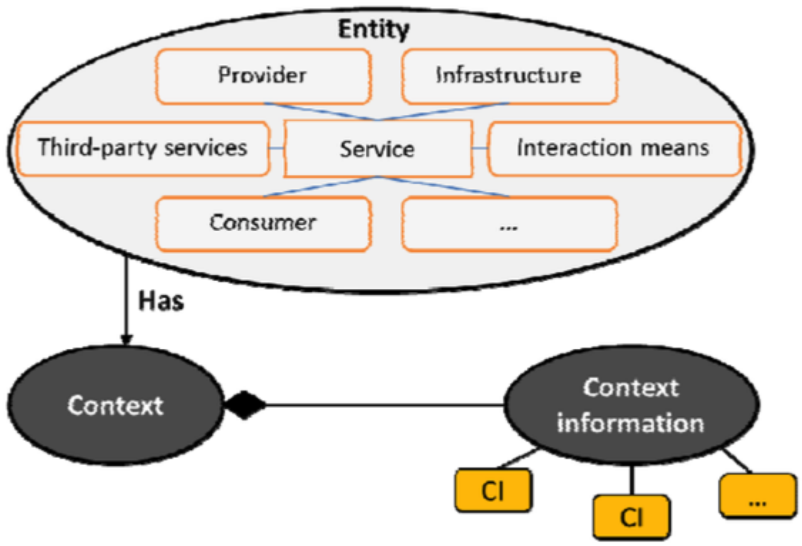

Figure 3 Schematic of Provisioning of Product-Service Bundles taken from, " A Context Ontology for Service Provisioning and Consumption", (2014)

Focusing on the context class, which is necessary in answering the competency questions focusing on each of the entities, we must identify the properties necessary to model the provisioning capabilities of the entity.

By looking at the general concepts of the ontology, focused on the context information class, we will be able to select properties that can contribute to the GCI Telecommunication & Innovation ontologies provisioning model. As the telecommunications service consumers demand new services the providers will have to implement them within the current network. In the future being able to model this ontologically will be important.

For now it is best used as a reference model that can address issues surrounding provisioning and the standardization of context hierarchies and inconsistencies between others.

A Context Ontology for Service Provisioning and Consumption

The service discovery ontology proposed by Knackstedt et al (2008) views services as economic entities that create outcomes or benefits that are mostly immeasurable by one agent for another. They stress the importance of recognizing the differences between a service and service capability, as the capability represents the customer’s need, while the service offers a solution. This allows them to model different services that have the same capability (cable internet connection vs. dial-up connection). This has useful ramifications for our model in that different residents will be connected to the telecommunication service through various means and all must be accounted for within the same service connection.

Taking a closer investigation of the service class, the similarities between this service class and those found in the above ontologies are numerous. The main addition is the ability to continuously add services through the capability property for continuous provisioning.

Table 3: Service Provisioning and Consumption Service Class Description

Class	**Property**	**Values**
Service	isSubjectTo	Condition
	offers	Capability
	isProvidedBy	Provider
	isDescribedBy	Non-functional Property
	isDescribedBy	Qualification
	requires	External factor
	hasInstance	String Value

4.6. Census Ontologies

There was only one census ontology that had any concepts relevant to the GCI Telecommunication & Innovation ontology. There did not exist any census ontologies that connected geographic locations to populations, distinguished residents from those populations, and allowed for those representations to be applied within specific domains.

A Census Address Ontology

The Census Address Ontology (CAO) dealt with how street addresses could be linked to different data sources to evaluate and validate the addresses with their physical representations. As an example, if you have an address, what data sources can validate it as a residential or commercial property, then give it a physical description? The ideas were represented at a very high level and did not offer any class structures, properties, or definitions necessary for the formation of a formal ontology. What we could extract for the GCI Telecommunication & Innovation ontology is that the address information we have can be connected to different data sources to provide residency validation or service area representations. Using ontologies like Geonames (www.geonames.org) and Icontact (Fox, 2011) we can establish locations of residencies and correlate them to the city and a service area.

4.7. GCI Foundation Ontology

The GCI Foundation Ontology (Fox, 2013) provides concepts and properties that are necessary to represent all ISO 37120 indicators. It defines the representation of meta-information associated with a single indicator number, including: placenames, units, time, provenance, validity and trust. It also defines the classes and properties for representing the definition of an indicator, including populations, how they are measured and how they are analytically combined within an indicator. The foundation ontology integrates and extends the following ontologies:

- Time (Hobbs & Pan, 2006).
- Measurement (Rijgersberg et al., 2011)

- Statistics (Pattuelli, 2009).
- Provenance (Belhajjame et al., 2012)
- Validity (Fox & Huang, 2005).
- Trust (Huang & Fox, 2006).

5. GCI Telecommunication & Innovation Ontology

The ISO 37120 Telecommunication & Innovation indicators have a numerator and denominator that consists of a numerical value represented by service usage and a city population respectively. The numerator defines how many residents of a city consume a service. The denominator defines the number of residents in the city, usually drawn from a census or some other external data source. The following defines the two ontologies required to construct the innovation indicators: residency and services.

5.1. Residency Ontology

All Telecommunication & 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). In New York City a resident is defined by "Regulation 105.20 (d)(1)" which stipulates, "the place which an individual intends to be his permanent home – the place to which he intends to return. It is the home with range of sentiment, feeling and permanent association. One must be domiciled in New York and maintain a home in New York, the time spent in the State is irrelevant" (McGladrey, 2009). In Germany, "a resident of Germany generally refers to an individual who has a domicile in Germany or spends more than six consecutive months in Germany (habitual place of abode)" (Seidel, 2011). As different cities have different definitions of residency we must create an ontology that allows each individual city the ability to create their own definition. What is consistent in all the varying definitions is that the person must have an address in the residing city, be recognized by the government through a vetted document, and be domiciled in the city.

As there exists no standard definition or method in 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 competency questions for the residency ontology:

1. (F) What proof of residency was used?
2. (F) Where does the resident reside?
3. (F) Deos the resident live in the city at the same time as the indicator measurement?
4. (F) How long has a person resided in the city?

We start by defining where a person resides. Using the property ‘HomeAddress’ as defined by the icontacts ontology (Fox, 2012) we created a property called ‘CityCurrentlyResidingIn’ that is bound by the 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.

Table 4: Resident Class Description

Class	Property	Value Restriction
Resident	owl:subClassOf	person OR organization
	owl:subClassOf	Residency
	CityCurrentlyResidingIn	Exactly 1 City
	reside_in	Residence
	hasProof	AcceptedResidencyDocument

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 5: Residence Class Description

Class	Property	Value Restriction
Residence	owl:subClassOf	BuildingClass
	owl:subClassOf	Residency
	hasUse	Human Habitation
	ic:has Address	Exactly 1 HomeAddress
	gci:for_city	Exactly 1 City

The following class defines the necessary documents through which residency can be proved. For specific city resident classes the document type span: Drivers License’s, Permit Cards, Residential Tenant Records, Emergency Records, and Government Census.

Table 6: AcceptedResidencyDocument Class Description

Class	Property	Value Restriction
AcceptedResidencyDocument	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 organization’
	gci:for_city	exactly 1 City

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 organization’s Accepted Residency Document must be the same address as the Residence

5.2. Service Ontology

Within the GCI Telecommunication & Innovation ontology, the indicators are measured by determining the number of connections made to a ICT-based service 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. When a resident of the city has access to one of the three communication services identified in ISO 37120, it is considered a connection. 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 have created a service consumption ontology that utilizes a purchase relationship to identify whether or not a service was purchased. The purchase indicates that a connection has been made between the service provider and the consumer (user). Following are the competency questions:

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 are consumed?
5. (F) What is the purchase price for the provided 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 valid?

Our ontology is based on the Document Service Ontology (SO) defined by Voß (2013). SO 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 telecommunication company that through the property '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 no telecommunication company will provide a service unless it is being purchased. This transaction is done at a price.

To represent this we created an 'APurchase' class (Table 9) that brings in properties from schema.org and SO. From schema.org we use 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 member of the Offer class since it forms a transaction between the 'ServiceProvider' and 'ServiceConsumer'.

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 SO we use the property 'consumer' to point to the entity making the purchase, and the property 'provider' that points to the service provider.

Table 7: Service Class Description

Class	**Property**	**Value Restriction**
Service	providedBy	some ServiceProvider

	limitedBy	some ServiceLimitation
	consumedBy	some ServiceConsumer
	delay	some time
	queue	exactly 1 nonNegativeInteger

'APurchase' guarantees that a connection is made since someone is paying for that service.

Table 8: APurchase Class Description		
Class	**Property**	**Value Restriction**
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

'ServiceConsumer' represents the resident who purchases a service, thus forming a connection.

Table 9: ServiceConsumer Class Description		
Class	**Property**	**Value Restriction**
ServiceConsumer	residentOf	exactly 1 City
	purchases	min 1 service
	consumes	min 1 service
	owl:equivalentClass	ServiceUser

Consistency Axioms

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

'ServiceProvider' is an organization that provides and sells a service to a consumer, completing the attributes of the 'APurchase' relationship.

Table 10: ServiceProvider Class Description		
Class	**Property**	**Value Restriction**
ServiceProvider	owl:subClassOf	Organization
	sells	min 1 service
	provides	min 1 service
	has_ownership	exactly 1 Ownership
	hasName	only string
	consistsOf	Division
	hasGoal	only Goal
	hasLegalName	exactly 1 String

This service ontology now provides the concepts necessary to represent different services within different domains. Here we will represent three services centered on telecommunication and communication based technologies: Internet Services, Mobile Cellular Services, and Landline Phone Services.

Using the service ontology, we will 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’). We first start by defining a resident internet user with a ‘InternetUser’ class.

> **InternetUser:** ‘Person’ or ‘Organization’ (as defined by the schema.org ontology) that consumes or purchases an Internet Service subscription from an Internet Subscription Provider.

Table 11: InternetUser Class Description

Class	Property	Value Restriction
InternetUser	owl:subClassOf	Organization or Person
	owl:subClassOf	ServiceConsumer
	owl:subClassOf	ServiceUser
	purchases	min 1 Service
	consumes	min 1 Service
	residentOf	exactly 1 City

InternetServiceProvider: an organization that has the goal of providing internet service.

Table 12: InternetServiceProvider Class Description

Class	Property	Value Restriction
InternetServiceProvider	owl:subClassOf	Organization
	owl:subClassOf	ServiceProvider
	sells	min 1 Service
	provides	min 1 InternetService

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 13: InternetService Class Description

Class	Property	Value Restriction
InternetService	owl:subClassOf	Organization
	owl:subClassOf	ServiceProvider
	sells	min 1 Service
	provides	min 1 InternetService

Using our general service ontology we begin building the mobile phone connection ontology by first representing a mobile user with the class ‘Tele_MobileUser’.

TeleMobileUser: a person or organization that consumes or purchases at least one mobile-based telecommunication Service subscription from a telecommunication subscription Provider.

Table 14: InternetServiceProvider Class Description		
Class	**Property**	**Value Restriction**
TeleMobileUser	owl:subClassOf	Organization or Person
	owl:subClassOf	ServiceConsumer
	consumes	min 1 MobileTelephoneService
	purchases	min 1 Service

In order for the service ontology to work through the 'APurchase' class there must be an entity that is providing the service which is being consumed. This entity is represented by the 'MobileTeleCommProvider' class.

MobileTeleComProvider: an organization that has the goal of providing mobile phone line services.

Table 15: InternetServiceProvider Class Description		
Class	**Property**	**Value Restriction**
MobileTeleComProvider	owl:subClassOf	Organization
	owl:subClassOf	ServiceProvider
	provides	min 1 MobileTelephoneService
	sells	min 1 Service

The mobile service rendered by the telecommunication provider is represented by the 'MobileTelecomService' class.

MobileTelecomService: a service provided by a mobile telecommunications company enabling a TeleMobileUser to connect to the telecommunications network.

Table 16: MobileTelecomService Class Description		
Class	**Property**	**Value Restriction**
MobileTeleComService	owl:subClassOf	Service
	delay	some time
	providedBy	some MobileTeleComProvider
	queue	exactly 1 nonNegativeInteger
	consumedBy	min 1 ServiceConsumer

The landline user is described in the class 'TeleLandlineUser'.

TeleLadlineUser: a person or organization (represented by schema.org) that consumes or purchases a landline-based telecommunication (through the service ontology) service subscription from a Telecommunication Subscription Provider

The relationship between the consumer and the provider is done through the 'APurchase' class.

Table 17: TeleLandlineUser Class Description		
Class	**Property**	**Value Restriction**
MobileTeleComService	owl:subClassOf	Organization or Person
	owl:subClassOf	ServiceConsumer
	consumes	min 1 LandlineTelecomService
	purchases	min 1 LandlineTelecomService

In order for the service ontology to work through the 'APurchase' class there must be an entity that is providing the service which is being consumed. This entity is represented by the 'LandlineTeleComProvider' class.

> **LandlineTeleComProvider:** an organization that has the goal of providing landline phone services.

Table 18: LandlineTelecomProvider Class Description		
Class	**Property**	**Value Restriction**
LandlineTelecomProvider	owl:subClassOf	Organization
	owl:subClassOf	ServiceProvider
	provides	min 1 LandlineTelecomService
	sells	min 1 LandlineTelecomService

The service model requires a description of the service being provided by the service provider. The 'LandlineTelecomService' class will describe landline-based services.

> **LandlineTelecomService:** a service provided by a telecommunications company that enables a Tele LandlineUser to connect to a telecommunications network

Table 19: LandlineTelecomService Class Description		
Class	**Property**	**Value Restriction**
LandlineTelecomService	owl:subClassOf	Service
	consumedBy	some TeleLandlineUser
	delay	some time
	providedBy	some LandlineTeleComProvider
	queue	exactly 1 nonNegativeInteger
	limitedBy	some ServiceLimitation

6. Telecommunication & Innovation Indicators Pattern

In Figure 4 we introduce the pattern for a ratio indicator defined using the GCI Foundation ontology (Fox, 2013).

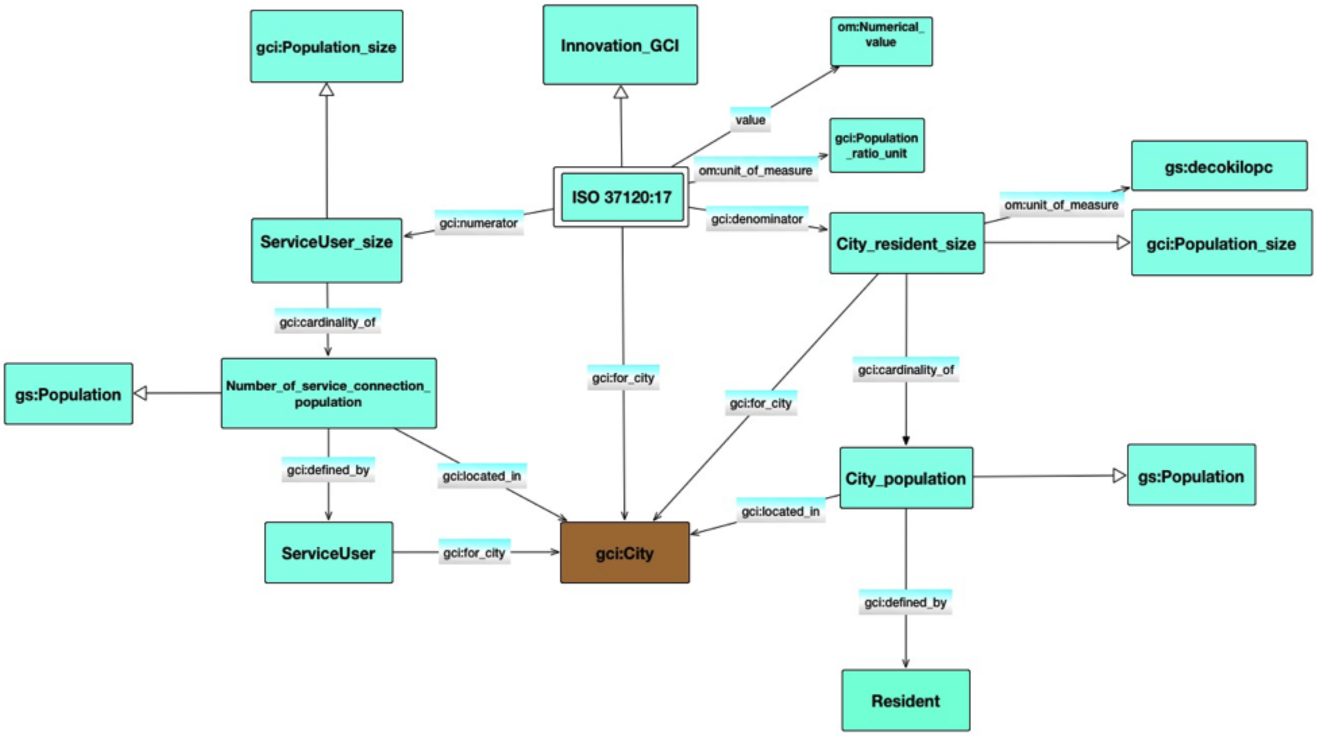

Figure 4 ISO 37120:17 Definition

The ISO 37120:17 innovation theme is a subClassOf of the Innovation GCI class. Its unit of measure is 'PopulationRatioUnit', which is defined as the ratio of the cardinality of two populations. For all Telecommunication & 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').

Table 20: LandlineTelecomService Class Description		
Class	**Property**	**Value Restriction**
ISO37120_Indicator	owl:subClassOf	'GCI Quantity'
	for_time_interval	only Interval
	'for city'	only City
	'for city service'	only 'City Service'
	unit_of_measure	only 'Unit of Measure'
	value	only Measure

'CityResidentSize' is a subclass of the GCI Population size class that defines the population associated with a place and will have a unit of measure property of a decokilopc as defined in Fox (2014). The 'CityResidentSize' is defined as the 'cardinality_of' the 'CityPopulation'.

Table 21: CityResidentSize Class Description

Class	Property	Value Restriction
CityResidentSize	owl:subClassOf	‘Population Size’
	unit_of_measure	exactly 1 Population_cardinality_unit
	cardinality_of	exactly 1 Population
	for_time_interval	only Interval
	'for city'	only City
	'for city service'	only 'City Service'
	unit_of_measure	only 'Unit of Measure'
	value	only Measure

The ‘CityPopulation’ is defined by a city and the definition of a resident. Note that in the definition of an ISO 37120 indicator the definition of a resident is generic. A City should provide a more specific definition that uniquely identifies residents of their city, using the resident ontology. Similarly, the numerator’s size is defined as the cardinality of a population which is, in turn, defined by a city and the service user.

Table 22: CityPopulation Class Description		
Class	**Property**	**Value Restriction**
CityPopulation	defined_by	only Resident
	located_in	exactly 1 City
	‘for city’	only City
	owl:subClassOf	City
	owl:subClassOf	Population

The numerator of each Telecommunication & Innovation indicator is defined as the size of the population with a service connection from a telecommunication service provider.

Table 23: NumberofServiceConnectionsSize Class Description		
Class	**Property**	**Value Restriction**
NumberofServiceConnectionsSize	owl:subClassOf	‘Population Size’
	unit_of_measure	exactly 1 Population_cardinality_unit
	cardinality_of	exactly 1 NumberofServiceConnectionsPopulation
	for_time_interval	only Interval
	'for city'	only City
	'for city service'	only 'City Service'
	unit_of_measure	only 'Unit of Measure'
	value	only Measure
	'numerical value'	exactly 1 string
	unit_of_measure	only 'Unit of Measure'
	unit_of_measure	exactly 1 Population_cardinality_unit
	cardinality_of	exactly 1 Population
	for_time_interval	only Interval
	'for city'	only City
	'for city service'	only 'City Service'

	wasGeneratedBy	some Agent
	generatedAtTime	only DateTimeDescription
	wasAttributedTo	some Agent
	wasDerivedFrom	only Entity
	unit_of_measure	only 'Unit of Measure'
	value	only Measure

The population of residents with service connections is defined as:

Table 24: NumberofServiceConnectionsPopulation Class Description

Class	**Property**	**Value Restriction**
NumberofServiceConnectionsPopulation	owl:subClassOf	'Population Size'
	owl:subClassOf	Quantity
	'for city'	only City
	defined_by	only ServiceUser
	unit_of_measure	only 'Unit of Measure'
	value	only Measure

The next section defines the numerator of each indicator definition. The data necessary to determine the number of service connections in a city can come from various sources:

- Government Census
- Official estimates
- Telecommunication Service Providers (TSP)

The issue that arises with the variety of sources is that, depending on each city, the indicator can be based on a different source thus affecting the validity of any transversal analysis. We will deal with Government Census and Official Estimates in section 8 of this paper.

7. ISO37120 Telecommunication & Innovation Indicators Ontology

This section defines each of the three ISO 37120 Telecommunication & Innovation indicators, using the GCI Foundation ontology plus the Residency and Service ontologies described herein. Starting with the pattern defined in Section 6, we specialize the numerator, i.e., ServiceUser_size, to each indicator's service.

7.1. (17.1) Number of Internet connections per 100 000 residents (core indicator)

The first Telecommunication & Innovation indicator is defined as: "The number of internet connections per 100 000 population shall be calculated as the number of internet connections in the city (numerator) divided by one 100 000th of the city's total population (denominator)." Focusing on internet connections, we specialize the numerator of the indicator to be the size of the resident population that purchases an internet connection.

Table 25: NumberofInternetServiceConnectionsSize Class Description

Class	**Property**	**Value Restriction**
NumberofInternetServiceConnectionsSize	owl:subClassOf	'Population Size'
	owl:subClassOf	Measure

	cardinality_of	exactly 1 NumberofInternetServiceConnectionsPopulation

The actual value measured is the cardinality of the population of internet users.

Table 26: NumberofInternetServiceConnectionsPopulation Class Description		
Class	**Property**	**Value Restriction**
NumberofInternetServiceConnectionsPopulaition	owl:subClassOf	Quantity
	owl:subClassOf	NumberofServiceConnectionsPopulation
	'for city'	only City
	defined_by	only ServiceUser
	unit_of_measure	only 'Unit of Measure'
	value	only Measure

The population of internet users, is defined as the number of residents who have InternetService, which is defined by InternetUser represented in Table 12.

7.2. (17.2) Number of cell phone connections per 100 000 population (core indicator)

The second Telecommunication & Innovation indicator is: "The number of cell phone connections per 100 000 shall be calculated as the total number of cell phone connections in the city (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of cell phone connections per 100 000 population." Focusing on cell phone connections, we specialize the numerator of the indicator to be the size of the resident population that purchases a cell phone connection.

NumberofTeleMobileServiceConnectionSize defines the units and numerical value of the number of Mobile telecommunication connections:

Table 27: NumberofTeleMobileServiceConnectionSize Class Description		
Class	**Property**	**Value Restriction**
NumberofTeleMobileServiceConnectionSize	owl:subClassOf	'Population Size'
	owl:subClassOf	Measure
	cardinality_of	exactly 1 NumberofMobileServiceConnectionsPopulation

The actual value measured is the cardinality of the population of cell phone users.

Table 28: NumberofTeleMobileServiceConnectionPopulation Class Description		
Class	**Property**	**Value Restriction**
NumberofTeleMobileServiceConnectionPopulation	owl:subClassOf	Quantity
	owl:subClassOf	NumberofServiceConnectionsPopulation
	'for city'	only City
	defined_by	only TeleMobileUser

The population of mobile users will be found by the number of users who have MobileTelephoneService which is defined by Tele_MobileUser represented in Table 15.

7.3. (17.3) Number of landline phone connections per 100 000 population (supporting indicator)

The third Telecommunication & Innovation indicator is: "The number of landline phone connections per 100 000 shall be calculated as the total number of landline telephone connections in the city (numerator) divided by one 100 000th of the city's total population (denominator)." Focusing on landline phone connections, we specialize the numerator of the indicator to be the size of the resident population that purchases a landline phone connection.

NumberofTeleLandlineServiceConnectionSize defines the units and numerical value of the number of landline telecommunication connections by counting the number of elements found in the Tele LandlineUser class.

Table 29: NumberofTeleLandlineServiceConnectionSize Class Description

Class	Property	Value Restriction
NumberofTeleLandlineServiceConnectionSize	owl:subClassOf	'Population Size'
	owl:subClassOf	Measure
	cardinality_of	exactly 1 NumberofLandlineServiceConnectionsPopulation

The actual value measured is the cardinality of the population of landline phone users.

Table 30: NumberofTeleLandlineServiceConnectionPopulation Class Description

Class	Property	Value Restriction
NumberofTeleLandlineServiceConnectionPopulation	owl:subClassOf	Quantity
	owl:subClassOf	NumberofServiceConnectionsPopulatio
	defined_by	only TeleLandlineUser
	'for_city'	only Coty

The population of landline users, is defined as the number of users who have LandlineTelephoneService which is defined by Tele_LandlineUser in Table 18.

8. Alternative Representations for the Telecommunication & Innovation GCI Numerator

The ISO 37120 Telecommunication & Innovation Indicators definitions allow for service usage to be taken from two other sources beyond the counts derived from the Telecomm Service Providers: Government Census and Official Estimates, neither of which requires a population size to determine the number of users. Both of these sources will have a predetermined value to which our ontology can point. The following two sections define the classes of both the government census and official estimate sources respectively.

8.1. Government Census

Statistics that are recorded, collected, and shared by government agencies about their population both individually and collectively are considered an official census. Using a government census currently has the limitation of being only available in democratic countries and few of those countries provide census information in machine readable formats. The GovernmentCensus (Table 32) class will allow the Telecommunication & Innovation GCI ratio to represent service usage by linking the numerator directly to the service count value. Using the Document Ontology (document_ont) we borrow the class Document to enable a description of a census being physically represented on paper instead of an electronic record. We also use the GovernmentAgency class defined by the DBpedia ontology to be "a permanent or semi-permanent organization in the machinery of government that is responsible for the oversight and administration of specific functions."[6]

Table 31: GovernmentCensus Class Description

Class	**Property**	**Value Restriction**
GovernmentCensus	owl:subClassOf	AcceptedResidencyDocument
	owl:subClassOf	Document
	owl:subClassOf	Quantity
	unit_of_measure	only 'Unit of Measure'
	value	value only Measure
	is_validated_by	exactly 1 'Government Organization'
	is_issued_by	exactly 1 'Government organization'
	forAddress	exactly 1 'Home Address'
	'for city'	exactly 1 City
	certification_Date	exactly 1 dateTime
	expiry_Date	exactly 1 dateTime

(Axioms)

1. The year of the census must be the same year used in the residency count found in the denominator.
2. The provided census must match the residency city used in the denominator.

8.2. Official Estimates

An Official Estimate is similar to a Government Census in that both have specific numerical values for the number of service users within a defined jurisdiction. The difference is in discerning the validity of the official estimate. How is an estimate deemed 'official' and by what authority? These questions will differ from city to city, so we first must introduce a standard method in determining if the estimate is official before we define it for use in the Telecommunication & Innovation ontology.

[6] Definition taking from http://dbpedia.org/ontology/GovernmentAgency

Table 32: Official_Estimate Class Description		
Class	**Property**	**Value Restriction**
Official_Estimate	owl:subClassOf	GovernmentCensus
	owl:subClassOf	Document
	owl:subClassOf	number_of_service_connection_size
	'for city'	only City

The Official Estimate Class can now be defined.

Table 32: AcceptedOfficialEstimateValue Class Description		
Class	**Property**	**Value Restriction**
AcceptedOfficialEstimateValue	owl:subClassOf	Official_Estimate
	owl:subClassOf	Document
	certification_Date	exactly 1 dateTime
	'for city'	only City
	expires	exactly 1 dateTime
	is_issued_by	exactly 1 'Government Organization'

9. Evaluation

Ontology engineering has yet to conclusively deal with verification and validation issues.[7]. In this section we verify the Telecommunication & Innovation Ontology by testing its consistency and demonstrating that the competency questions can be answered with it. We then evaluate the ontology by confirming that our definitions of the ISO 37120 Telecommunication & Innovation indicators can be used to test the consistency of city data.

In the next two subsections, we use the City of Toronto in the Province of Ontario, Canada to illustrate the competency questions. Prefixes are defined in the Appendix.

This first table defines the instances that provide background information on the city of Toronto (accepted residency documentation, and an accredited census agency).

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	sc:City
Rogers	rdfs:type	gci-i InternetServiceProvider
	gci-i:provides	InternetService
StatsCanada	rdfs:type	GovernmentOrganization
	rdfs:label	“Canadian Statistics Agency”

[7] See Ontology Summit 2013 at http://ontolog.cim3.net/cgi-bin/wiki.pl?OntologySummit2013

JohnSmith_OntarioDriversLicense	rdfs:type	Accepted_residency_document
	gci-i:is_issued_by	GovernmentOrganization
	gci:for_City	"Toronto"
Ministry of Transportation	rdfs:type	GovernmentOrganization
	gci:for_City	gn:6167865

The following table defines the instances that instantiate the 17.1 indicator.

Instance	Property	Value
17.1_TO2013_ex (instance of 17.1)	rdfs:type	iso: TO2013_17.1
	gci:numerator	17.1_TO2013_InternetUser_size
	gci:denominator	17.1_TO2013_City_resident_size
	gci:for_City	gn:6167865
	om:value	17.1_TO2013_ex_value
17.1_TO2013_ex_value (the value of 17.1)	rdfs:type	om:Measure
	om:numerical_value	89700
	om:unit_of_measure	gci:Population_ratio_unit
17.1_ TO2013_InternetUser_size (numerator of 17.1)	rdfs:type	isoi:17.1_InternetUser_population_size
	gci:cardinality_of	17.1_TO2013_Internet_connection_population
	om:value	17.1_TO2013_InternetUser_size_value
17.1_ TO2013_InternetUser_size_value (value of the numerator of 17.1)	rdfs:type	om:Measure
	om:numerical_value	2771770
	om:unit_of_measure	gci:Population_cardinality_unit
17.1_TO2013_City_resident_size (denominator of 17.1)	rdfs:type	isoi:17.1_City_resident_population_size
	gci:cardinality_of	17.1_TO2013_CIty_resident_population
	om:value	17.1_TO2013_City_resident_size_value
17.1_TO2013_City_resident_size_value (value of the denominator of 17.1)	rdfs:type	om:Measure
	om:numerical_value	28
	om:unit_of_measure	gci:Population_cardinality_unit
17.1_TO2013_ InternetUser_population (Numerator population)	rdfs:type	isoi:InternetUser_Population
	gci:locatedin	gn:6167865
	gci:defined_by	17.1_TO2013_InternetUser
17.1_TO2013_City_resident_size_population (Denominator population)	rdfs:type	isoi:17.1_City_resident_Population
	gci:locatedin	gn:6167865
	gci:defined_by	17.1_TO2013_Resident
17.1_TO2013_InternetUser	rdfs:subClassOf	isoi:17.1_Person OR 17.1_Organization
	gci-i:has_Service	17.1_TO2013_InternetService
17.1_TO2013_InternetService	rdfs:subClassOf	schema:service
	gci-i:providedBy	17.1_TO2013_InternetServiceProvider
	gci-i:serviceType	'Connection to the World Wide Web'
17.1_TO2013_InternetServiceProvider	rdfs:subClassOf	isoi:17.1_Organization
	gci-:sells	some Service
	gci-i:provides	17.1_TO2013_InternetService
17.1_TO2013_Resident	rdfs:subClassOf	Isoi:17.1_Person
	gci-i:has_Proof	Isoi:AcceptedResidencyDocument
	ic:forAddress	ic:HomeAddress
	ic:has_City	gn:6167865
	gci-i:is_issued_by	ic:GovernmentOrganization
	gci-i:expiry_Date	August 2016

9.1. Verification

We take two approaches to verification, i.e., what we have implemented conforms to the ontology specifications. The first is to determine whether the ontology is consistent. The consistency of our Telecommunication & Innovation ontology is dependent upon the ontologies it imports. The following diagram depicts the ontology import hierarchy.

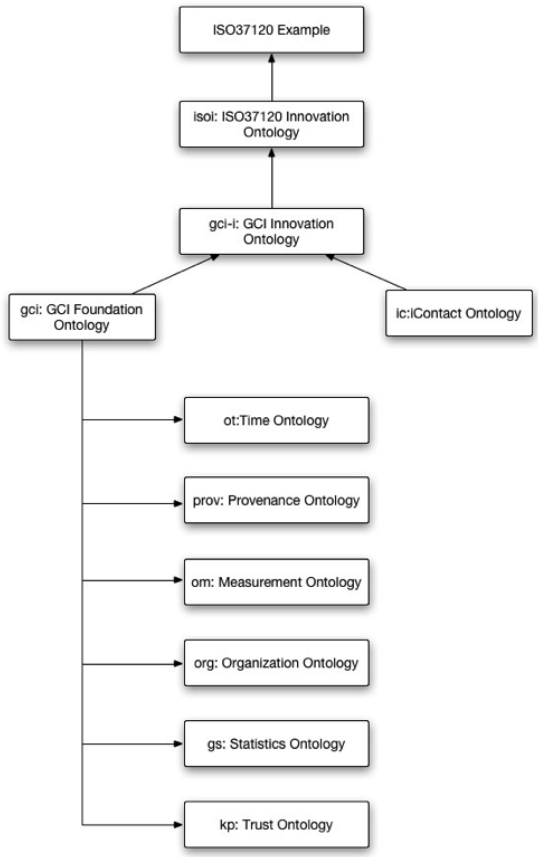

Figure 5 Innovation Ontology import hierarchy

For a list of URI for each of the imported ontologies please refer to the Appendix. Using Protégé's Hermit reasoner, we can test an ontologies consistency. In this case, the ontologies in Figure 7 were found to be consistent.

The second approach we have taken to verification is to use competency questions as specifications. The following shows how the consistency questions for '17.1' are implemented in SPARQL.

1. (F) What city is the indicator for?

   SELECT ?city WHERE { 17.1_TO2013_ex
   gci:for_City ?city}

2. (F) What is the population of the city

   SELECT DISTINCT (COUNT(?population) AS ?count) WHERE {
   ?population a gci-i:Resident.
   }

3. (CD) Are the internet users residents of the city?
   Identifies each internet user that is a member of the resident population and checks to see if their primary residence is the same city as the indicator instance.

```
SELECT ?InternetUser WHERE
        { 17.1_TO2013_ex gci-i:for_City ?city .
          ?InternetUser org:memberOf InternetUser_population.
          ?InternetUser gci-i:CityCurrentlyResidingIn ?CCRI .
          ?CCRI ic:has_City ?city }
```

4. (F) What organizations provide internet service?

```
SELECT  * WHERE {?organization a isoi:InternetServiceProvider}
```

5. (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
```

6. (F) At what minimum price does the service provider provide service to the subscriber?

```
SELECT ?s ?price WHERE {
         ?s schema:price ?price }
         ORDER BY DESC(?price) LIMIT 1
```

7. (D) Did the subscriber purchase the service within the census year?
   We will use the 2014 census year for this illustration.

```
SELECT *
{ ?purchase a APurchase:InternetService.

?purchase gci-i:certification_date ?date
   FILTER (
   ?date > "2013-1-1"^^xsd:date &&
   ?date < "2013-12-31"^^xsd:date
  )
}
```

8. (D) Is the reported number of internet subscribers (connections) certified by the government?

```
SELECT ?govag WHERE
         { #_of_Service_Connections_size gci-i:for_City ?city
```

#_of_Service_Connections_size OfficialEstimate ?cert.
?cert prov:wasGeneratedBy ?govag.
?govag subclassOf GovernmentAgency}

As an example of the results these SPARQL queries return, lets look at the 5th competency question.

(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
```

To test the query we created the following instances.

Instances	Property	Value
internetUser1	rdfs:type	isoi:InternetUser
	service:consumes	rogersInternetService1
internetUser2	rdfs:type	isoi:InternetUser
	service:consumes	rogersInternetService1
internetUser3	rdfs:type	isoi:InternetUser
	service:consumes	rogersInternetService2
internetUser4	rdfs:type	isoi:InternetUser
	service:consumes	bellInternetService1
rogers	rdfs:type	isoi:InternetServiceProvider
	service:provides	internetService1
	service:provides	internetService2
bell	rdfs:type	isoi:InternetServiceProvider
	service:provides	bellInternetService1
rogersInternetService1	rdfs:type	isoi:InternetService
	gci-i:providedBy	rogers
	gci-i:consumedBy	internetUser1
	gci-i:consumedBy	internetUser2
rogersInternetService2	rdfs:type	isoi:InternetService
	gci-i:providedBy	rogers
	gci-i:consumedBy	internetUser3
bellInternetService1	rdfs:type	isoi:InternetService
	gci-i:providedBy	bell
	gci-i:consumedBy	internetUser4

Figure 6 shows the results, where SPARQL returns a count of Rogers 3 and Bell 1 which is correct.

```
PREFIX isoi: <http://ontology.eil.utoronto.ca/GCI/ISO37120/Innovation.owl#>
PREFIX gci-i: <http://ontology.eil.utoronto.ca/GCI/Innovation/GCI-Innovation.owl#>
PREFIX service:<http://purl.org/ontology/service#>


SELECT   DISTINCT (COUNT (?internetUser) as ?count)  ?internetProvider
#SELECT *

WHERE {?internetProvider a isoi:InternetServiceProvider.
?internetProvider service:provides ?internetService.
?internetUser  service:consumes ?internetService.
?internetService a isoi:InternetService}

GROUP BY  ?internetProvider
```

count	
"3"^^<http://www.w3.org/2001/XMLSchema#integer>	rogers
"1"^^<http://www.w3.org/2001/XMLSchema#integer>	bell

Figure 6 Screen capture of the SPARQL query

9.2. Validation

Validation refers to whether the ontology accomplishes its intended purpose. Our research 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).

In this section we will use the Telecommunication & Innovation ontology for consistency analysis. Root cause analysis will be investigated 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 of the necessary properties and satisfy the property restrictions defined in the class it is a member of?
2. How do we manage definitional constraints that cannot be represented in OWL?

To resolve the first type of consistency, we implemented a set of prolog rules that 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.

The second type of consistency is handled by representing each constraint as prolog rules that can be applied to any individuals/instances of 17.1 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.

We were able to validate the GCI Telecommunication & Innovation Ontology by representing the City of Toronto's Telecommunication & Innovation indicators using the ontology.

10. Conclusions

The ultimate goals of this research are to:

1. Define an ontology so that Telecommunication & Innovation indicator definitions and their the corresponding supporting data provided by a city can be published on the Semantic Web using a standard ontology, and
2. Automate the analysis of a city's performance, as represented by these indicators, in order to identify root causes of differences over time and between cities.

Towards this end we had to introduce two 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 & 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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12. References

2ThinkNow (2013), "Innovation Cities", Program Retrieved from http://www.innovationcities.com.

Belhajjame, K., Deus, H., Garijo, D., Klyne, G., Missier, P., Soiland-Reyes, S., and Zednik,S., (2012), "PROV Model Primer", http://www.w3.org/TR/prov-primer.

Cabrera, O., Franch, X., Marco, J., (2014), "A context ontology for service provisioning and consumption", Research Challenges in Information Science (RCIS), IEEE Eighth International Conference.

ITU, 1992, "Constitution of the International Telecommunication Union", c 1 ss2 (d).

Dey AK, Abowd GD. Towards a better understanding of context and context-awareness. CHI'2000 Workshop on the What, Who, Where, When, and How of Context-Awareness, 2000, ftp://ftp.cc.gatech.edu/pub/gvu/tr/1999/ 99-22.pdf.

Fox, M.S., (2012), "International Contact Ontology: Addresses, phone numbers and emails" http://ontology.eil.utoronto.ca/icontact.owl.

Fox, M.S., (2013), "A Foundation Ontology for Global City Indicators", Working Paper 3, Global Cities Institute, University of Toronto. Latest version can be accessed at: http://eil.utoronto.ca/smartcities/papers/GCI-Foundation-Ontology.pdf.

Fox, M.S., (2015), " PolisGnosis Project: Representing and Analysing City Indicators", Working Paper, Enterprise Integration Laboratory, University of Toronto. Latest version: http://eil.utoronto.ca/smartcities/papers/PolisGnosis.pdf.

Fox, M.S., and Huang, J., (2005), "Knowledge Provenance in Enterprise Informa- tion", International Journal of Production Research, Vol. 43, No. 20., pp. 4471-4492. http://www.eil.utoronto.ca/km/papers/fox-ijpr05.pdf.

Grüninger, M., and Fox, M. S., (1995), "Methodology for the Design and Evaluation of Ontologies." Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing, IJCAI-95, Montreal, Canada.

Hobbs, J.R., and Pan, F., (2006), "Time Ontology in OWL", http://www.w3.org/TR/owltime/.

Hoornweg, D., Nunez, F., Freire, M., Palugyai, N., Herrera, E.W., and Villaveces, M., (2007), "City Indicators: Now to Nanjing", World Bank Policy Research Working Paper 4114.

CASEI, (2010), "Internet Ontology v1.0 and v2.0", Retrieved from https://code.google.com/p/casei/wiki/InternetOntology

ISO37120, (2014), "ISO37120: Sustainable Development of Communities – Indicators for City Services and Quality of Life", International Organization for Standardization, First Edition, 2014-05-15, ISO37120:2014(E).

ITU's ICT-Eye. (2013). Topics. Retrieved from http://www.itu.int/net4/itu-d/icteye/Topics.aspx?TopicID=6.

Knackstedt, R., Kuropka, D., Mu¨ller, O., & Polyvyanyy, A. (2008). An Ontology-based Service Discovery Approach for the Provisioning of Product-Service Bundles.
36

Li, J. (1991). Taxation in the People's Republic of China. New York: Praeger.

McCarney, P. L., (2009), "City indicators on climate change: implications for policy leverage and governance", Paper prepared for the World Bank's 5th Urban Research Symposium, Marseilles, France.

McGladrey, New York State/City Resident Defined, 2009, Regulation 105.20 (d)(1).

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

Qiao ,X., Li, X., Chen, J,. (2012) "Telecommunications Service Domain Ontology: Seman- tic Interoperation Foundation of Intelligent Integrated Services. In Telecommunications Networks - Current Status and Future Trends, pages 183–210. InTech, 2012.

Rijgersberg, H., Wigham, M., and Top, J.L., (2011), "How Semantics can Improve Engineering Processes: A Case of Units of Measure and Quantities", Advanced Engineering Informatics, Vol. 25, pp. 276-287.

Seidel, Frank., (2011) THINKING BEYOND BORDERS: MANAGE- MENT OF EXTENDED BUSINESS TRAVELERS Retrieved from https://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Documents/thinking-beyond-borders-2011/ies-tbb-2011-germany.pdf.

Voß, J., (2013), "The Service Ontology". Retrieved from http://dini-ag- kim.github.io/service-ontology/service.html.

World Bank Development Indicators. (2013). "Science & Technology", Retrieved from http://data.worldbank.org/data-catalog/world-development-indicators.

13. Appendix

- The Global City Indicator Foundation ontology can be found in:
  - gci: http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl.
- The Global City Indicator Innovation ontology can be found in:
  - isoi: http://ontology.eil.utoronto.ca/GCI/Innovation/GCI-Innovation.owl.
- Definitions of the ISO37120 innovation indicators
  - http://ontology.eil.utoronto.ca/GCI/ISO37120/Innovation.owl.
- URIs for all of the ISO37120 indicators can be found in:
  - iso: http://ontology.eil.utoronto.ca/ISO37120.owl

Other ontologies used by the Foundation and Innovation ontologies are:

- Geonames Ontology
  - gn: http://sws.geonames.org/
- Schema Ontology

    - sc: http://schema.org/
- The International Contact Ontology
    - ic: http://ontology.eil.utoronto.ca/icontact.owl
- The Time Ontology
    - ot: http://www.w3.org/2006/time
- The Provenance Ontology
    - prov: http://www.w3.org/ns/prov
- The Measurement Ontology
    - om: http://www.wurvoc.org/vocabularies/om-1.8/
- The Organization Ontology
    - org: http://ontology.eil.utoronto.ca/organization.owl
- The Statistics Ontology
    - gs: http://ontology.eil.utoronto.ca/govstat.owl
- Trust and validity ontology
    - kp: http://ontology.eil.utoronto.ca/trust.owl