A Transportation Ontology for Global City Indicators (ISO 37120)

Wael A. Yousif and Mark S. FOX
wael.yousif@mail.utoronto.ca; msf@eil.utoronto.ca

Enterprise Integration Laboratory, University of Toronto
5 King's College Road, Toronto ON, M5S 3G8

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GCI Transportation Ontology:
http://ontology.eil.utoronto.ca/GCI/Transportation/GCI-Transportation.owl
ISO 37120 Transportation Theme Indicator Definitions:
http://ontology.eil.utoronto.ca/GCI/ISO37120/Transportation.owl

1.0 Introduction

In this paper, an indicator is defined as a metric for evaluating performance. Thus, a city indicator is a performance evaluating metric specific to a city. For example, an indicator for a city can be, "annual number of public transport trips per capita" which is one of the indicators specified in ISO 37120 [1]. These indicators are then used by cities as a means of evaluating their performance [2] which would be used by the city for their own purposes, which may include determining where improvements are needed. The term Global City Indicators[1] was created to describe these indicators for evaluating cities.

The purpose of evaluating cities using these indicators is to measure a city's performance for improving quality of life and sustainability on a global scale [3]. ISO claims the main issue with existing indicators is that they are often not standardized, consistent, nor comparable over time or across cities [3]. It is important to note that the standards developed in ISO 37120 do not provide recommended values or thresholds for cities to follow or set as a goal, instead, the standard provides what should be measured and how it should be measured with the hopes that cities will be able to compare and evaluate their performance metrics in a balanced, uniform manner.

So in order to provide cities with a tool for fairly evaluating their city performances, ISO 37120 was developed. This standard is broken down into 17 indicator themes which are listed below.

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[1] "Global City Indicators ©" is a term created by the Global City Indicators Facility in 2010 at the University of Toronto.

Each theme consists of up to 9 city indicators which specify how and what should be measured. In the case of the transportation indicator theme, there are 9 indicators.

- Economy
- Environment
- Shelter
- Finance
- Health
- Wastewater
- Education
- Recreation
- Solid Waste
- Fire and Emergency Response
- Transportation
- Water and Sanitation
- Energy
- Safety
- Telecommunications and Innovation
- Governance
- Urban Planning

The next problem that must be overcome is the fact that there are over 100 indicators [2] contained in ISO 37120 between all 17 themes. The sheer amount of data that needs to be analyzed is difficult and time-consuming. Ideally, a software application that can read, understand, and analyze the data automatically would be created. That is where the PolisGnosis [2] project comes in.

The PolisGnosis project is designed to analyse how and why a city's indicators change over time as well as analyse how and why a city's indicators differ between cities. Essentially, the PolisGnosis project's main goal is to automate the process of analysing city indicator data contingent on the city following the ISO 37120 standard. Theoretically, when a city publishes data on the Semantic Web following the standard, the PolisGnosis analysis software will automatically retrieve, read, and analyze the data.

The PolisGnosis project requires ontologies to be developed covering each of the 17 themes representing all city indicators. In this paper, the transportation theme ontology will be developed. The following list specifies what is to follow in this paper.

- First, the transportation theme indicators will be defined, as specified in ISO 37120, as well as create competency questions that the ontology must answer.
- Next, we will look into whether or not there are any transportation ontologies that have already been developed, and determine whether or not they can be used or modified to fit into our ontology. It must be able to answer the competency questions.
- Then, the ISO 37120 transportation themed indicators will be used to create an ontology representing it.
- Finally, the developed ontology will be evaluated by determining whether or not it can answer our competency questions.

2.0 Indicators and their Competency Requirements

Each transportation indicator defined in ISO 37120 will be reviewed and summarized to follow. Afterwards, a set of competency questions will be developed with the goal of assuring quality of our transportation ontology. These competency questions will also be used to evaluate existing ontologies and would help us determine whether or not they satisfy our standards that we will develop in this section. It is important to note that questions involving measurement, theory, provenance, validity, and trust will not be included here since they are addressed in the GCI foundation ontology.

Competency questions fall into the following 4 categories [5].

- **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 that can be deduced from the instantiation.

2.1 ISO 37120 Transportation Indicators

2.1.1 Kilometres of High Capacity Public Transport System per 100 000 Population (ISO 37120:18.1)

The first transportation indicator focuses on the total kilometres of transport system within a city, per 100 000 people in the population. The exact indicator is quoted below.

> "The kilometres of high capacity public transport system per 100 000 population shall be calculated by adding the kilometres of high capacity public transport systems operating within the city (numerator) divided by 100 000th of the city's total population (denominator). The result shall be expressed as the kilometres of high capacity public transport system per 100 000 population.
>
> High capacity public transport may include heavy rail metro, subway systems and commuter rail systems." [1]

The distance in this case should not be confused with distance travelled by the public transport system. Instead, it looks at kilometres of installed infrastructure. The population is based on a per 100 000 people basis. So a city with a population of 200 000 would have a value of 2.

Competency Questions

1. (F) What city is the indicator for?
2. (CD) What types of transportation are classified as high capacity transportation?
3. (F) What high capacity transportation lines does the city have?
4. (F) What is the length of line X?
5. (D) What is the mode of transportation for line X?
6. (D) How much does it cost to travel on transportation line X?
7. (F) When was the trip made?

2.1.2 Kilometres of Light Passenger Public Transport System per 100 000 population (ISO 37120:18.2)

This section is concerned with the total amount of installed public transportation within the "light passenger" group. The definition of a light passenger system is defined by ISO.

> “The kilometres of light passenger public transport system per 100 000 population shall be calculated by adding the kilometres of light passenger transport systems provided within the city (numerator) divided by one 100 000th of the city’s total population (denominator). The result shall be expressed as the kilometres of light passenger transport system per 100 00 population. Expressed as per 100 000 population.
>
> Light passenger transport may include light rail streetcars and tramways, bus, trolleybus and other light passenger transport services.” [1]

Competency Questions

Since light passenger public transportation is very similar in definition to high capacity public transportation, the competency questions are the same and thus are referred back to. High capacity transportation is replaced with light passenger in the questions above and each mode of transportation referred to above should be replaced with light rail streetcars and tramways, buses, and trolleybuses.

2.1.3 Annual Number of Public Transport Trips per Capita (ISO 37120:18.3)

This indicator takes into account all forms of transportation (both heavy and light) and compares it to the total population of a city. The definition provided by ISO is as follows.

> “Annual number of public transport trips per capita shall be calculated as the total annual number of transport trips originating in the city - “ridership of public transport” - (numerator), divided by the total city population (denominator). The result shall be expressed as the annual number of public transport trips per capita.
>
> Transport trips shall include trips via heavy rail metro or subway, commuter rail, light rail streetcars and tramways, organized bus, trolleybus, and other public transport services.
>
> Cities shall only calculate the number of transport trips with origins in the city itself.” [1]

Competency Questions

1. (F) What city is the indicator for?
2. (F) What is the primary mode of transportation for the trip?
3. (F) Were any transfers made in the trip?
4. (F) What is the start point of trip X?
5. (F) What is the end point of trip X?
6. (CD) Is the rider a senior, adult, or child?
7. (CD) Is the rider a student?
8. (D) Is the trip for work, leisure, or business?

2.1.4 Number of Personal Automobiles per Capita (ISO 37120:18.4)

This indicator is concerned with the total number of personal automobiles and compares it with the total population of a city.

> "The number of personal automobiles per capita shall be calculated as the total number of registered personal automobiles in a city (numerator) divided by the total city population (denominator). The result shall be expressed as the number of personal automobiles per capita.
>
> The total number of registered personal automobiles shall include automobiles used for personal use by commercial enterprises.
>
> This number shall not include automobiles, trucks, and vans that are used for delivery of goods and services by commercial enterprises." [1]

Competency Questions

1. (F) What city is the indicator for?
2. (CD) Does automobile X have an owner?
3. (CD) Does the owner of automobile X reside in the city?
4. (CD) Is automobile X insured?
5. (F) What type of vehicle is automobile X? (SUV, sedan, van, truck, etc.)?
6. (F) What is the make and model of the vehicle?
7. (F) Is the automobile used by commercial enterprises to deliver goods and services?

2.1.5 Percentage of Commuters Using a Travel Mode to Work other than a Personal Vehicle (ISO 37120:18.5)

This indicator is concerned with how people within the city - who are not necessarily residents of the city - utilize non-private single occupancy vehicles.

> "Percent of commuters using a travel mode to work other than a personal vehicle shall be calculated as the number of commuters working in the city who use a mode of transportation other than a private Single Occupancy Vehicle (SOV) as their primary way to travel to work (numerator) divided by all trips to work, regardless of mode (denominator). The result shall then be multiplied by 100 and expressed as a percentage of commuters using a travel mode other than a personal vehicle.
>
> Modes other than non-SOV may include carpools, bus, mini-bus, train, tram, light rail, ferry, motorcycle and non-motorized two-wheel vehicles such as bicycles, and walking, and other modes.
>
> NOTE This indicator uses commuters who work in the subject city, regardless of where they live. Even if these individuals do not live in the subject city, they use the transportation resources of the city, and therefore create impacts on the city's entire transportation system.

For cases where multiple modes are used, the indicator shall reflect the primary travel mode, either by length of trip on that mode or by distance travelled on that mode. For example, if a person drives a SOV from home to a suburban train station (5 minutes), takes a 30-minute train ride to the central city, and then takes a 5-minute bus ride to their office, the primary travel mode is the passenger train.” [1]

Competency Questions

1. (F) Which city is being examined?
2. (F) How many modes of transportation, or segments, did user X use?
3. (CD) Which modes of transportation did user X use?
4. (CD) Which mode of transportation was used in each segment?
5. (F) Where does user X begin their trip?
6. (F) Where does user X end their trip?
7. (F) Does the user live outside the city?

2.1.6 Number of Two-Wheel Motorized Vehicles per Capita (ISO 37120:18.6)

This indicator looks to compare the total number of two-wheeled motorized vehicles, such as scooters and motorcycles, with the total population of the city.

> “The number of two-wheel motorized vehicles per capita shall be calculated as the total number of two-wheel motorized vehicles in the city (numerator) divided by the total city population (denominator). The result shall be expressed as the number of two-wheel motorized vehicles per capita.
>
> Two-wheel motorized vehicles shall include scooters and motorcycles. This shall not include non motorized vehicles such as bicycles.” [1]

Competency Questions

These questions are similar to the competency questions used in section 2.1.4 (Number of personal automobiles per capita). The only difference being instead of personal automobiles, this indicator is more concerned with the number of two-wheeled motorized vehicles such as scooters and motorcycles as stated in the definition.

2.1.7 Kilometres of Bicycle Paths and Lanes per 100 000 Population (ISO 37120:18.7)

This indicator is concerned with the total length of bicycle paths and lanes per 100 000 population of the city. Here, bicycle paths and lanes are distinct. The requirements for each respective distinction is defined by ISO and can be seen below.

> “Kilometres of bicycle paths and lanes per 100 000 population shall be calculated as the total kilometres of bicycle paths and lanes (numerator) divided by one 100 000th of the city’s total population (denominator). The result shall be expressed as the kilometres of bicycle paths and lanes per 100 000 population.

Bicycle lanes shall refer to part of a carriageway designated for cycles and distinguished from the rest of the road/carriageway by longitudinal road markings.

Bicycle paths shall refer to independent road or part of a road designated for cycles and sign-posted as such. A cycle track is separated from other roads or other parts of the same road by structural means.” [1]

Competency Questions

1. (F) Which city is the indicator for?
2. (CD) Is the bicycle road a lane or a path?
3. (F) Where does bicycle path/lane X start?
4. (F) Where does bicycle path/lane X end?
5. (F) How long is bicycle path/lane X?
6. (F) For what calendar period was the data collected?

2.1.8 Transportation Fatalities per 100 000 Population (ISO 37120:18.8)

This indicator compares the number of transportation related fatalities per 100 000 population. Transportation in this context refers to both personal and public transportation systems.

“Transportation fatalities per 100 000 population shall be calculated as the number of fatalities related to transportation of any kind within the city borders (numerator), divided by one 100 000th of the city’s total population (denominator). The result shall be expressed as the number of transportation fatalities per 100 000 population.

The city shall include in this indicator deaths due to any transportation-related proximate causes in any mode of travel (automobile, public transport, walking, bicycling, etc.). The city shall count any death directly related to a transportation incident within city limits, even if death does not occur at the site of the incident, but is directly attributable to the accident.

NOTE Transportation fatalities are used here as a proxy for all transportation injuries. Whereas many minor injuries are never reported - and thus cannot be measured - deaths are almost always reported. It is also worth noting that differences in the quality of the roadway, the quality of motorized vehicles, and the nature of law enforcement can change the relationship between injury and fatality. Cities and countries may have different definitions of causality, specifically related to the amount of time that can elapse between a traffic incident and a death.” [1]

Competency Questions

1. (F) Which city is the indicator for?
2. (CD) Is the fatality related to transportation?
3. (CD) Where was the accident?
4. (CD) Where was the fatality?
5. (F) When was the accident?

6. (F) When was the fatality?
7. (D) What is the cause of the accident? (E.g. poor roads, drivers, pedestrians)
8. (CD) Is the fatality a death or injury?

2.1.9 Commercial Air Connectivity (Number of Non-Stop Commercial Air Destinations) (ISO 37120:18.9)

In this section, airports within a two hours of the examined city are counted. All non-stop flights are added up. In this context, non-stop can refer to scheduled. Connecting flights are not counted.

> "Commercial air connectivity shall be expressed as the sum of all non-stop commercial (i.e. scheduled) flights departing from all airports serving the city.
>
> Airports serving the city shall include all airports within a two hour travel distance from the subject city.
>
> EXAMPLE Paris could count flights departing from Charles de Gaulle and Orly airports.
>
> Connecting flights shall be excluded because travel is theoretically possible between any two cities in the world, given an unlimited number of connections." [1]

Airports are defined in the oxford dictionary as follows:

> "A complex of runways and buildings for the take-off, landing, and maintenance of civil aircraft, with facilities for passengers." [7]

Competency Questions

1. (F) Which city is being examined?
2. (CD) Is the flight managed by a commercial airliner, or privately owned?
3. (CD) How many buildings does the airport have?
4. (CD) How many runways does the airport have?
5. (CD) How many airplanes does the airline have?
6. (F) How many flights depart from the city?
7. (F) How many departure airports serve the city?
8. (F) How many arrival airports serve the city?
9. (F) What time is the flight?
10. (F) What is the flight number?

2.2 Ontology Requirements

ISO 37120 was developed with the goal of providing cities with a universal standard for collecting and analyzing data based on their city. This standard should make the comparison and analysis of cities uniform, consistent, and comparable over time as well as across different cities. The standard outlines what should be measured and how it should be measured.

To better make use of this information, the data needs to be machine readable so that the collection of data and analysis could be done automatically by a machine. An ontology that completely defines a theme's indicators would be used by the machine in its processes of finding and analysing the data.

In the case of the transportation theme, the concepts or microtheories are based on the 9 indicators as specified in ISO 37120. A quick summary what is generally required to determine the indicator is listed below.

- Indicator 1, 2, 7: Total kilometres of heavy public transport, light public transport, and bicycle path infrastructure per 100 000 population
- Indicator 3, 4, 6: Total number of public transport trips, personal automobiles, and two-wheel motorized vehicles per capita respectively
- Indicator 5: Percentage of the population using a travel mode other than a personal vehicle
- Indicator 8: Number of fatalities per 100 000 residents
- Indicator 9: Total number of air transport flights

Each transportation indicator is counted from city officials through either automatic counting systems or surveys. Population data is gathered from city officials. The final indicator data is collected from airport operators. No sensors are required for any of these indicators, the data is always gathered and added up and compared with its respective population sample (per 100 000 or per capita) if applicable.

Thus, to describe the indicators completely, a separate ontology needs to be created that defines length of transportation lines, tallies per capita and per 100 000 residents (i.e., number of personal automobiles per capita), and should also define each vehicle type.

3.0 Background

3.1 City Indicators

ISO is not the first or only organization to look at standardizing the evaluation of city's. In Canada, the Transportation Association of Canada (TAC) [8] does what ISO 37120 is also doing. They differ in the depth of their analyses (i.e., number of indicators) as well as their scope. ISO 37120, for example, looks at over 100 indicators but spread across 17 themes. The transportation theme has 9 indicators. TAC, an association dedicated to the evaluation of city transportation solely, continually adds to their indicators as needed, and have done. They have 68 indicators as of 2016 [8].

The Urban Transportation Indicators (UTI) is what the Transportation Association of Canada (TAC) names their indicators. Listing each and every indicator would be excessive for the scope of this report, instead the various sections that each theme falls into will be listed and a small description will be given. TAC's indicators fall into 7 sections, as can be seen below. The full list of indicators can be found in Appendix D of the TAC's Urban Transportation Indicators - Fifth Survey [8].

1. *Background* - This section's indicators are generic and are concerned with population, the number of employed people, as well as the land area of the region, all broken down into the urban area and the business district.

2. *Land Use Characteristics* - These series of indicators are concerned with things such as population density, employment density, proportion of jobs, and the employment to population ratio.

3. *Transportation Supply* - These indicators are concerned with the length of road per capita and parking spaces available per employee. The length of road indicators are all broken down further into more specific subsections such as bike lanes and expressway lanes.

4. *Transportation Demand* - These indicators are concerned with how much each transportation mode is being used and by which populations. For example, one of the indicators is AM Peak Period Mode Shares to Central Business District. Then this indicator is broken down into 3 sub-indicators, such as Transit Modes, Auto (Driver+Passenger), and Non-Motorized.

5. *Transportation System Performance* - These indicators look at work trip distances and fuel usage. An example indicator is "Median Home-Work Trip Distance (km)" [8].

6. *Transportation Cost and Finance* - These indicators are concerned with the expenditures of transportation within a city. An example indicator is, "Total Road Expenditures per Capita" [8].

7. *Health* - This final section of indicators has a large amount of indicators. They vary from the activeness of the population, the weight, and the number of illnesses. The indicators then begin to relate to transportation with indicators such as percentage of students walking to school and the traffic accident fatalities per capita - which is a common indicator with the ISO 37120 fatality indicator.

3.2 Transportation Standards

Transportation standards are important for any city. ISO 37120, which is being analyzed in this report is only designed as a tool for its user to analyze a city. In this case, the transportation aspect is being analyzed. However, ISO 37120 does not provide and standards or guidelines that a city should strive to achieve. Thus, this section will aim to determine who determines the transportation standards that the ISO 37120 analysis should meet.

In Canada, Transport Canada - a government of Canada resource found in [9] is responsible for all the transportation guidelines in standards in Canada. "Transport Canada administers a number of Acts (laws) related to transportation. It also assists with the administration of many others." [9].

The List of Acts section of the Transport Canada website offers the full list of federal Acts and Regulations which is provided by the Department of Justice Canada [9]. These include air acts, marine acts, rail acts, and road acts. For example, one of the acts is called the Motor Vehicle Fuel

Consumption Standards Act. This Act contains the fuel consumption standards that vehicles in Canada must meet.

The European Union (EU) has their own standards that they recommend countries to follow [10]. The EU has passed a number of transportation directives, decisions, and regulations and the full list can be seen on their website [11].

Finally, international standards are developed by ISO. It is important to note that ISO is not the only organization developing international standards. ISO has 11 technical committees responsible for the development of transportation standards according to their website [12]. The following table lists all the committees that ISO has created to develop transport standards.

Reference	**Title**	**Published Standards**	**Standards Under Development**
ISO/TC 8	Ships and marine technology	313	119
ISO/TC 20	Aircraft and space vehicles	653	230
ISO/TC 22	Road vehicles	863	255
ISO/TC 23	Tractors and machinery for agriculture and forestry	366	82
ISO/TC 31	Tyres, rims and valves	79	27
ISO/TC 110	Industrial trucks	71	22
ISO/TC 149	Cycles	28	3
ISO/TC 188	Small craft	106	28
ISO/TC 204	Intelligent transport systems	253	85
ISO/TC 241	Road traffic safety management systems	1	1
ISO/TC 269	Railway applications	5	13

Table 1 - List of ISO Technical Committees [12]

So to recap, the idea is that ISO 37120 is used in the transportation ontology to come, which would be used by the PolisGnosis Project. The PolisGnosis Project will, ideally, automatically retrieve the data published by, for example, the City of Toronto, and evaluate it. The government official can then compare the results to the -potentially new- standards set by Transport Canada to determine if Toronto meets standard.

3.3 Relevant Ontologies

Before an ontology is created, existing ontologies should be reviewed. If an ontology has a significant relevance to ISO 37120, it will be absorbed and used in the ontology being created and developed here. If an ontology can answer a significant amount of competency questions, it will be used. Otherwise, it will be mentioned here but not used.

Some ontologies were discovered with the help of Katsumi and Fox's work [13] where they surveyed existing ontologies for transportation. A list of the discovered ontologies are as follows:

1. Ontology for Transportation Networks [13] (http://rewerse.net/A1/otn/OTN.owl)
2. Road Accident Ontology [13] (https://www.w3.org/2012/06/rao.html)
3. iCity Ontology [13] (https://w3id.org/icity/TransportationSystem/)
4. Smart City Artifacts [16] (http://ci.emse.fr/opensensingcity/ns/wp-content/plugins/smartcities/survey_files/vocabs/vocabulary_65)
5. Route Ontology [17] (http://ci.emse.fr/opensensingcity/ns/wp-content/plugins/smartcities/survey_files/vocabs/vocabulary_78)

Ontology for Transportation Networks (http://rewerse.net/A1/otn/OTN.owl)

The information to follow was collected from the survey done in [13] since it goes into good detail on what the ontology contains. The Ontology for Transportation Networks (OTN) was a part of the Reasoning on the Web with Rules and Semantics (REWERSE) project [13]. The OTN was made to "formalize and extend the Geographic Data Files (GDF) standard" [13] originally created by ISO.

The OTN was created with some terms relevant to ISO 37120. Some relevant concepts include the definitions and routes of public transportation, railways, roads and fairy features, as well as land cover and use.

Figure 1 below shows some basis classes in the OTN.

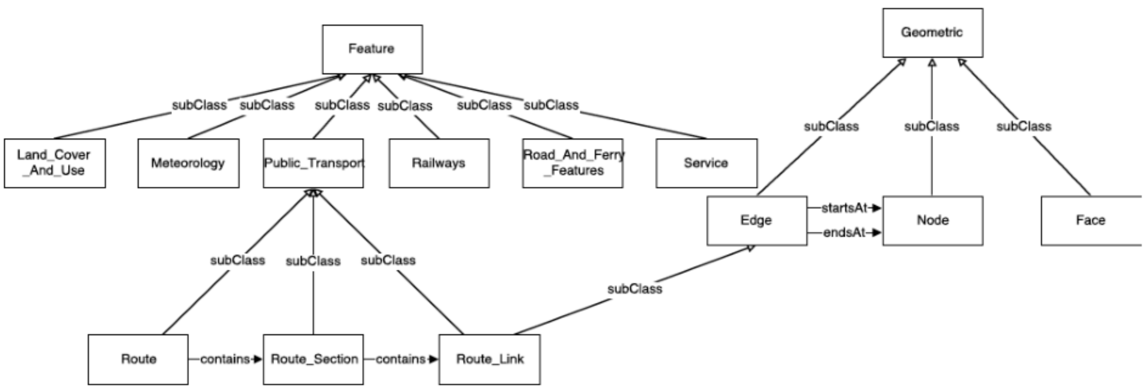

Figure 1 - Basic Classes in OTN and their relationships [13]

While this does have some relevant terms and definitions, it does not answer enough of our competency questions to be used in the ontology that will be created in this report. To parse through and retrofit this ontology would be more effort than starting from scratch.

Thus, it will not be used.

Road Accident Ontology (https://www.w3.org/2012/06/rao.html)

This ontology is made to encompass road accidents. Information include, but are not limited to, location, cause, and involved parties [13]. Unfortunately the OWL file does not load any information, and seems to be removed when attempting to access the direct link to the OWL file shown in [14] linked from their website. The webpage offers some background information and relevant terms.
The figure below shows how the ontology is laid out. It has some relevant information but a lot of irrelevant information as well that goes beyond the scope of the competency questions. Concepts such as robot and animals are listed as things that can be involved in a road accident. These concepts do not need to be defined according to the ISO 37120 definition. It is also important to reiterate that the OWL file provided does not seem to be accessible as of the time of writing this report even though it defines some important concepts.

Therefore, it will not be used.

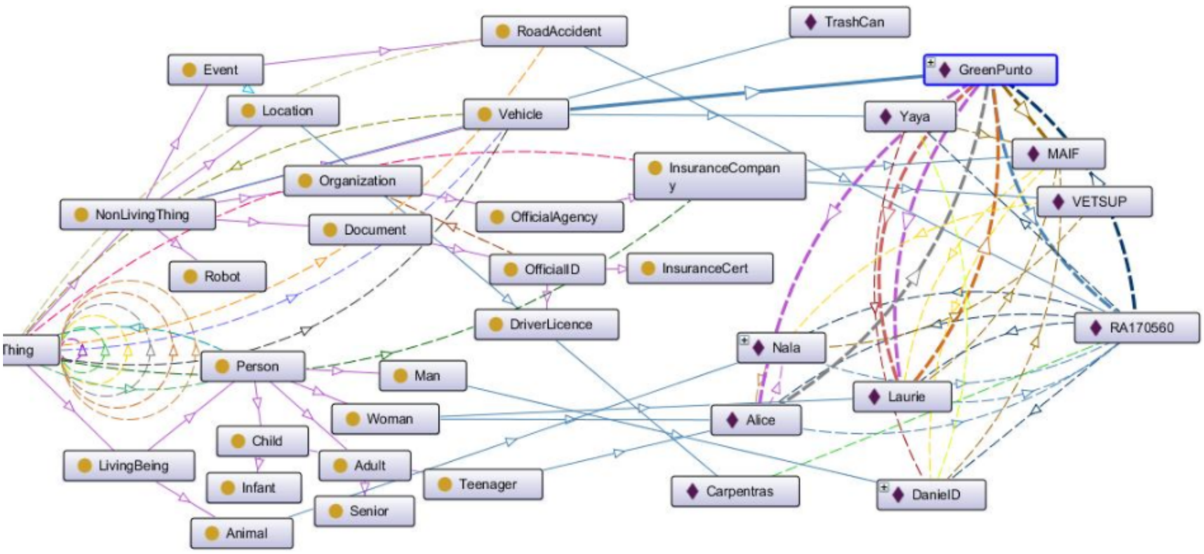

FIgure 2 - Road Accident Ontology Draft [15]

iCity Ontology (https://w3id.org/icity/TransportationSystem/)

This Ontology contains several sub-ontologies - one of which is a Transportation System ontology [13]. This ontology defines core transportation network concepts using Nodes and Arcs which have access to the physical infrastructure [13]. This ontology defines many transportation concepts. In the case with the ISO 37120 definition, concepts that encompass modes of transportation, units of measure, land cover and use, and transportation networks for transit, road, and rail are all relative concepts. This ontology also defines trips which is also necessary in the ontology being developed in this case.
The figure below depicts the basic structure of the iCity Transportation Network Ontology.

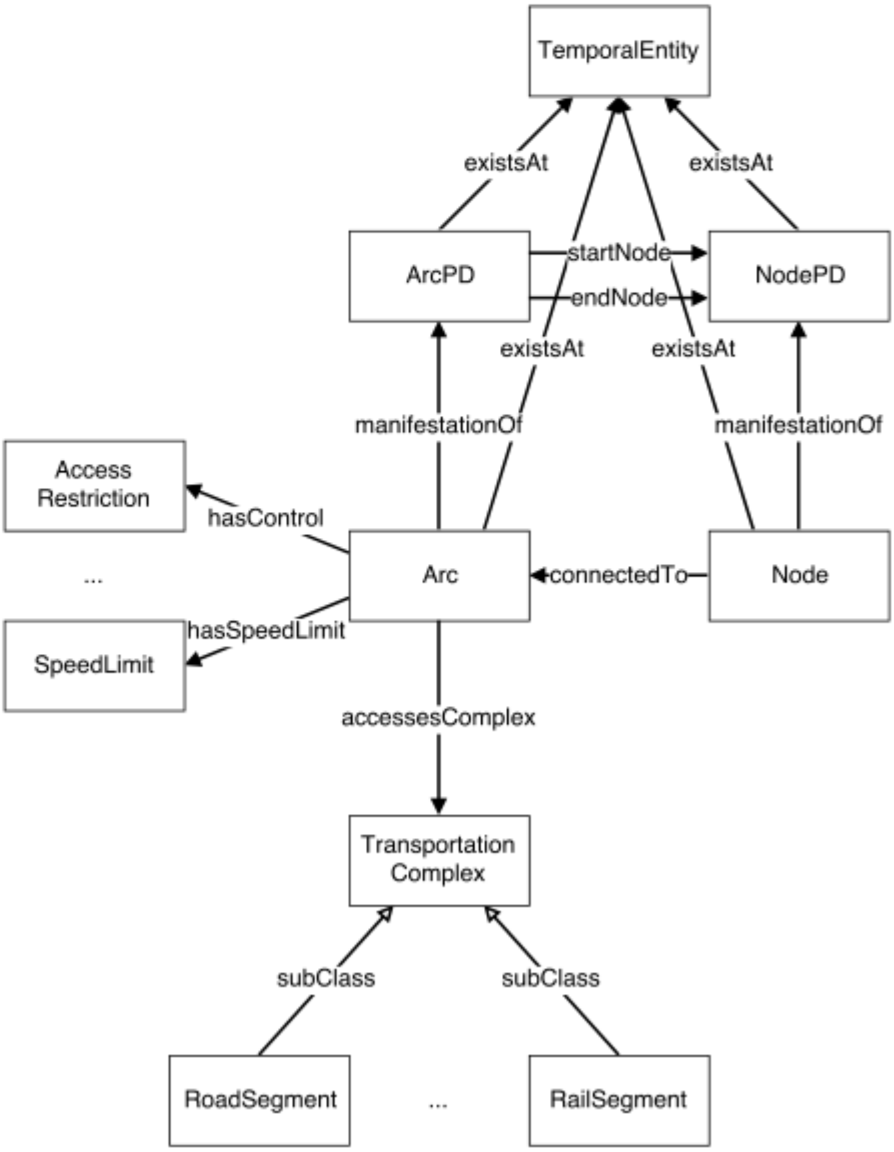

Figure 3 - Structure of iCity Transportation Network [13]

This ontology will not be used because it does not go in depth enough into the definitions of each mode of transportation nor road information. Concepts such as what differentiates public and private transport, modes of transportation (i.e. cars versus buses) are not defined here. While this ontology seem like it defines routes using nodes and arcs, it does so in a way that would not be helpful in answering the competency questions.

To reiterate, this ontology will not be used.

Smart City Artifacts - Transport Ontology (http://ci.emse.fr/opensensingcity/ns/wp-content/plugins/smartcities/survey_files/vocabs/vocabulary_65)

A description of this ontology was not provided by its creator. From opening the ontology in Protege, it seems that it focuses on defining transportation concepts such as carrier (in terms of public transportation), routes, stations, ticket information, as well as the mode of transportation being used. Unfortunately it does not go into enough detail and would not be able to answer enough competency questions to be used.

Below is a figure of the class hierarchy in Protege.

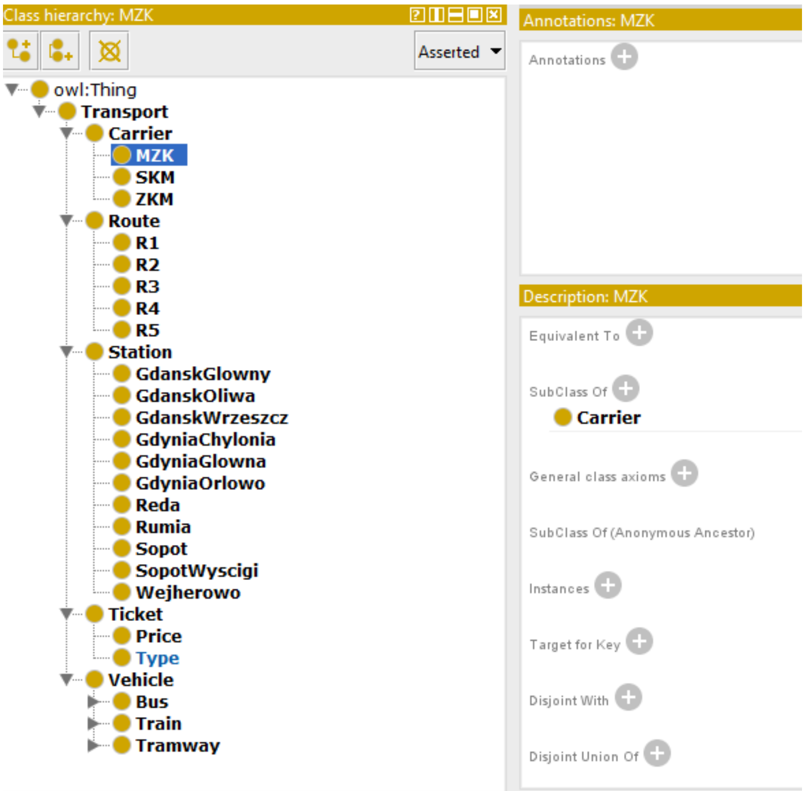

Figure 4 - Class Hierarchy of Transport Ontology [16]

Since this ontology does not answer enough of the competency questions, nor go into enough detail in terms of route information, it will not be used in the ontology created for this report.

Vehicle Ontology (https://w3id.org/ictiy/Vehicle/1.2/)

The Vehicle ontology will be used because it defines the Mode subclass which is important. This ontology also defines the class ‘VehiclePD’ which would have been used but the ISO standard would be better defined in a vehicle class that goes into more detail and contains subclasses for different vehicle types. This is important because each indicator is usually specific to a certain kind of vehicle or vehicles.

This short ontology’s classes can be seen in the image below.

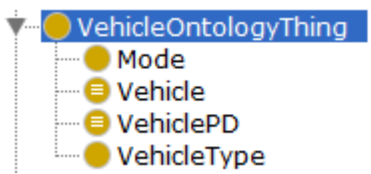

Figure 5 - Class Hierarchy of Vehicle Ontology

Trip Ontology (https://w3id.org/icity/Trip)

This ontology goes into a significant amount of detail for trips. The 'Trip' class is far too detailed for what is required of the standard. Thus the classes won't be used but the object properties such as startLoc for starting location will be used.

This ontology will be imported and used.

3.4 Global City Indicator Foundation Ontology

Before any serious work can be done in the Transportation Ontology for ISO 37120, a foundation ontology had to be developed first. This ontology is responsible for being the foundation of the ISO 37120 standard and as such, will relate all the city themes detailed in the standard. Thus, the Global City Indicator (GCI) Foundation Ontology[2] was created. It integrates and extends the following existing ontologies.

- Time [19]
- Measurement [20]
- Statistics [21]
- Validity [22]
- Trust [23]
- Placenames (www.geonames.org)

Figure 6 shows the used ontologies and their how they're related.

[2] The GCI Foundation Ontology can be found at http://ontology.eil.utoronto.ca/GCI/GCI-Foundation.owl along with its documentation at http://ontology.eil.utoronto.ca/GCI/GCI-Foundation.html. The prefix "gci" will be used as required.

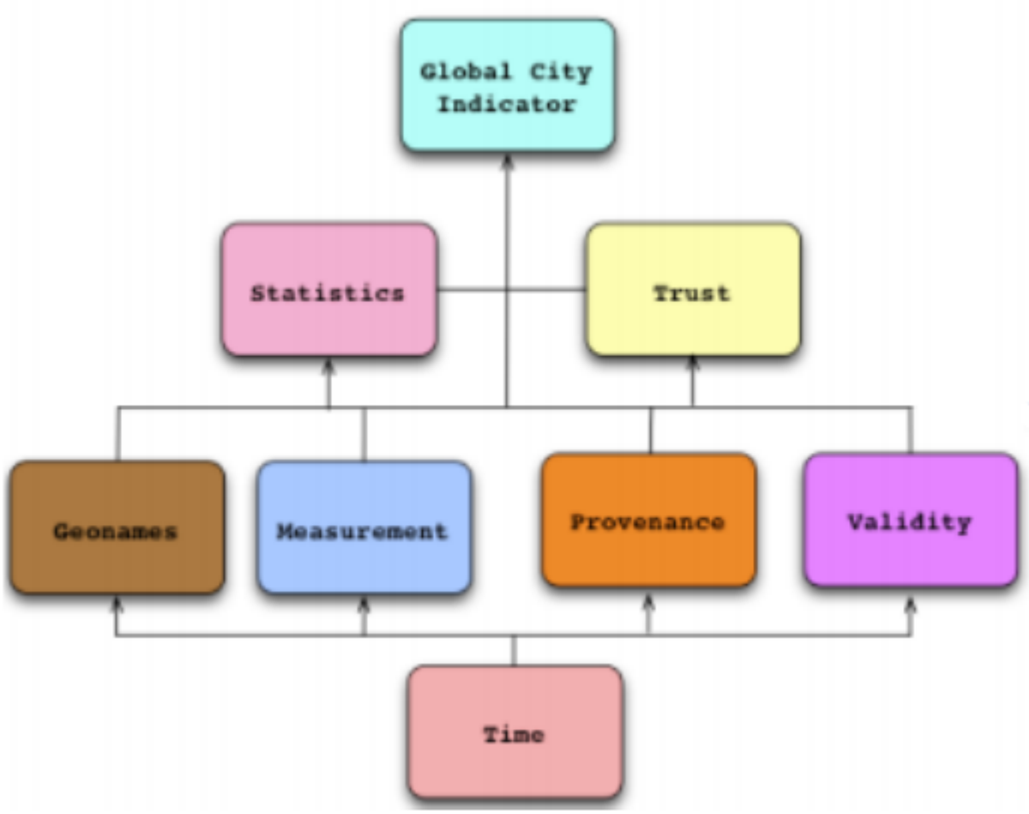

Figure 6 - GCI Foundation Ontology [5]

The metadata for all indicators is based on this foundation ontology. Combined, this is what will be used as the foundation for all indicator themes, including the transportation theme covered in this report. Each ontology builds upon this foundation ontology and adds all relevant information used in that theme.

4.0 Architecture of the Global City Indicator Ontology

The complete ISO 37120 ontology that we are developing contains every indicator theme created by ISO. The layout of how our ontology is organized can be seen in the figure below. As can be seen, the highest level contains the ISO 37120 module[3]. This module contains the globally unique identifier (IRI) for each ISO 37120 indicator. It is also important that figure 7 does not show every ISO 37120 indicator. This was done to conserve space. All ISO 37120 indicators are below the ISO 37120 module.

For example, the IRI for the 'Annual number of public transport trips per capita' indicator is: "http://ontology.eil.utoronto.ca/ISO37120.owl#18.3".

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

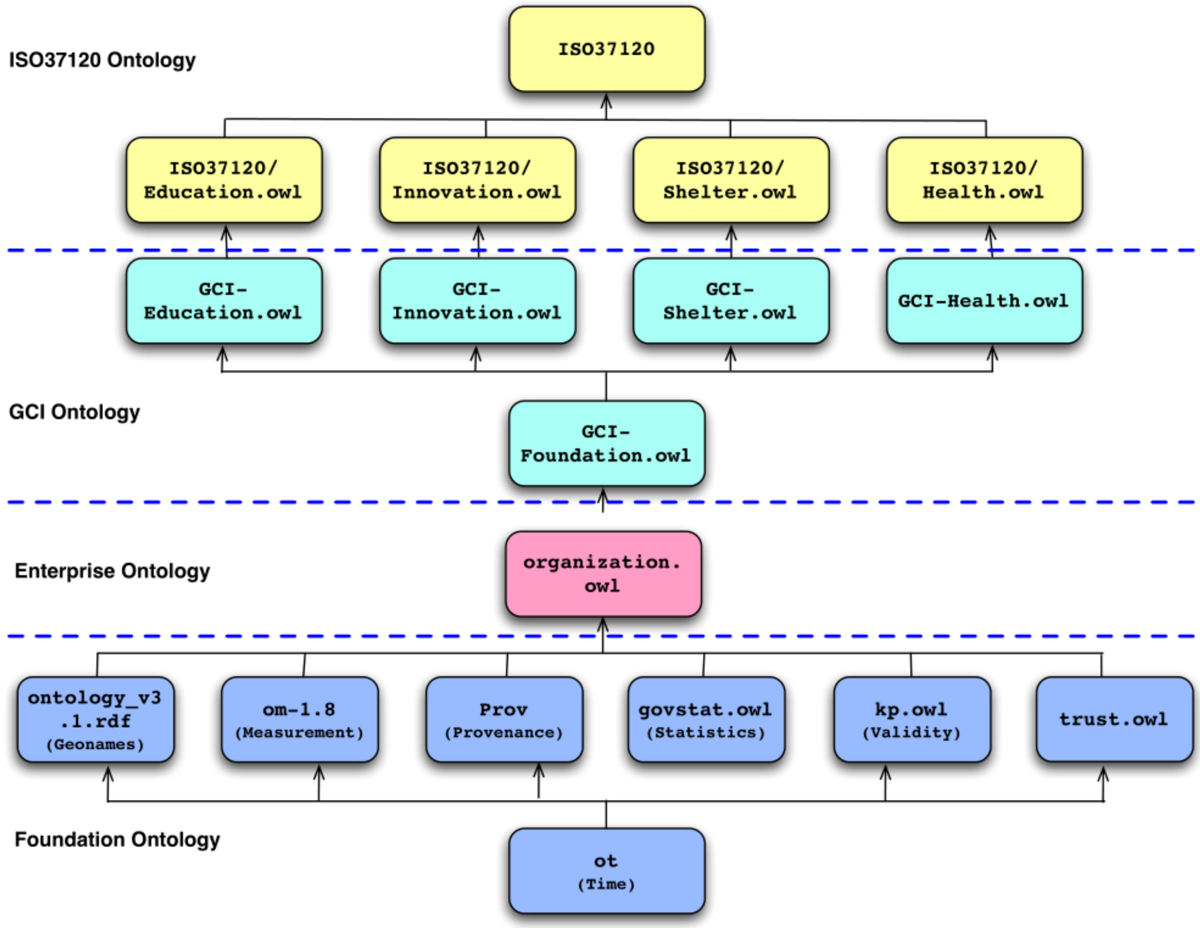

Figure 7 - ISO 37120 Ontology Modules [5]

Each ISO 37120 indicator contains a separate file that provides its definition. For example, for the transportation indicator, there is an OWL file that defines it. Its location is parallel to the education module in the figure above and it would be labelled as ISO37120/Transportation.owl[4]. This module defines all 9 indicators.
The GCI Ontology level provides the category specific ontologies that is necessary in defining the specified category's indicators. For example, to completely define the ISO 37120 Transportation indicators, a transportation ontology that covers concepts such as trains, buses, cars, subways, etc. would need to be created. Thus, GCI-Transportation.owl[5] defines such concepts.

For more generic concepts (i.e. population counts and ratios, meta-information, etc.) are defined in the GCI Foundation Ontology[6]

The Enterprise Ontology level contains Enterprise Modelling ontologies. In the figure shown above, only the Organization Ontology file is shown. This ontology is one of the TOVE Enterprise

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[4] The transportation indicators are defined in the ontology located at http://ontology.eil.utoronto.ca/GCI/ISO37120/Transportation.owl.
[5] The GCI Transportation ontology can be found at http://ontology.eil.utoronto.ca/GCI/Transportation/GCI-Transportation.owl. Its documentation can be found at http://ontology.eil.utoronto.ca/GCI/Transportation/index.html. The prefix "gcit" will be used as needed.
[6] 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/index.html. The prefix "gci" will be used as required.

Modelling ontologies. TOVE has ontologies that span various subjects including the Organization ontology. They are as follows:

- Activities and States [24]
- Resources [25]
- Quality Measurement [26]
- Activity-Based Costing [27]
- Product [28]
- Product Requirements [29]
- Human Resources [30]

Finally, very basic ontologies that were selected as the foundation for the GCI-Foundation.owl ontology was provided in the Foundation Ontology as stated in section 3 of this report.

An important ontology within the foundation ontology is the OM Measurement ontology. Its purpose is to provide the semantics of a number. Information such as what is being measured and the unit of measurement being used is defined in the OM Measurement ontology. This is important because it allows the numbers to be comparable in terms of units. For instance, the units for the indicators that measure the amount of high capacity and low capacity public transportation in an infrastructure will all be in kilometers and thus, the two numbers are comparable.

5.0 GCI Transportation Ontology

In order to represent the definitions of the of the ISO 37120 transportation indicators, an ontology needs to be created which defines more basic, but relevant, transportation concepts.
To reiterate, 2 ontologies were created. The GCI-Transportation.owl ontology defines transportation concepts which will be imported and used in the Transportation.owl ontology which defines the transportation indicators as specified in ISO 37120.

The GCI-Transportation ontology has 4 major components.

- Vehicle Types
- Routes
- Trips
- Fatalities

5.1 Vehicle Types

The following competency questions are concerned with vehicle types.

1. (F) What type of vehicle is automobile X? (SUV, sedan, van, truck, etc.)?
2. (CD) Does automobile X have an owner?
3. (CD) Does the owner of automobile X reside in the city?
4. (CD) Is automobile X insured?
5. (F) What is the make and model of the vehicle?
6. (F) Is the automobile used by commercial enterprises to deliver goods and services?

The vehicle classes will be used to describe the indicators which will be defined in the transportation ontology. For example, ‘kilometres of high capacity public transport system per 100 000 population’ will be restricted to the ‘High_Capacity_Public_Transport’ class which will be restricted to its relevant vehicles.

The following image illustrates the class taxonomy of ‘GCI_Vehicle’. For simplicity, the subclasses for light passenger vehicles are not included in the figure.

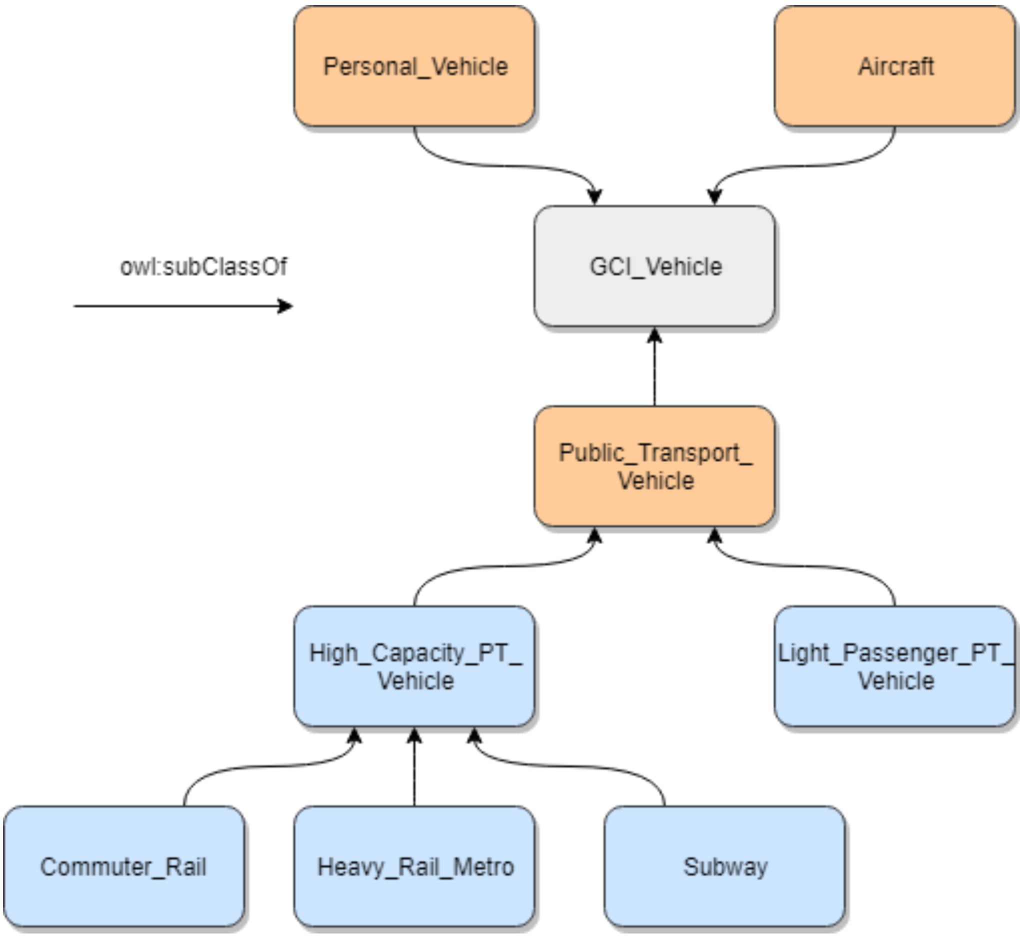

Figure 8 - Vehicle Types Taxonomy

Several class, properties, and restrictions are taken from the Vehicle ontology https://w3id.org/icity/Vehicle/

The class vehicle:Mode comes from the vehicle ontology from the previous link. The only class restriction is that it is a subclass of ‘VehicleOntologyThing’. The class is defined with the dc:description, “A Mode indicates the means by which the vehicle performs transportation (e.g. road, rail, etc.)”.

Class	**Property**	**Value Restriction**
GCI_Vehicle	owl:subClassOf	GCITransportationOntology Thing

Aircraft	owl:subClassOf	GCI_Vehicle
	vehicle:hasMode	exactly 1 vehicle:Mode
vehicle:Mode	owl:subClassOf	vehicle:VehicleOntologyThin g
	dc:description	“A Mode indicates the means by which the vehicle performs transportation (e.g. road, rail, etc.)”
Personal_Vehicle	owl:subClassOf	GCITransportationOntology Thing
	vehicle:hasMode	exactly 1 vehicle:Mode
	hasMake	exactly 1 VehicleMake
	hasModel	exactly 1 VehicleModel
	hasModelYear	exactly 1 VehicleModelYear
	hasInsuranceProvider	exactly 1 xsd:string
	hasOwner	exactly 1 prov:Person
	vehicle:hasVehicleType	exactly 1 Personal_Vehicle_Type
	primarilyUsedFor	exactly 1 xsd:string
Public_Transport_Vehicle	owl:subClassOf	GCI_Vehicle
	vehicle:hasMode	exactly 1 vehicle:Mode
High_Capacity_PT_Vehicle	owl:subClassOf	Public_Transport_Vehicle
Commuter_Rail	owl:subClassOf	High_Capacity_PT_Vehicle
Heavy_Rail_Metro	owl:subClassOf	High_Capacity_PT_Vehicle
Subway	owl:subClassOf	High_Capacity_PT_Vehicle

Table 2 - Vehicle Taxonomy

For simplicity, the class 'Light_Passenger_PT_Vehicle follows the same format as 'High_Capacity_PT_Vehicle' except the light passenger class has subclasses, 'Bus', 'Streetcar', 'Tramway', and 'Trolleybus'.

Also, the 'Personal_Vehicle' class is restricted to the subclass 'Personal_Vehicle_Type' which consists of subclasses that are based on the types of cars. The classes represented include vans, hatchbacks, trucks, sedans, and SUVs. Every class consists of the same properties with different restrictions. Only SUV will be depicted here to conserve space.

Class	**Property**	**Value Restriction**
SUV	owl:subClassOf	Personal_Vehicle_Type
	hasGroundClearance	exactly 1 RaisedGroundClearance
	hasWeightInKg	exactly 1 xsd:positiveInteger [>=1577, <=2460]
	numberOfWheels	exactly 1 xsd:positiveInteger [>=4, <5]
	schema:driveWheelConfiguration	exactly 1 (4WD or RWD or FWD)
	schema:numberOfDoors	exactly 1 xsd:positiveInteger [>=4, <5]
	schema:vehicleSeatingCapacity	exactly 1 xsd:positiveInteger [>=5, <=7]

Table 3 - SUV Properties

It will be up to the user to identify which class a vehicle belongs to, but the properties used should help determine which vehicle type a car belongs to. For example, SUV would be between 1577 kg and 2460 kg in weight, have a raised ground clearance, exactly 4 wheels, either 4WD, RWD, or FWD, exactly 4 doors, and have between 5 and 7 seats.

Since protege does not allow an integer to have an exact value as far as I understand, a restriction is made to constrain the number between 2 numbers. For instance, to restrain the number of wheels to be 4 exactly, the integer has to be greater than or equal to 4 but less than 5. It can only equal 4.

Many of the vehicle characteristics (such as average vehicle weight) was determined from the sources [32], [33], [34], and [35]. Numbers were also rounded off in some situations.

5.2 Routes

The following competency questions are related to routes:

1. (F) What is the length of line X?

2. (CD) Which mode of transportation was used in each segment?
3. (F) Where does user X begin their trip?
4. (F) Where does user X end their trip?
5. (F) Does the user live outside the city?
6. (CD) Is the bicycle road a lane or a path?
7. (F) Where does bicycle path/lane X start?
8. (F) Where does bicycle path/lane X end?
9. (F) How long is bicycle path/lane X?

These series of classes describe the relevant route data and organizes them.

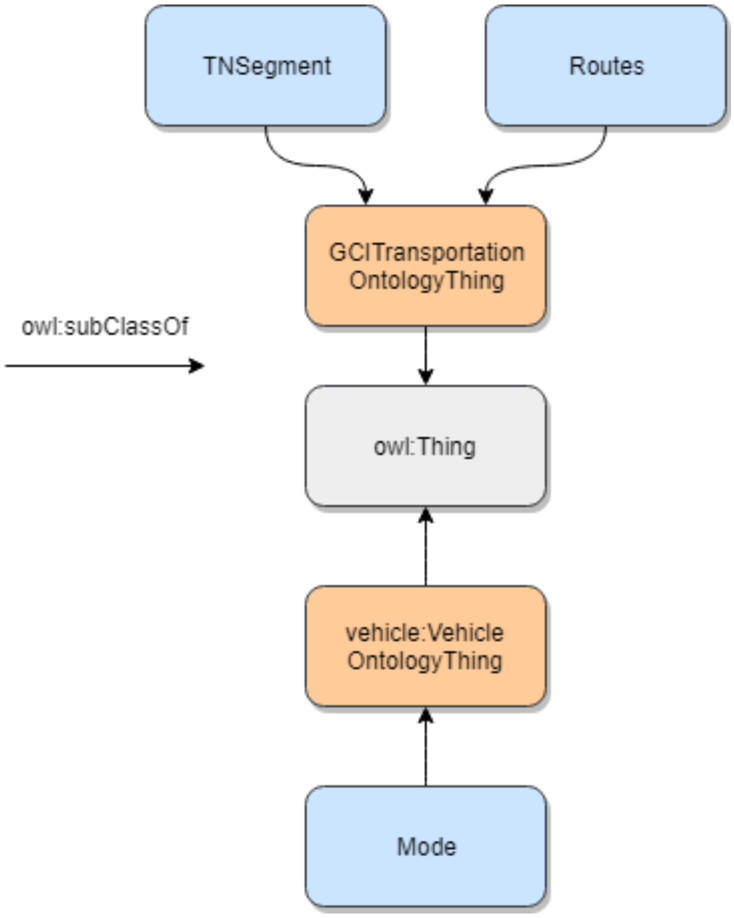

FIgure 9 - Routes Taxonomy

The following table defines the ‘Routes’ class.

Class	**Property**	**Value Restriction**
Routes	owl:subClassOf	GCITransportationOntology Thing
	vehicle:hasMode	min 1 vehicle:Mode

	hasSegment	min 1 TNSegment
	time:hasDuration	exactly 1 time:DurationDescription
	tc:tripCostOf	exactly 1 RouteCost

Table 4 - Routes Restrictions

A route is composed of at least 1 segment. Therefore, the 'Routes' class is restricted to having at least 1 'TNSegment' which stands for transportation network segment. The following table defines the 'TNSegment' class.

Class	**Property**	**Value Restriction**
TNSegment	owl:subClassOf	GCITransportationOntologyThing
	trip:startLoc	exactly 1 otn:Intersection
	trip:endLoc	exactly 1 otn:Intersection
	distanceBetween	exactly 1 xsd:positiveInteger
	gcit:forVehicle	only Vehicle
	om:unit_of_measure	exactly 1 om:Unit_of_measure

Table 5 - TNSegment Restrictions

The distance between 2 intersections is important for the indicators and is defined with the property 'distanceBetween'. It defines the distance between the starting location and ending location of a transportation network segment.

5.3 Trip Classes

This section will define the GCI_Trip class and its restrictions. A trip is different from a route. A trip has a start and end location, but can contain at least 1 route. For example, a person trying to get to work in another city would have to take a bus to the train station, board a train to the destination city, then take the subway the rest of the way. In this example, a trip from home to work consists of 3 public transit routes with different modes of transportation and costs. A trip cost is the summation of all the individual route costs.

The following are the relevant competency questions.

1. (D) How much does it cost to travel on transportation line X?
2. (F) When was the trip made?

3. (F) What is the primary mode of transportation for the trip?
4. (F) Were any transfers made in the trip?
5. (F) What is the start point of trip X?
6. (F) What is the end point of trip X?
7. (CD) Is the rider a senior, adult, or child?
8. (CD) Is the rider a student?
9. (D) Is the trip for work, leisure, or business?
10. (CD) Which modes of transportation did user X use?

It is important to note that ISO 37120 defines the primary mode of transportation for a trip to be the mode that has the longest duration in the trip. This is found out by analyzing the 'Route' class which has a departure and arrival class restriction. The trip with the longest duration is the primary mode of travel.

Class	**Property**	**Value Restriciton**
GCI_Trip	owl:subClassOf	GCITransportationOntology Thing
	trip:startLoc	exactly 1 icontact:Address
	trip:endLoc	exactly 1 icontact:Address
	dateOfDeparture	exactly 1 time:DateTimeDescription
	dateOfArrival	exactly 1 time:DateTimeDescription
	vehicle:hasMode	min 1 vehicle:Mode
	mere:hasComponent	min 1 Routes
	tc:tripCostOf	exactly 1 TripCost
	riderType	min 1 {resident} or {visitor}
	riderAge	exactly 1 xsd:positiveInteger
	riderStudentStatus	exactly 1 xsd:string
	reasonForTrip	exactly 1 xsd:string

Table 6 - GCI_Trip Defined

As stated earlier, a trip cost is the sum of all route costs. Thus, a TripCost is defined as follows.

Class	Property	Value Restriction
TripCost	owl:subClassOf	GCITransportationOntology Thing
	owl:subClassOf	Sum_Quantity
	sum_term	min 1 RouteCost
	unit_of_measure	exactly 1 Monetary_unit
RouteCost	owl:subClassOf	GCITransportationOntology Thing
	owl:subClassOf	Quantity
	unit_of_measure	exactly 1 Monetary_unit

Table 7 - Trip and Route Costs

5.4 Fatality Classes

This section will examine the fatality classes that will be used in defining the ISO 37120 transportation indicators. The following figure shows the basic class hierarchy and the following tables will go into detail.

The competency questions relevant to fatalities are:

1. (CD) Is the fatality related to transportation?
2. (CD) Where was the accident?
3. (CD) Where was the fatality?
4. (F) When was the accident?
5. (F) When was the fatality?
6. (D) What is the cause of the accident? (E.g. poor roads, drivers, pedestrians)
7. (CD) Is the fatality a death or injury?
8. (F) How many modes of transportation, or segments, did user X use?

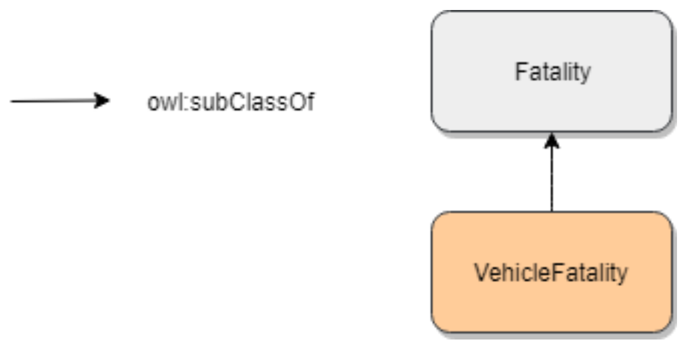

Figure 10 - Fatality Classes Taxonomy

The ‘Fatality’ class is dependant on the other four subclasses of ‘Transport_Fatalities_Data’. They are defined below.

Class	Property	Value Restriction
Fatality	owl:subClassOf	GCITransportationOntology Thing
VehicleFatality	owl:subClassOf	Fatality
	hasAccidentDate	time:DateTimeDescription
	hasFatalityDate	time:DateTimeDescription
	hasAccidentLocation	ic:Address
	hasFatalityLocation	ic:Address
	hasCause	xsd:string
	hasDescription	xsd:string
	forVehicle	exactly 1 GCI_Vehicle

Table 8 - Fatality Class Restrictions

5.5 Flight Classes

This section defines some flight related classes since ISO 37120 introduces flights as a separate indicator to anything else.

The following competency questions are relevant.

1. (F) Which city is being examined?
2. (CD) Is the flight managed by a commercial airliner, or privately owned?
3. (CD) How many buildings does the airport have?
4. (CD) How many runways does the airport have?
5. (CD) How many airplanes does the airline have?
6. (F) How many flights depart from the city?
7. (F) How many departure airports serve the city?
8. (F) How many arrival airports serve the city?
9. (F) What time is the flight?
10. (F) What is the flight number?

Class	Property	Value Restriction

GCI_Flight	owl:subClassOf	18.9_Things
	owl:subClassOf	GCI_Trip
	hasMode	exactly 1 Aircraft
	hasFlightNumber	exactly 1 xsd:string
	hasFlightTime	exactly 1 time:DateTimeDescription
	hasOwner	exactly 1 Airline
	arriveAirport	exactly 1 GCI_Airport
	departAirport	exactly 1 GCI_Airport
GCI_Airport	owl:subClassOf	18.9_Things
	numberOfBuildings	exactly 1 xsd:positiveInteger
	numberOfRunways	exactly 1 xsd:positiveInteger
	numberOfAircraft	exactly 1 xsd:positiveInteger
	citiesServed	min 1 schema:City

Table 9 - Flight Classes

6.0 Foundation Ontology Infrastructure

Before the transportation indicators can be defined, it is important to review the basic structure of a ratio indicator. This is defined in the GCI Foundation ontology [31]. The transportation indicators are based on the foundation ontology.

The OM measurement ontology (created by Rijgersberg et al., 2011) is at the core of the foundation ontology. The purpose of the measurement ontology is to provide the underlying semantics of a number. Things such as what is being measured and the unit of measurement used are defined. It is important to keep all units consistent to allow for easy comparison of numbers within an ontology. For example, one of the indicators is the number of Non-SOV trips to work. This number is a ratio between Non-SOV trips to work to all trips to work. It is important to use the same scale for both (i.e. thousands vs. millions).

The figure to follow shows the basic classes of the OM ontology used to represent an indicator. The three main classes in OM are ‘Quantity’, ‘Unit of Measure’, and a ‘Measure’. ‘Quantity’ denotes what is being measured (e.g. diameter of a ball). 'Unit of Measure' denotes how the quantity is measured (e.g. centimeters). 'Measure' denotes the value of the measurement which is linked to both 'Quantity' and 'Unit of Measure'.

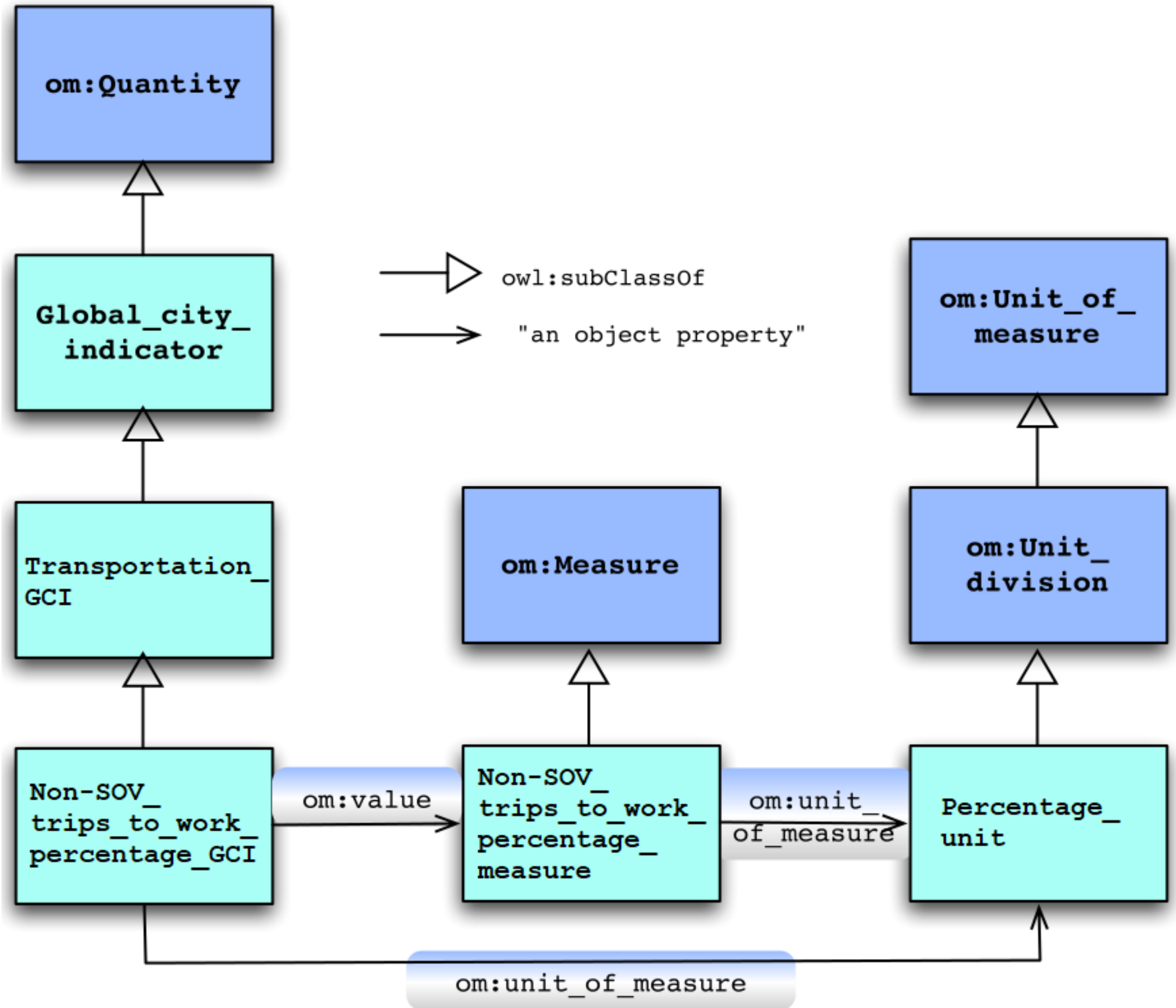

Figure 11 - Measurement Ontology

The non-SOV trips to work percentage indicator is the ratio of non-SOV trips to work and total trips to work. This can be viewed as both a statistical measurement - in the sense that there is a population that requires measurement where measurement is a count of the number of members that satisfy both the numerator and denominator. This indicator requires a simple count but other measures might require statistics such as mean or standard deviation as an example. Thus, another core ontology is the GovStat[7] general statistics ontology (created by Pattuelli in 2009).

[7] The GovStat ontology is not available online, but a version with the GCI extensions can be found at: http://ontology.eil.utoronto.ca/govstat#

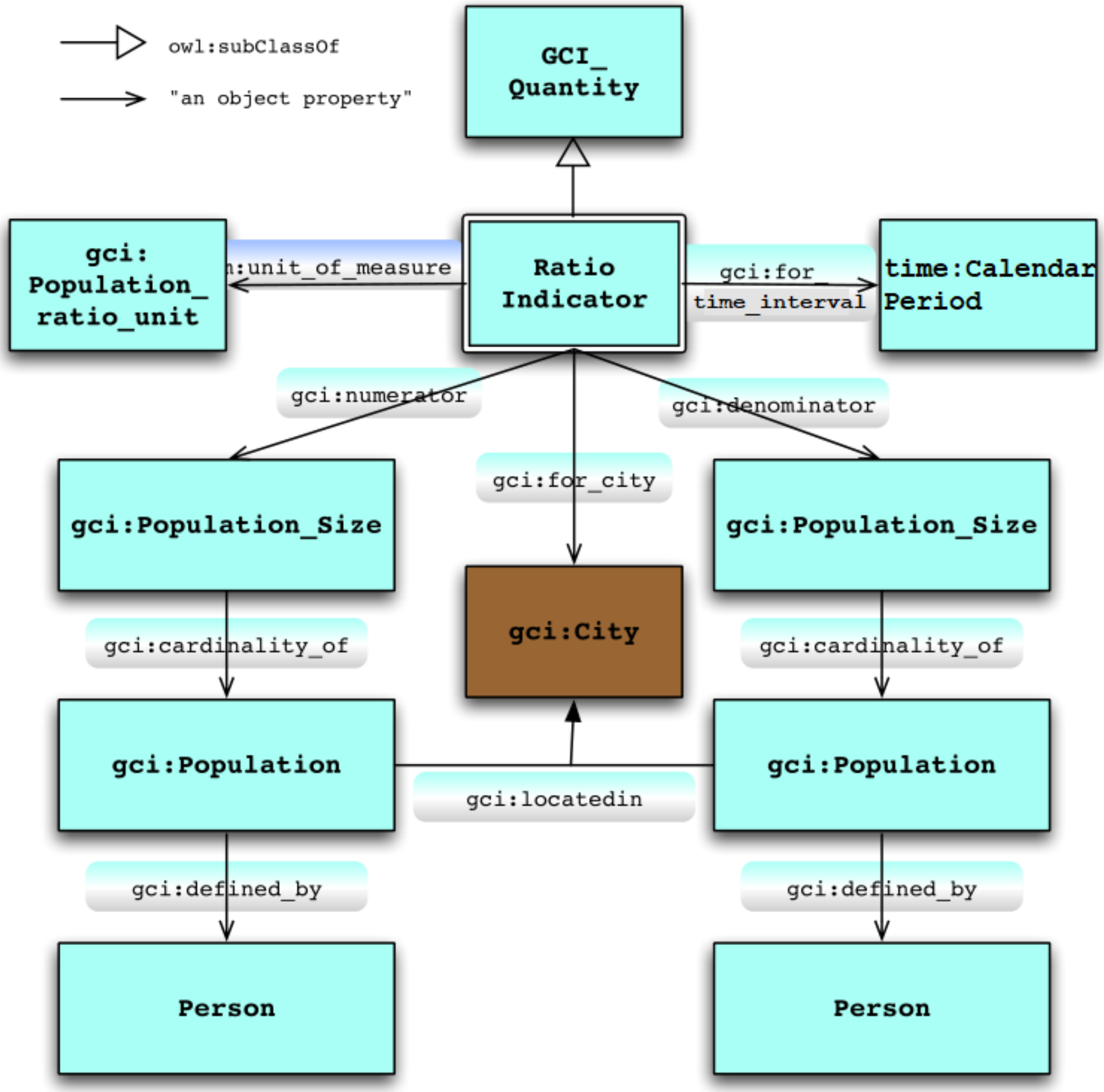

Figure 12 - Foundation Ontology Ratio Definition

7.0 ISO 37120 Transportation Indicators Definitions

This section defines each of the ISO 37120 transportation indicators using the GCI Transportation ontology introduced in section 5.

The OWL 2 definitions can be found at:
http://ontology.eil.utoronto.ca/GCI/ISO37120/Transportation.owl

The prefixes are defined as follows:

om: https://wurvoc.org/vocabularies/om-1.8/
gs: https://ontology.eil.utoronto.ca/govstat.owl#
gci: http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation-v2.owl#
vehicle: https://w3id.org/icity/Vehicle/
gcit: http://ontology.eil.utoronto.ca/GCI/Transportation/GCI-Transportation.owl#

7.1 Kilometres of High Capacity Public Transport System Per 100 000 Population (18.1)

The following figure defines the important aspects of the definition of ISO 37120 indicator 18.1.

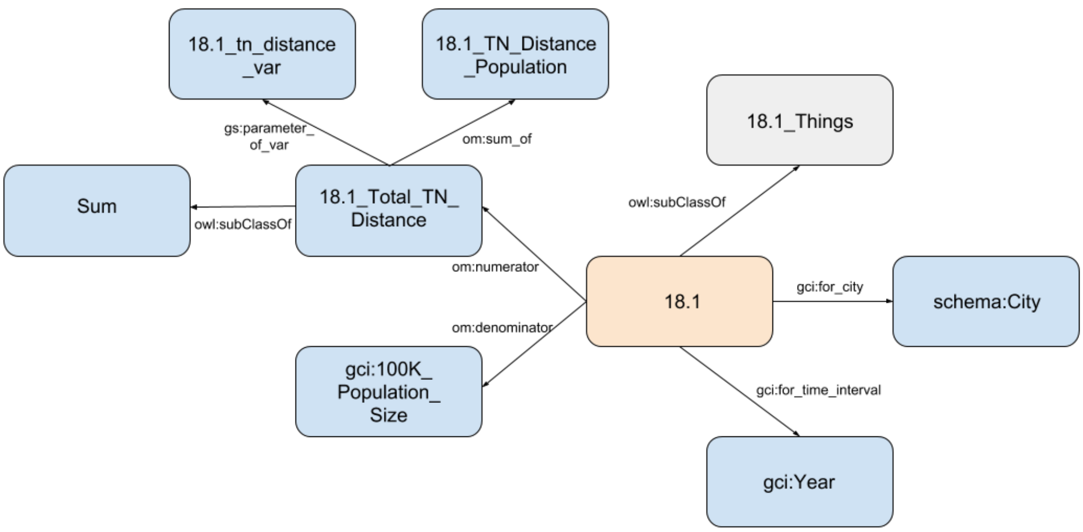

Figure 13 - Illustration of the Transportation Ontology ISO37120:18.1
The following table breaks down the 3 major classes of the class '18.1_Things'.

Class	Property	Value Restriction

18.1	owl:subClassOf	18.1_Things
	owl:subClassOf	ISO37120_Indicator
	owl:subClassOf	om:Division_Quantity
	om:unit_of_measure	value gci:population_ratio_unit
	om:numerator	exactly 1 18.1_Total_TN_Distance
	om:denominator	exactly 1 gci:100K_Population_Size
	gci:for_city	exactly 1 schema:City
	gci:for_time_interval	exactly 1 gci:Year
18.1_Total_TN_Distance	owl:subClassOf	18.1_Things
	owl:subClassOf	om:Sum
	gci:sum_of	only 18.1_TN_Distance_Population
	gs:parameter_of_var	value 18.1_tn_distance_var
18.1_TN_Distance_Population	owl:subClassOf	18.1_Things
	owl:subClassOf	gci:Population
	gci:defined_by	exactly 1 gcit:18.1_TN_Distance
	gci:located_in	exactly 1 schema:City
	gci:for_time_interval	exactly 1 time:DateTimeInterval
18.1_TN_Distance	owl:subClassOf	18.1_Things
	owl:subClassOf	gcit:TNSegment
	om:unit_of_measure	value kilometre

	gcit:forVehicle	min 1 gcit:High_Capacity_PT_Vehicle
18.1_tn_distance_var	rdfs:type	gs:Variable
	gs:has_Name	“distanceBetween”

Table 10 - Indicator 18.1 Breakdown

7.2 Kilometres of Light Passenger Public Transport System Per 100 000 Population

Indicator 18.2 of the ISO 37120 standard shares a very similar structure to indicator 18.1 that was defined in section 7.1 of this report. The differences being that the total length is restricted to the light passenger vehicles - bus, light rail streetcar, tramway, and trolleybus. The city population size class and 18.2 class are the same otherwise.

Class	Property	Value Restriction
18.2	owl:subClassOf	18.2_Things
	owl:subClassOf	ISO37120_Indicator
	owl:subClassOf	om:Division_Quantity
	om:unit_of_measure	value gci:population_ratio_unit
	om:numerator	exactly 1 18.2_Total_TN_Distance
	om:denominator	exactly 1 gci:100K_Population_Size
	gci:for_city	exactly 1 schema:City
	gci:for_time_interval	exactly 1 gci:Year
18.2_Total_TN_Distance	owl:subClassOf	18.2_Things
	owl:subClassOf	om:Sum
	gci:sum_of	only 18.2_TN_Distance_Population
	gs:parameter_of_var	value 18.2_tn_distance_var

18.2_TN_Distance_Population	owl:subClassOf	18.2_Things
	owl:subClassOf	gci:Population
	gci:defined_by	exactly 1 gcit:18.2_TN_Distance
	gci:located_in	exactly 1 schema:City
	gci:for_time_interval	exactly 1 time:DateTimeInterval
18.2_TN_Distance	owl:subClassOf	18.2_Things
	owl:subClassOf	gcit:TNSegment
	om:unit_of_measure	value kilometre
	gcit:forVehicle	min 1 gcit:Light_Passenger_PT_Vehicle
18.2_tn_distance_var	rdfs:type	gs:Variable
	gs:has_Name	“distanceBetween”

Table 11 - 18.2 Indicator Definition

7.3 Annual Number of Public Transport Trips Per Capita

This indicator shares a similar city population structure shown in section 7.1. The main difference is in determining the number of public trips instead of length. The following table breaks down the public transport trips.

Class	**Property**	**Value Restriction**
18.3	owl:subClassOf	18.3_Things
	owl:subClassOf	ISO37120_Indicator
	owl:subClassOf	om:Division_Quantity
	om:unit_of_measure	value gci:population_ratio_unit

	om:numerator	exactly 1 18.3_Public_Transport_Trip_Population_Size
	om:denominator	exactly 1 gci:City_Population_Size
	gci:for_city	exactly 1 schema:City
	gci:for_time_interval	exactly 1 gci:Year
18.3_Public_Transport_Trip_Population_Size	owl:subClassOf	Population_size
	owl:subClassOf	18.3_Things
	om:cardinality_of	exactly 1 18.3_Public_Transport_Trip_Population
18.3_Public_Transport_Trip_Population	owl:subClassOf	18.3_Things
	owl:subClassOf	Population
	gci:defined_by	exactly 1 18.3_Public_Transport_Trip_Resident
	gci:located_in	exactly 1 schema:City
18.3_Public_Transport_Trip_Resident	owl:subClassOf	18.3_Things
	owl:subClassOf	GCI_Trip
	vehicle:hasMode	min 1 gcit:Public_Transport_Vehicle

Table 12 - Indicator 18.3 Breakdown

The indicator itself is very similar to the section 7.1, except capita is used in this indicator for the denominator as opposed to 'per 100 000 population'.

7.4 Number of Personal Automobiles Per Capita

This indicator has a class named '18.4_City_Population_Size' which follows the exact same structure as '18.3_City_Population_Size' shown in the above table. The differences are in the numerator and will be shown in the table below.

Class	Property	Value Restriction
18.4	owl:subClassOf	18.4_Things
	owl:subClassOf	ISO37120_Indicator
	owl:subClassOf	om:Division_Quantity
	om:unit_of_measure	value gci:population_ratio_unit
	om:numerator	exactly 1 18.4_Personal_Automobile_Population_Size
	om:denominator	exactly 1 gci:City_Population_Size
	gci:for_city	exactly 1 schema:City
	gci:for_time_interval	exactly 1 gci:Year
18.4_Personal_Automobile_Population_Size	owl:subClassOf	18.4_Things
	owl:subClassOf	gci:Population_size
	gs:cardinality_of	exactly 1 18.4_Personal_Automobile_Population
18.4_Personal_Automobile_Population	owl:subClassOf	18.4_Things
	owl:subClassOf	gci:Population
	gci:located_in	exactly 1 schema:City
	gci:defined_by	exactly 1 18.4_Personal_Automobile_Resident
18.4_Personal_Automobile_Resident	owl:subClassOf	18.4_Things
	owl:subClassOf	gcit:Personal_Vehicle
	ownerType	value resident

Table 13 - Indicator 18.4 Breakdown

7.5 Percentage of Commuters Using a Travel Mode Other Than a Personal Vehicle

This section is very similar to section 7.4. It involves calculating the ratio of 2 populations. The difference is in the denominator - instead of city population, it looks at total number of trips to work. To clarify, the numerator is the total number of trips to work in a non-single occupancy vehicle and the denominator is the total trips to work.

It is important to note that SOV refers to single occupancy vehicles and Non-SOV refers to everything other than a SOV - non-single occupancy vehicle.

Class	Property	Value Restriction
18.5	owl:subClassOf	18.5_Things
	owl:subClassOf	ISO37120_Indicator
	owl:subClassOf	om:Division_Quantity
	om:unit_of_measure	value gci:population_ratio_unit
	om:numerator	exactly 1 18.5_NonSOV_Trips_Population_Size
	om:denominator	exactly 1 18.5_Trips_Population_Size
	gci:for_city	exactly 1 schema:City
	gci:for_time_interval	exactly 1 gci:Time
18.5_NonSOV_Trips_Population_Size	owl:subClassOf	18.5_Things
	owl:subClassOf	gci:Population_size
	gs:cardinality_of	exactly 1 18.5_NonSOV_Trips_Population
18.5_NonSOV_Trips_Population	owl:subClassOf	18.5_Things
	owl:subClassOf	gci:Population
	gci:defined_by	exactly 1 18.5_NonSOV_Trips

	gci:located_in	schema:City
18.5_NonSOV_Trips	owl:subClassOf	18.5_Things
	owl:subClassOf	gcit:GCI_Trip
	vehicle:hasMode	min 1 (gcit:Bicycle or gcit:Motorcycle or gcit:Public_Transport_Vehicle)
18.5_Trips_Population_Size	owl:subClassOf	18.5_Things
	owl:subClassOf	gci:Population_size
	gs:cardinality_of	exactly 1 18.5_Trips_Population
18.5_Trips_Population	owl:subClassOf	18.5_Things
	owl:subClassOf	gci:Population
	gci:defined_by	exactly 1 18.5_Trips
	gci:located_in	exactly 1 schema:City
18.5_Trips	owl:subClassOf	18.5_Things
	owl:subClassOf	gcit:GCI_Trip
	vehicle:hasMode	min 1 (gcit:Personal_Vehicle or gcit:Public_Transport_Vehicle)

Table 14 - Indicator 18.5 Breakdown

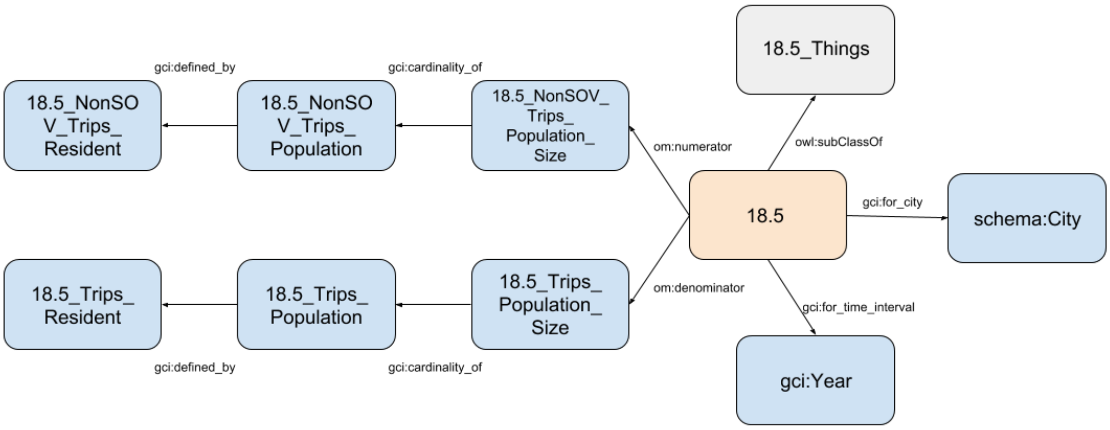

Figure 14 - Illustration of the Transportation Ontology Indicator 18.5 for ISO37120

7.6 Number of Two-Wheeled Motorized Vehicles Per Capita

This section is similar to section 7.4 which represented ISO37120:18.4. The only difference is the numerator is concerned with number of two-wheeled motorized vehicles as opposed to all personal vehicles. Units and basic structure are the same otherwise.

Class	Property	Value Restriction
18.6	owl:subClassOf	18.6_Things
	owl:subClassOf	ISO37120_Indicator
	owl:subClassOf	om:Division_Quantity
	om:unit_of_measure	value gci:population_ratio_unit
	om:numerator	exactly 1 18.6_Two-Wheel_Vehicle_Population_size
	om:denominator	exactly 1

		gci:City_Population_Size
	gci:for_city	exactly 1 schema:City
	gci:for_time_interval	exactly 1 gci:Year
18.6_Two-Wheel_Vehicle_Population_size	owl:subClassOf	18.6_Things
	owl:subClassOf	gci:Population_Size
	gs:cardinality_of	exactly 1 18.6_Two-Wheel_Vehicle_Population
18.6_Two-Wheel_Vehicle_Population	owl:subClassOf	18.6_Things
	owl:subClassOf	gci:Population_Size
	gci:defined_by	exactly 1 18.6_Two-Wheel_Vehicle_Resident
	gci:located_in	exactly 1 schema:City
18.6_Two-Wheel_Vehicle_Resident	owl:subClassOf	18.6_Things
	owl:subClassOf	gcit:Motorcycle
	gci:located_in	exactly 1 schema:City

Table 15 - Indicator 18.6 Breakdown

7.7 Kilometres of Bicycle Paths and Lanes Per 100 000 Population

This section is similar to section 7.1 and shares similar units and structure. The key difference is the numerator is concerned with the total lengths of all bicycle paths and lanes within a city. The differentiating factor is the class is restricted with the expression, ‘gcit:forVehicle min 1 Bicycle’ which should restrict the numerator to bicycle related modes of transportation routes.

Class	**Property**	**Value Restriction**
18.7	owl:subClassOf	18.7_Things
	owl:subClassOf	ISO37120_Indicator
	owl:subClassOf	om:Division_Quantity

	om:unit_of_measure	value gci:population_ratio_unit
	om:numerator	exactly 1 18.7_Total_TN_Distance
	om:denominator	exactly 1 gci:100K_Population_Size
	gci:for_city	exactly 1 schema:City
	gci:for_time_interval	exactly 1 gci:Year
18.7_Total_TN_Distance	owl:subClassOf	18.7_Things
	owl:subClassOf	om:Sum
	gci:sum_of	only 18.7_TN_Distance_Population
	gs:parameter_of_var	value 18.7_tn_distance_var
18.7_TN_Distance_Population	owl:subClassOf	18.7_Things
	owl:subClassOf	gci:Population
	gci:defined_by	exactly 1 gcit:18.7_TN_Distance
	gci:located_in	exactly 1 schema:City
	gci:for_time_interval	exactly 1 time:DateTimeInterval
18.7_TN_Distance	owl:subClassOf	18.7_Things
	owl:subClassOf	gcit:TNSegment
	om:unit_of_measure	value kilometre
	gcit:forVehicle	only gcit:Bicycle
18.7_tn_distance_var	rdfs:type	gs:Variable
	gs:has_Name	“distanceBetween”

Table 16 - Indicator 18.7 Breakdown

7.8 Transportation Fatalities Per 100 000 Population

The denominator is the same as the denominator for 7.1 which restricts the population to a per 100,000 basis. The numerator is similar in structure to 7.3 which is concerned with the cardinality of transportation fatalities.

Class	Property	Value Restriction
18.8	owl:subClassOf	18.8_Things
	owl:subClassOf	ISO37120_Indicator
	owl:subClassOf	om:Division_Quantity
	om:unit_of_measure	value gci:population_ratio_unit
	om:numerator	exactly 1 18.8_Fatalities_Population_Size
	om:denominator	exactly 1 gci:100K_Population_Size
	gci:for_city	exactly 1 schema:City
	gci:for_time_interval	exactly 1 gci:Year
18.8_Fatalities_Population_Size	owl:subClassOf	18.8_Things
	owl:subClassOf	gci:Population_Size
	gs:cardinality_of	exactly 1 18.8_Fatalities_Population
18.8_Fatalities_Population	owl:subClassOf	18.8_Things
	owl:subClassOf	gci:Population
	gci:located_in	exactly 1 schema:City
	gci:defined_by	exactly 1 18.8_Fatalities
18.8_Fatalities	owl:subClassOf	18.8_Things

	owl:subClassOf	gcit:VehicleFatality

Table 17 - Indicator 18.8 Breakdown

7.9 Commercial Air Connectivity (Number of Non-Stop Commercial Air Destinations)

This indicator is simply a count of non-stop commercial flights. These two classes define the '18.9_Commercial_Flights_Resident' class.

Class	Property	Value Restriction
18.9	owl:subClassOf	18.9_Things
	owl:subClassOf	ISO37120_Indicator
	om:unit_of_measure	value gci:population_cardinality_unit
	owl:subClassOf	gs:Distinct_count
	gs:distinct_count_of	exactly 1 18.9_Commercial_Flights_Population
	gs:parameter_of_var	value 18.9_Destination_var
	gci:for_time_interval	exactly 1 gci:Year
	gci:located_in	exactly 1 schema:City
18.9_Commercial_Flights_Population	owl:subClassOf	18.9_Things
	owl:subClassOf	gci:Population
	gci:defined_by	exactly 1 18.9_Commercial_Flight
18.9_Commercial_Flight	owl:subClassOf	18.9_Things
	owl:subClassOf	gcit:GCI_Flight
	departAirport	exactly 1 (GCI_Airport and (
18.9_Destination_var	rdfs:type	gs:Variable

	gs:has_Name	“arriveAirport”

Table 18 - Indicator 18.9 Breakdown

8.0 Evaluation

This section is concerned with evaluating the transportation ontology by attempting to answer the competency questions. Indicator 18.9, “commercial air connectivity (ISO 37120:18.9)” will be analyzed as an example.

The prefixes are as follows:

gn: http://www.geonames.org/
geo: http://www.geonames.org/ontology/ontology_v3.1rdf#
gcit: http://ontology.eil.utoronto.ca/GCI/Transportation/GCI-Transportation.owl#
ic: http://ontology.eil.utoronto.ca/icontact.owl#
schema: http://schema.org/
iso: http://ontology.eil.utoronto.ca/ISO37120.owl#
isot: http://ontology.eil.utoronto.ca/GCI/Transportation/Transportation.owl#
gs: http://ontology.eil.utoronto.ca/govstat.owl#
gci: http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl#
om: http://www.wurvoc.org/vocabularies/om-1.8/
trip: https://w3id.org/icity/Trip/
time: http://www.w3.org/2006/time#

The Toronto Pearson International Airport in Toronto, Ontario, Canada will be the starting location in this example. The ending location will be California, USA.

Instance	**Property**	**Value**
gn:6296338	rdfs:label	“Toronto Pearson International Airport”
	rdfs:type	geo:Feature
	rdfs:type	gcit:GCI_Airport
	gcit:citiesServed	gn:9972749
	gcit:numberOfBuildings	12
	gcit:numberOfRunways	5
gn:6296205	rdfs:label	“John C. Munro Hamilton International Airport”

	rdfs:type	geo:Feature
	rdfs:type	gcit:GCI_Airport
	gcit:citiesServed	gn:9972749
	gcit:numberOfBuildings	5
	gcit:numberOfRunways	2
gn:5969782	rdfs:label	“Hamilton”
	rdfs:type	ic:Address
	rdfs:type	geo:Feature
	rdfs:type	schema:City
gn:6093943	rdfs:label	“Ontario”
	rdfs:type	geo:Feature
	rdfs:type	schema:State
gn:6251999	rdfs:label	“Canada”
	rdfs:type	geo:Feature
	rdfs:type	schema:Country
gn:9972749	rdfs:label	“Greater Toronto Area”
	rdfs:type	geo:Feature
	rdfs:type	schema:City
gn:5368361	rdfs:label	“Los Angeles”
	rdfs:type	geo:Feature
	rdfs:type	schema:City

gn:5368418	rdfs:label	“Los Angeles International Airport”
	rdfs:type	18.9_Airport
	rdfs:type	geo:Feature
	gcit:citiesServed	gn:11071615
	numberOfBuildings	6
	numberOfRunways	5

Table 19 - Location Identifiers

The following table summarizes the instances used in this indicator.

Instance	**Property**	**Value**
18.9_ex *(instance of 18.9)*	rdfs:type	18.9
	gs:distinct_count_of	18.9_distinct_destinations
	om:value	18.9_distinct_destinations_value
	gci:located_in	gn:9972749
	gci:for_time_interval	18.9_Year_ex
18.9_Year_ex	rdfs:type	gci:Year
	om:numerical_value	2018
18.9_destinct_destinations_value	rdfs:type	om:Measure
	om:numerical_value	1
18.9_destinct_destinations	rdfs:type	18.9_Commercial_Flights_Population
	gs:is_composed_of	18.9_Flight_ex_1
	gs:is_composed_of	18.9_Flight_ex_2

18.9_flight_ex_1	rdfs:type	18.9_Flight
	trip:startLoc	gn:9972749
	trip:endLoc	gn:11071615
	gcit:dateOfArrival	18.9_arrival_date_time_ex_1
	gcit:dateOfDeparture	18.9_depart_date_time_ex_1
	gcit:departAirport	gn:6296338
	gcit:arriveAirport	gn:5368418
	gcit:hasOwner	air_canada
	hasFlightNumber	“AC1765”
	gcit:hasMode	boeing_787
18.9_flight_ex_2	rdfs:type	18.9_Flight
	trip:startLoc	gn:5969782
	trip:endLoc	gn:5368361
	gcit:dateOfArrival	18.9_arrival_date_time_ex_2
	gcit:dateOfDeparture	18.9_depart_date_time_ex_2
	gcit:departAirport	gn:6296205
	gcit:arriveAirport	gn:5368418
	gcit:hasOwner	air_canada
	hasFlightNumber	“8821”
	gcit:hasMode	boeing_787
air_canada	rdfs:type	gcit:Airline

	gcit:numberOfAircraft	415
boeing_787	rdfs:type	gcit:Aircraft
18.9_arrival_date_time_ex_1	rdfs:type	time:DateTimeDescription
	time:second	00
	time:minute	24
	time:hour	14
	time:day	02
	time:month	02
	time:year	2018
18.9_depart_date_time_ex_1	rdfs:type	time:DateTimeDescription
	time:second	00
	time:minute	23
	time:hour	13
	time:day	01
	time:month	02
	time:year	2018
18.9_arrival_date_time_ex_2	rdfs:type	time:DateTimeDescription
	time:second	00
	time:minute	33
	time:hour	15
	time:day	03

	time:month	02
	time:year	2018
18.9_depart_date_time_ex_2	rdfs:type	time:DateTimeDescription
	time:second	00
	time:minute	45
	time:hour	12
	time:day	02
	time:month	02
	time:year	2018

Table 20 - Example Individuals

The following uses SPARQL syntax to answer the competency questions shown in section 5.5.

1. (F) Which city is being examined?

    SELECT ?city WHERE
    { isot:18.9_ex gci:located_in ?id .
    ?id rdfs:label ?city }

    ANSWER “Greater Toronto Area”

2. (CD) Is the flight managed by a commercial airliner, or privately owned?

    SELECT ?Flight ?owner ?type WHERE
    {isot:18.9_ex gs:distinct_count_of ?Flight_Population.
    ?Flight_Population gs:is_composed_of ?Flight.
    ?Flight gcit:hasOwner ?owner.
    ?owner rdf:type ?type}

    ANSWER:
    18.9_flight_ex_1 air_canada Airline
    18.9_flight_ex_2 air_canada Airline

3. (CD) How many buildings does the airport have?

    SELECT ?airport_name ?buildings WHERE

{isot:18.9_ex gs:distinct_count_of ?flight_pop.
?flight_pop gs:is_composed_of ?flight.
?flight gcit:departAirport ?airport.
?airport gcit:numberOfBuildings ?buildings.
?airport rdfs:label ?airport_name}

ANSWER
"Toronto Pearson International Airport" 12
"John C. Hamilton International Airport" 5

4. (CD) How many runways does the airport have?

SELECT ?airport_name ?runways WHERE
{isot:18.9_ex gs:distinct_count_of ?flight_pop.
?flight_pop gs:is_composed_of ?flight.
?flight gcit:departAirport ?airport.
?airport gcit:numberOfRunways ?runways.
?airport rdfs:label ?airport_name}

ANSWER
"Toronto Pearson International Airport" 5
"John C. Hamilton International Airport" 2

5. (CD) How many airplanes does the airline have?

SELECT DISTINCT ?owner ?number WHERE
{isot:18.9_ex gs:distinct_count_of ?flight_pop.
?flight_pop gs:is_composed_of ?flight.
?flight gcit:hasOwner ?owner.
?owner gcit:numberOfAircraft ?number}

ANSWER
air_canada 415

6. (F) How many flights depart from the city?

SELECT ?flights WHERE
{isot:18.9_ex om:value ?totalflights.
isot:18.9_ex gci:located_in gn:9972749.
?totalflights om:numerical_value ?flights}

ANSWER "2"

7. (F) How many departure airports serve the city?

SELECT (COUNT(distinct ?dp) as ?dpcount) WHERE
{isot:18.9_ex gs:distinct_count_of ?flight_pop.

?flight_pop gs:is_composed_of ?flight.
?flight gcit:departAirport ?dp}

ANSWER “2”

8. (F) How many arrival airports serve the city?

SELECT (COUNT(distinct ?ap) as ?apcount) WHERE
{isot:18.9_ex gs:distinct_count_of ?flight_pop.
?flight_pop gs:is_composed_of ?flight.
?flight gcit:arriveAirport ?ap}

ANSWER “1”

Note: Questions 7 and 8 confirm that this counting method works since there are two flights in this example, one leaves from Pearson Airport and the other leaves from Hamilton Airport but both arrive at Los Angeles Airport. Meaning there are 2 departure airports that serve the city and 1 arrival airport that serves the city in this scenario.

9. (F) What time is the flight?

SELECT ?flight ?hour ?minute ?second WHERE
{isot:18.9_ex gs:distinct_count_of ?flightpop.
?flightpop gs:is_composed_of ?flight.
?flight gcit:dateOfDeparture ?date.
?date time:hour ?hour.
?date time:minute ?minute.
?date time:second ?second}

ANSWER

flight	**hour**	**minute**	**second**
18.9_flight_ex_2	12	45	00
18.9_flight_ex_1	13	23	00

10. (F) What is the flight number?

SELECT ?flight ?flightnumber WHERE
{isot:18.9_ex gs:distinct_count_of ?flightpop.
?flightpop gs:is_composed_of ?flight.
?flight gcit:hasFlightNumber ?flightnumber}

18.9_flight_ex_2	8821
18.9_flight_ex_1	AC1765

9.0 Conclusion

Creating an ontology that could represent the ISO 37120 Transportation theme indicator definitions as well as the data was the goal of this research. Before doing that, a generic transportation ontology had to be created first. This ontology houses concepts that were required in the indicator definitions but also goes beyond and leaves room for adding more details. For instance, a class for personal vehicles was created that differentiates the differences between different vehicle types such as bicycles, motorcycles, hatchbacks, pickup trucks, sedans, SUVs, and Vans. However, since there exists many more vehicle types, this can be expanded upon in the future. This also includes a subset of classes related to trips and routes which can also be used in other applications.

The following contributions were made from this research:

1. A generic Transportation ontology was created which could be further expanded upon and used in other transportation related ontologies.
2. An ontology that defines the ISO37120:18 transportation indicators was created.
3. Creates a precise definition of ISO37120:18 and does so using Semantic Web standards
4. Creates a precise definition of vehicles, trips, and routes in a generic transportation ontology that follows the Semantic Web standards as well as create precise definitions of the mentioned concepts.

10.0 Acknowledgements

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