Public Transport Ontology for Passenger Information Retrieval

Gaurav V. Jain[1], S. S. Jain[2], Manoranjan Parida[3]

Received: 02.02.2014 *Accepted: 14.06.2014*

Abstract:
Passenger information aims at improving the user-friendliness of public transport systems while influencing passenger route choices to satisfy transit user's travel requirements. The integration of transit information from multiple agencies is a major challenge in implementation of multi-modal passenger information systems. The problem of information sharing is further compounded by the multi-lingual and multi-cultural population of developing countries such as India. Ontology, by explicit specification of conceptualisation, not only addresses the issues pertaining to syntactic interoperability arising due to widely varied system architectures and software used by different agencies, but also ensures semantic interoperability caused by cognitive and naming heterogeneity. This paper develops a domain-specific ontology for public transport systems, which is further integrated with the domain-ontology of urban features with an objective of supporting multi-modal public transport information retrieval. The ontology thus developed is formalised using Web Ontology Language. In order to evaluate the capability of ontology in passenger information retrieval, the proposed ontology is implemented for five regular bus service routes and one bus rapid transit route in Ahmedabad city. The study defines 1336 named individuals (instances of concepts in ontology) including 293 instances of urban features and 1043 instances of public transport features. The capability of ontology in supporting general service information queries, itinerary planning, and multimodal trip planning have also been demonstrated. The study concludes that the domain-specific public transport ontology when integrated with urban features ontology, not only enables sharing of data across multiple transit agencies, but also expands the search space for passenger route choices by sharing the meaning of information.

Keywords: Ontology, public transport, passenger information, multimodal transport, semantic interoperability

---

Corresponding author Email:gvj@sac.isro.gov.in

1-Research Scholar, Indian Institute of Technology, Roorkee and Scientist\Engineer, Space Applications Centre, Ahmedabad, Gujarat, India.

2-Professor, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India

3-Professor and Head, Centre for Transportation Systems (CTRANS),Indian Institute of Technology Roorkee,,Roorkee, Uttarakhand, India

1. Introduction

Passenger information aims at improving the user-friendliness of public transport systems while influencing passenger route choices to satisfy transit user's travel requirements. The information, which may be of static nature such as route maps, schedules, and fares, or may be of dynamic nature such as route delays and real-time arrival estimates [Casey et al, 2000], needs to be conveyed to the commuters in timely, accurate, and convenient form so as to be effective and usable. The web-based passenger information systems have become a common medium of information dissemination for transit agencies, particularly due to their any-time, any-where availability, ability to support multimodal transport, and multi-linguistic capability. The transit travel involving multiple modes further adds complexities in terms of choices offered to the commuters, as it involves integration of information of schedules and routes of public transport services from multiple agencies, determination of feasible itineraries from such large datasets, and identifying the feasible itineraries satisfying multiple user preferences [Zografos and Androutsopoulos, 2009]. The web-based transit trip planners typically provide users with input options to minimize walking, minimize transfers, minimize journey time, selection of modes, and selection of arrival and departure times [Raddin et al, 2002], besides map-based and / or text-based choices for defining trip origin and destination points [Cherry et al, 2006]. Modesti and Sciomachen (1997) proposed a utility function considering six service attributes namely time spent in personal vehicle, time spent in public transport, time spent waiting for public transport, total walking time, total cost of travel, and discommodity due to travel in rush. Lozano et al (2001) introduced a set of constraints applicable in multi-modal networks for identifying viable multimodal shortest paths. Aifandopoulou et al (2006) developed multi-objective linear programming model incorporating the compatibility of modes, intermodal stations, and user's preferences. Kasturia and Verma (2010) proposed an objective function incorporating the in-vehicle time, transfer time, waiting time, walking time, and travel cost. The passengers of multi-model transport therefore are offered plethora of route choices by the passenger information systems, assuming seem-less integration of information across several agencies.

The public transport information in large cities, however, particularly those with multimodal transport systems, are scattered across several agencies. The information needs of commuters thus require mechanisms for data sharing across multiple agencies to serve adequate and reliable information for transit itinerary planning and multi-modal travel. Furthermore, in order to maximize the use of public transport and attract more commuters, the information on transit systems need to be linked to the purpose of making a trip such as shopping, leisure, tourism, etc [Watkins, 2010]; the information on which is maintained independently by separate agencies. Thus, the information regarding boarding and alighting points of public transport systems alone, may not be adequate for planning transit trips unless transit access points are integrated with the information of other objects of interest in urban environment. The public transport information therefore requires flow of information within transit agencies, between the transit agencies, between commuters and transit agencies, and between transit agencies and other information service providers.

The need for sharing information across multiple stakeholders has resulted in development of standards for data exchange covering various aspects of public transportation. Transmodel, standardizing public transport concepts and data structures to support public transport information systems, has been adopted as European Standard (EN 12896) in entire Europe [Kizoom and Miller, 2008]. Google Transit Feed Specification (GTFS), similar in many aspects to Transmodel [Kizoom and Miller, 2008], is being widely adopted by transit agencies globally for sharing of public transport data [Google Inc., 2013]. The Transit Communications Interface Profiles (TCIP) Standards, defined by American Public Transportation Association (APTA), provides standards for information exchange across transit agencies and transit suppliers [APTA, 2009]. SAE International (2004) standardized the message exchange mechanisms to communicate among different trip planning systems as part of its J2354 standard for defining message sets for Advanced Traveller Information System (ATIS). Peng and Kim (2008) demonstrated the application of J2354 standards in integration of trip planners across the jurisdictions of two or more transit agencies. In United Kingdom, standards such as JourneyWeb, TransXChange, NaPTAN and National Public Transport Gazetteer have resulted into successful deployment of Transport Direct enabling nationwide public transport information flows [DfT, 2013]. These efforts have succeeded in attaining syntactic interoperability across multiple systems, thereby allowing standardisation of data formats, database schemas, and data dictionaries across multiple agencies. The Extensible Mark-up Language (XML), which has become de-facto language for sharing information over web, has however limitations in attaining the semantic interoperability [Antoniou and Harmelen, 2008]. The XML is intended for describing the information about an information, rather than the actual meaning of its contents which may lead to misleading results due to different conceptualisations of the real world giving genesis to the problems of 'naming heterogeneity' and 'cognitive heterogeneity' [Billen et al, 2011].

Ontologies, defined as explicit specification of conceptualisation [Gruber, 1993], have been recognised as an effective medium for communication of meaning associated with the text in the digital world. In past, ontologies have been applied for public transportation applications such as transportation data sharing [Zhang et al, 2008], query systems [Wang et al, 2006], and transit trip planners [Timpf, 2002, Houda et al, 2010 and Peng et al, 2011]. Wang et al (2006) proposed urban public transport ontology, and demonstrated its capability in differentiating the same station names, and querying with more semantic information. Zhang et al (2008) developed an algorithm for transformation of transportation data in Unified Modelling Language (UML), which is used for modelling transportation systems data models, to Web Ontologies Language (abbreviated as OWL), which facilitated the interoperability of transportation data at the semantic level and enabled integration of semantically heterogeneous data from discrete sources. Peng et al (2011) proposed a framework and prototype for geospatial semantic web services demonstrating its applicability to transit trip planner by amalgamating ontology, Web Feature Services (WFS), and relational database query functions. The ontology of transportation network developed by Lorenz et al (2005) includes the concepts of public transportation systems which are based on the GDF data model. Houda et al (2008) developed ontology for public transport systems for assisting user travel planning. This ontology suggests journey patterns such as 'direct journey pattern', 'shopping journey pattern', 'leisure journey pattern', etc. on the basis of proximity of stop points to the geographic infrastructure elements like library, shopping malls, etc. It is therefore evident that ontologies offer possibilities of attaining semantic interoperability in exchange of passenger information across public transit stake-holders. While most of the studies have focussed on conceptualisation and formalisation of public transport ontology, its implementation and evaluation towards meeting the requirements of passenger information queries on multimodal public transport system remains to be seen.

The integration of transit information from multiple agencies is a major challenge in implementation of multi-modal passenger information systems. The development of standards for data exchange has only resulted in partially addressing the issue of information integration ensuring the syntactic interoperability arising due to widely varied system architectures and software applications adopted by various transit service providers. Ontologies provide a viable alternative to attain both the syntactic as well as the semantic interoperability in data exchange across several agencies. The earlier attempts towards implementation of ontology have focused on domain ontology for public transport alone with limited demonstration. This paper not only attempts to develop domain ontology for public transportation systems, but also extends it further by integrating it with the urban features ontology, which is derived from the available geographic content in Indian cities. The ontology thus developed is evaluated for the multimodal public transportation system in the city of Ahmedabad. The city, which is the largest city of the state of Gujarat in Western part of India, is served by the fixed-route regular bus service operated by Ahmedabad Municipal Transport Service (AMTS) and Bus Rapid Transit Service (BRTS) operated by Ahmedabad Janmarg Ltd (AJL). The information on BRTS is available from the website of AJL. The passenger information on regular bus service is available either from the printed transit timetables published by AMTS, or from the web-based transit trip planner incorporated in Google Transit. The lack of integration of information from different sources is a major hindrance to multimodal trip planning. Moreover, the information available from printed transit timetables and Google Transit have several differences with regard to naming of bus stops. In order to assess the quality of information on public transport in Ahmedabad city, spatial database of public transport network of the city was created in GIS environment, and 156 bus stops were randomly selected from the database thus created for identifying the difference of bus stop names in Google Transit with the reference database. As shown in Table 1, while only 50 stops in 156 samples had exactly same stop name, 40.38% stops had typographical errors and 27.56% of the bus stops had different stop names. The differences in bus stop names vary in different degrees as measured by Jaro Winkler distance. The lower the value of Jaro Winkler distance, the lower is the similarity between strings being compared. Table 2 shows examples of differences in names of bus stops as observed in the sample. While the typographical errors may be ignored to certain extent by use of string similarity algorithms like Jaro Winkler distance or Levenshtein distance, ontology offers solutions for overcoming the errors arising due to use of different names for same bus stop. This paper attempts to address the issues of semantic interoperability in multi-modal public transport with the aid of ontology. The paper comprises of four sections. Section 2 presents the methodology discussing the conceptualisation and formalisation of ontologies for public transport and urban features. Section 3 implements the ontology for public transport system in Ahmedabad city and evaluates it for passenger information queries. Section 4 concludes the paper with directions for future research.

2. Methodology

The domain ontologies are intended to capture the knowledge within some domain of interest [Guarino and Giaretta, 1995]. Ontology, which literally means 'study of being' (derived from the Greek words 'ont-' meaning 'being' and '-logy' meaning 'study of'), comprises of concepts and the relationships between those concepts as a prerequisite for representing any domain knowledge [Agrawal, 2005]. The design of ontology must ensure clarity, coherence, extendibility, minimum encoding bias, and minimal ontological commitment [Pretorius, 2004]. In order to achieve these design goals of ontology development, systematic methodologies such as Enterprise Ontology, Methontology, Toronto

Table 1. Types of errors in bus stop names

Type of Error	No. of Samples	% of Total
Typographical Error	63	40.38
Different Names	43	27.56
No Error	50	32.05
Total	**156**	**100.00**

Table 2. Examples of differences in names of bus stops

Type of Error	Bus Stop Name in Database	Bus Stop Name in Google Transit	Jaro Winkler Distance
Typographical Error	*G Ward*	*Jivod*	45
	Jashodanagar Navi Vasahat	*Navi Baha Hatt*	59
	Shelat Bhavan	*Shilak Bhawan*	87
	Harbolanath Park	*Hardol Nath Park*	92
	Dariapur Tower	*Dariyapur Tower*	98
Different Names	*Torrent Power Sub-station*	*Grid Station*	52
	Iscon Temple	*ISKCON Mandir*	76
	Tragad Village	*Tragad Gram*	89
	Sola Cross Road	*Sola Police Chowki*	79
	Swami Vivekanand Society	*Swami Vivekanand Flats*	93

Virtual Enterprise (TOVE) Ontology, etc. have evolved. In general, the development of ontology requires definition of its intended purpose, conceptualisation, implementation, and validation [Houda, 2010]. The ontology for public transport system represents various aspects of transit systems that may be on interest to passengers such as route information, stops, schedules, etc. While the public transport journey connects two transit stops, the actual intended origin as well as the destination of transit journey is in reality an urban feature such as a building. Moreover, the transit stops are mostly named after the nearby landmark such as an important building or road intersection etc. These features in urban environment are represented using urban feature ontology. The conceptualisation of these ontologies is based on review of existing ontologies and standards, coupled with existing public transportation system in the city of Ahmedabad. The concepts and their relationships are implemented in OWL using Protégé 4.2 software.

2.1 Public Transport Ontology

The major concepts defined by the public transport ontology are described in Table 3. These concepts are defined on the basis of the public transport data model proposed by Transmodel (2008) and GTFS (2013) besides the conceptualisations presented by Lorenz et al (2005) and Houda et al (2010). Furthermore, the definitions of key concepts are adopted from Vuchik (2005) to avoid any ambiguity.

A public transport system comprises of a set of transit lines and transit stops, operated and managed by a transit agency. The transit agency may operate one or more transit lines. Transit lines may have vehicle journeys along these transit lines. Transit vehicle journey has an origin transit stop and a destination transit stop. It provides transit service as per its transit calendar, which defines the operating days for a given service. Transit vehicle journey operates as per transit schedule specifying the departure times of a transit vehicle. The public transport ontology proposed by Lorenz et al (2005) and Houda et al (2010) conceptualise a transit vehicle journey as composed of route sections or vehicle journey part, each with a start and end stop point. This conceptualisation allows

Table 3. Concepts in public transport ontology

Sr. No.	Concept	Description	Reference
1	Transit Agency	The agency or authority operating transit lines is represented by the transit agency concept. It holds the information about the transit agency.	[GTFS, 2013]
2	Transit Line	A transit line is the infrastructure and service provided on a fixed alignment by vehicles or trains operating on a predetermined schedule.	[Vuchic, 2005]
3	Transit Route	A transit route is often synonymous with transit line, but it usually designates street transit, often overlapping lines, rather than major metro or regional rail lines.	[Vuchic, 2005]
4	Transit Stop	A transit stop is a location along a line at which transit vehicles stop to pick up or drop off passengers; its equipment may include signs, information, a bench, and shelter.	[Vuchic, 2005]
5	Transit Calendar	Transit calendar defines the operating days and dates when the service is available.	[GTFS, 2013]
6	Transit Service	Transit Service is a vehicle journey operating as per particular Transit Calendar.	[Transmodel, 2008]
7	Vehicle Journey	A transit vehicle journey or transit trip is a one-way journey from an origin stop to the destination stop, along the route. A transit route may have one or more such transit trips.	[Transmodel, 2008]
8	Vehicle Journey Stop	The stopping point (transit stop) of a transit vehicle journey.	-

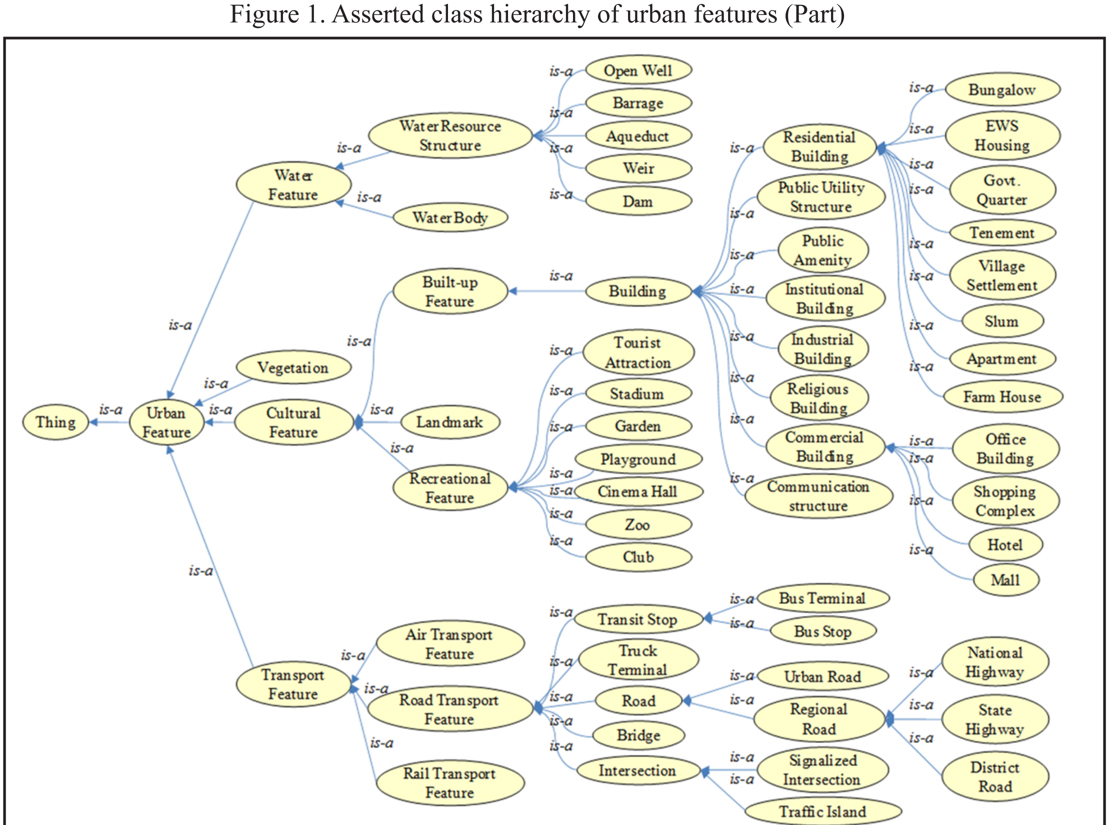
for defining the vehicle journey path independent of infrastructure, which may not be appropriate for transit systems using road or other shared right of way. This will also require explicit concepts for transfer links to establish connections between multiple modes. As transit users are more interested in knowing the stops of vehicle journey rather than the path followed by the transit vehicle, a concept of 'vehicle journey stop' has been introduced which defines the transit stops and their respective sequence in the vehicle journey. Several other concepts such as transit stop equipments, transit infrastructure, journey time, etc may be linked with this public transport ontology to further enhance the knowledge base.

2.2 Urban Feature Ontology

The urban feature ontology aims at defining physical objects in urban environment. An urban ontology comprises of objects, relations, events and processes in order to enable horizontal and vertical reuse of information [Fonseca et al, 2000]. Ordnance Survey's 'Buildings and Places Ontology' is the ontology intended to describe the building feature and place classes surveyed by Ordnance Survey [Liu et al, 2013]. City GML ontology incorporates the Open Geospatial Consortium's (OGC) City GML specifications [OGC, 2012] which provide a common semantic information model for representing 3D urban objects [COST Action TU0801, 2012]. Towntology contemplates domain ontology for urban planning and management [Berdier and Roussey, 2007]. Lorenz et al (2005) have incorporated urban features in the Ontology of Transportation Network (OTN), under which the public transportation systems are also defined. Similarly, Houda et al (2010) have included the urban feature concepts as part of geographic elements which are further related to transit stop points. These public transport ontologies have therefore limited linkages to urban features, while the urban feature ontologies themselves are so exhaustive that in Indian cities, such detailed information is unavailable.

As the primary purpose of urban ontology in this study is to represent various urban objects referred in public transport database, the ontology for urban features is based on the concepts defined in existing spatial data

Figure 1. Asserted class hierarchy of urban features (Part)



sources such as National Urban Information Systems (NUIS) and Large Scale Mapping (LSM). LSM provides the base layers comprising the point, line and polygon features in urban environment at 1:10,000 scale [NNRMS Standards Committee, 2005]. The NUIS includes thematic maps of 12 primary themes including urban land use, roads, railway lines, transportation nodes etc [TCPO, 2006]. The asserted class hierarchy of urban features developed by combining concepts defined in NUIS and LSM datasets is shown in Figure 1. Urban feature, which defines the top-level concept, includes Cultural features, transportation features, vegetation, and water features. Cultural feature may be a building, a recreational feature or any other landmark. Buildings are further grouped under different categories as per the use of building such as residential building, commercial building, religious building, etc. Transportation features include the concepts of road transport, rail transport and air transport. Water features include the various types of water bodies in the city along with other water resources structures such as dams, wells, etc.

In addition to urban features, a concept of administrative regions is also defined which includes district, block, municipal corporations, municipality, villages and wards. An object property "contains", is defined on administrative features which identifies urban features situated inside an administrative region. The inverse of "contain" object property is "inside". Both "contain" and "inverse" object properties are transitive properties; e.g. if building A is "inside" Ward AA, and Ward AA is "inside" Municipal Corporation BB, then building A is also "inside" Municipal Corporation BB. All urban features are identified inside some administrative region. Furthermore, as urban features can be near other urban features, a reflexive transitive object property, "is near" has been defined.

2.3 Integration of Ontologies

The ontology of public transport and urban features are merged in Protege 4.2 software to develop an integrated ontology. As the transit stop points defined in public transport ontology are also urban features, the object properties "inside" and "is near" are also defined for the individuals of transit stops.

3. Evaluation of Passenger Information Query using Ontology

The ontology of public transportation systems and urban features, formalized in OWL, is implemented for five routes of the regular bus service operated by AMTS and one route of bus rapid transit service operated by AJL in Ahmedabad city. Figure 2 shows the map of bus routes in the Ahmedabad city of Gujarat state in India that are implemented in the ontology. This ontology is used to query public transport information using SPARQL Protocol and RDF Query Language (SPARQL), which is an RDF (Resource Description Framework) Query language and data access protocol for semantic web [Yu, 2011]. Table 4 shows the number of named individuals of each concept implemented in the ontology. This includes 293 instances of urban features and 1043 instances of public transport which comprises instances of AMTS and BRTS public transit services. The web-based transit trip planners provide information of transit boarding and alighting points using text-based searches or the map-based searches [Cherry et al, 2006]. The text-based searches invariably use address geo-coding if addresses are structured as in USA or they use geo-coded landmarks if addresses are unstructured. The map-based searches require user to identify the locations of trip origin and destination on the map, invariably requiring support of Internet GIS [Peng and Huang, 2000 and Cherry et al, 2006]. The

Table 4. Implementation of ontology

Concept	No. of Named Individuals
Transit Agency	2
Transit Route	6
Transit Vehicle Journey	10
Transit Vehicle Journey Stop	729
Transit Stop	296
Urban Features	293

text-based search of bus stops is important for the users of transit websites when destinations are not known in advance. In developing countries such as India where postal addresses are not structured, address geo-coding becomes cumbersome and difficult to achieve [Sengar, 2007]. The information about landmarks may serve as a useful reference to begin with but geo-coding of such landmarks at city-level may prove to be a time and resource intensive task. The query and retrieval of bus stops on the basis of their names using text-based searches may only be useful if correct names are provided by the users. The differences in the names of land marks and bus-stops, both in user specified search string as well as in the reference database, may lead to erroneous results for keyword-based searches.

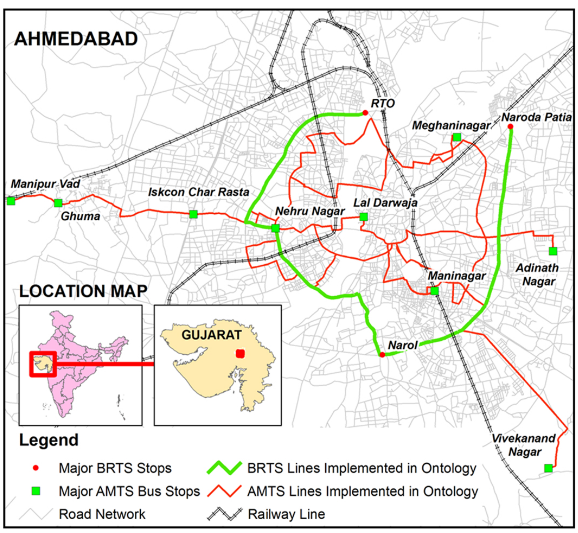


Figure 2. Study Area: Ahmedabad City

The ontology-based searches can expand the search space by finding the related concepts, e.g. Figure 3 shows the graph of concepts containing the keyword 'iskcon' and other related concepts including transit stop 'Iskcon Char Rasta' and the vehicle journeys stopping at this stop, the road intersection 'Iskcon Char Rasta' and the temple named 'ISKCON' located near 'Iskcon Char Rasta', and the administrative region 'Vejalpur Village Panchayat' containing 'Iskcon Char Rasta' bus stop as well as the road intersection named 'Iskcon Char Rasta'. It further shows that the temple 'ISKCON' is a tourist attraction. It may further be observed that most of the relationships are the inferred relationships as derived by FaCT++ reasoner.

The SPARQL query as shown in Figure 4, to search keyword 'iskcon' from the ontology not only queries the bus stops with keyword 'iskcon' in bus stop names, but also identifies other related concepts such as type of features associated with the bus stop, which in this case is a road intersection, and a temple which is also a tourist attraction. The search space can be expanded to include other religious places and road intersection. Thus, while a simple keyword based search using a string similarity algorithm will return two bus stops namely 'Iskcon Temple' and 'Iskcon Cross Road", an ontology based search provides 50 bus stops including four stops near tourist places, 11 stops near temples, and remaining stops near the road intersections, besides providing information to the commuter that the term 'iskcon' refers to a temple, which is also a tourist attraction.

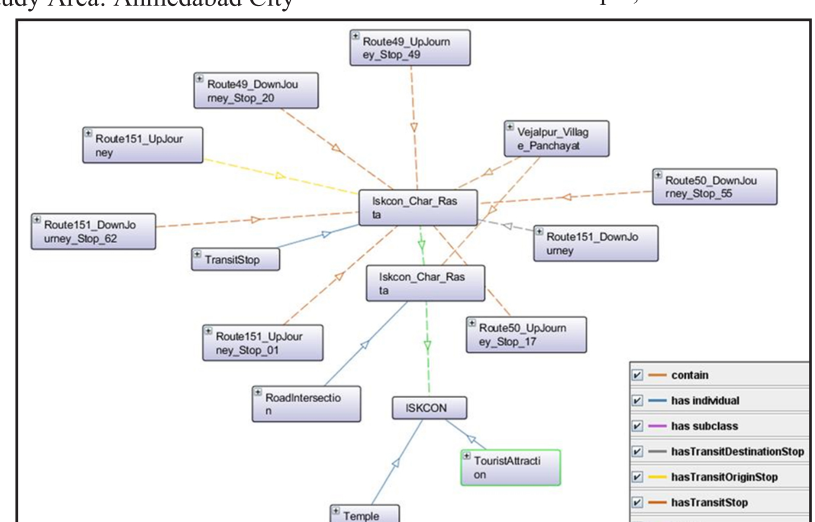
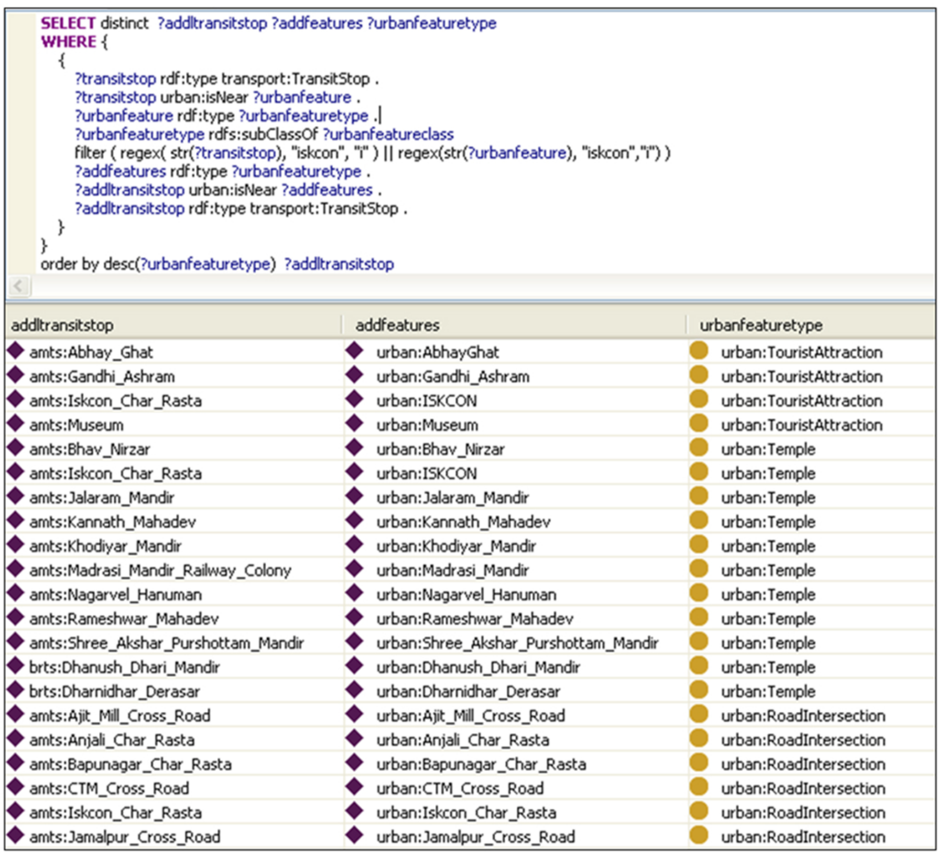


Figure 3. Graph of concepts containing 'iskcon' keyword, showing inferred relations by dotted line and asserted relationships by continuous line.

The route queries provide information on the routes passing through a transit stop and the route connecting a pair of origin and destination stops. The ontology based passenger information query can utilise the additional information linked to transit stations such as the nearby urban features or administrative regions containing the transit station. Figure 5 shows SPARQL query to find all routes that are passing through an administrative region. The query determines the vehicle journeys which have stops that are located inside the administrative region whose name contains the keyword '*vejalpur*'. The SQL based query to retrieve this information from Object Relational Database Management Systems (ORDBMS) like Oracle or POSTGRES will not only require the prior information of table schemas of multiple tables stored in these databases, but also require spatial overlay functions to determine transit stops located inside a given administrative region.

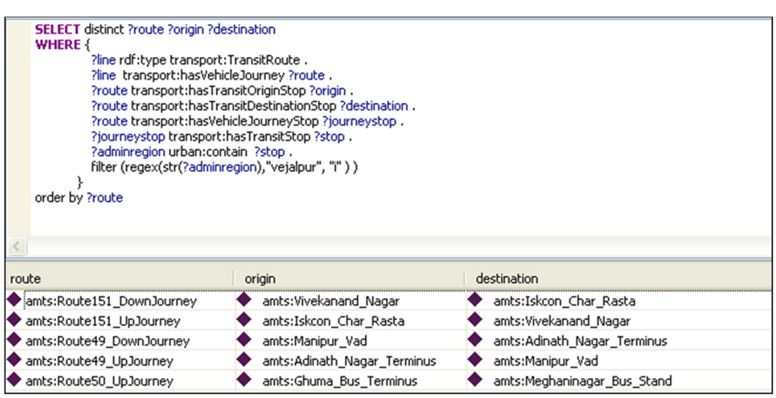


```
SELECT distinct ?addltransitstop ?addfeatures ?urbanfeaturetype
WHERE {
  {
    ?transitstop rdf:type transport:TransitStop .
    ?transitstop urban:isNear ?urbanfeature .
    ?urbanfeature rdf:type ?urbanfeaturetype .
    ?urbanfeaturetype rdfs:subClassOf ?urbanfeatureclass
    filter ( regex( str(?transitstop), "iskcon", "i" ) || regex(str(?urbanfeature), "iskcon","i") )
    ?addfeatures rdf:type ?urbanfeaturetype .
    ?addltransitstop urban:isNear ?addfeatures .
    ?addltransitstop rdf:type transport:TransitStop .
  }
}
order by desc(?urbanfeaturetype) ?addltransitstop
```

addltransitstop	addfeatures	urbanfeaturetype
amts:Abhay_Ghat	urban:AbhayGhat	urban:TouristAttraction
amts:Gandhi_Ashram	urban:Gandhi_Ashram	urban:TouristAttraction
amts:Iskcon_Char_Rasta	urban:ISKCON	urban:TouristAttraction
amts:Museum	urban:Museum	urban:TouristAttraction
amts:Bhav_Nirzar	urban:Bhav_Nirzar	urban:Temple
amts:Iskcon_Char_Rasta	urban:ISKCON	urban:Temple
amts:Jalaram_Mandir	urban:Jalaram_Mandir	urban:Temple
amts:Kannath_Mahadev	urban:Kannath_Mahadev	urban:Temple
amts:Khodiyar_Mandir	urban:Khodiyar_Mandir	urban:Temple
amts:Madrasi_Mandir_Railway_Colony	urban:Madrasi_Mandir	urban:Temple
amts:Nagarvel_Hanuman	urban:Nagarvel_Hanuman	urban:Temple
amts:Rameshwar_Mahadev	urban:Rameshwar_Mahadev	urban:Temple
amts:Shree_Akshar_Purshottam_Mandir	urban:Shree_Akshar_Purshottam_Mandir	urban:Temple
brts:Dhanush_Dhari_Mandir	urban:Dhanush_Dhari_Mandir	urban:Temple
brts:Dharnidhar_Derasar	urban:Dharnidhar_Derasar	urban:Temple
amts:Ajit_Mill_Cross_Road	urban:Ajit_Mill_Cross_Road	urban:RoadIntersection
amts:Anjali_Char_Rasta	urban:Anjali_Char_Rasta	urban:RoadIntersection
amts:Bapunagar_Char_Rasta	urban:Bapunagar_Char_Rasta	urban:RoadIntersection
amts:CTM_Cross_Road	urban:CTM_Cross_Road	urban:RoadIntersection
amts:Iskcon_Char_Rasta	urban:Iskcon_Char_Rasta	urban:RoadIntersection
amts:Jamalpur_Cross_Road	urban:Jamalpur_Cross_Road	urban:RoadIntersection

Figure 4. SPARQL query to find bus stop

a. Find bus routes



```
SELECT distinct ?route ?origin ?destination
WHERE {
        ?line rdf:type transport:TransitRoute .
        ?line  transport:hasVehicleJourney ?route .
        ?route transport:hasTransitOriginStop ?origin .
        ?route transport:hasTransitDestinationStop ?destination .
        ?route transport:hasVehicleJourneyStop ?journeystop .
        ?journeystop transport:hasTransitStop ?stop .
        ?adminregion urban:contain  ?stop .
        filter (regex(str(?adminregion),"vejalpur", "i" ) )
      }
order by ?route
```

route	origin	destination
amts:Route151_DownJourney	amts:Vivekanand_Nagar	amts:Iskcon_Char_Rasta
amts:Route151_UpJourney	amts:Iskcon_Char_Rasta	amts:Vivekanand_Nagar
amts:Route49_DownJourney	amts:Manipur_Vad	amts:Adinath_Nagar_Terminus
amts:Route49_UpJourney	amts:Adinath_Nagar_Terminus	amts:Manipur_Vad
amts:Route50_UpJourney	amts:Ghuma_Bus_Terminus	amts:Meghaninagar_Bus_Stand

Figure 5. SPARQL query to find bus routes serving an administrative region

Figure 6 shows SPARQL query to determine the vehicle journey originating at '*iskcon*' and ending at '*nehru*'. The query firstly finds the transit stops near the urban features with names having '*iskcon*' and '*nehru*', and subsequently determines the vehicle journeys stopping at these transit stops. The vehicle journeys which stops at both of these transit stops and where the stop sequence of origin stop is before destination stop forms the required result.

SPARQL query can also be used to plan itineraries between a pair of urban features that are not directly connected by a transit line. Figure 7 shows the SPARQL query statement to determine route originating at '*maninagar*' bus stop and ending '*iskcon*' bus stop. The query firstly finds all the bus stops which are directly connected to the origin bus stop, i.e. the transit stops with keyword '*maninagar*' in their names, and then from each of these connected bus stops, it identifies direct vehicle journeys to the destination bus stop. The results are further arranged in ascending order of the number of intermediate bus stops in entire vehicle journey from the origin to destination stops. The query

```
SELECT distinct ?origin ?route1 ?destination
WHERE {
        ?origin rdf:type transport:TransitStop .
        ?origin urban:isNear ?f1 .
        filter (regex(str(?origin), "iskcon" ,"i" ) || regex(str(?f1), "iskcon" ,"i" ) ) .

        ?destination rdf:type transport:TransitStop .
        ?destination urban:isNear ?f2 .
        filter (regex(str(?destination), "nehru" ,"i" ) || regex(str(?f2), "nehru" ,"i" ) ) .

        ?route1 rdf:type transport:TransitVehicleJourney .
        ?route1 transport:hasVehicleJourneyStop ?st1.
        ?st1 transport:hasTransitStop ?origin .
        ?st1 transport:hasStopSequence ?seq1 .

        ?route2 rdf:type  transport:TransitVehicleJourney .
        ?route2 transport:hasVehicleJourneyStop ?st2.
        ?st2 transport:hasTransitStop ?destination .
        ?st2 transport:hasStopSequence ?seq2 .

        filter ( ( xsd:integer(str(?seq1)) < xsd:integer(str(?seq2)) )  ) .
        filter (regex( str(?route1), str(?route2), "i") ) .

  }
```

[origin]	route1	destination
amts:Iskcon_Char_Rasta	amts:Route49_DownJourney	amts:Nehru_Nagar
amts:Iskcon_Char_Rasta	amts:Route151_UpJourney	amts:Nehru_Nagar

Figure 6. SPARQL query to find bus routes between a pair of urban features

```
SELECT ?origin ?trip1 ?stop1  ?trip2 ?destination  ((?sq2 - ?sq1) + (?sq4 - ?sq3) )
WHERE {
   ?trip1 transport:isVehicleJourneyOf ?line1 .
   ?line1 transport:isOperatedBy ?agency1 .
   ?trip1 transport:hasVehicleJourneyStop ?st1 .
   ?st1 transport:hasTransitStop ?origin .
   ?st1 transport:hasStopSequence ?sq1 .
   FILTER (regex (str(?origin) , "maninagar" ,"i")) .
   ?trip1 transport:hasVehicleJourneyStop ?st2 .
   ?st2 transport:hasTransitStop ?stop1 .
   ?st2 transport:hasStopSequence ?sq2 .
   FILTER (xsd:integer (str(?sq2)) > xsd:integer (str(?sq1)) ) .
   ?trip2 transport:isVehicleJourneyOf ?line2 .
   ?line2 transport:isOperatedBy ?agency2 .
   ?trip2 transport:hasVehicleJourneyStop ?st3 .
   ?st3 transport:hasTransitStop ?destination .
   ?st3 transport:hasStopSequence ?sq3 .
   FILTER (regex (str(?destination) , "iskcon" ,"i")) .
   ?trip2 transport:hasVehicleJourneyStop ?st4 .
   ?st4 transport:hasTransitStop ?stop2 .
   ?st4 transport:hasStopSequence ?sq4 .
   FILTER (xsd:integer (str(?sq4)) > xsd:integer (str(?sq3)) ) .
   FILTER (regex (str(?stop1), str(?stop2),"i") ) .
} ORDER BY ((?sq2 - ?sq1) + (?sq4 - ?sq3) )
```

Figure 7. SPARQL Query to retrieve vehicle journey between a pair of bus stops with single transfer

c. Multimodal route query

returns **112** possible itineraries with minimum **38** stops to maximum **150** stops.

The multimodal route query involves information from more than one mode, the information about which is usually scattered across multiple sources. In conventional multi-modal network data models, transfer links and transfer nodes are defined for connecting different modes. As in the study area, public transport service is offered by two agencies, namely AMTS and AJL, the multimodal transport network of the city will require incorporation of links connecting BRTS corridor with urban roads so as to enable transfer across the modes. However, in ontology based implementation, as the nearest features of all transit stops are also defined, those stops which are having common nearest feature can act as transfer stops, e.g. traffic island named '*Nehru Nagar Circle*' is near to both '*Nehru Nagar Bus Stop*' as well as '*Nehru Nagar BRTS Stop*'. The SPARQL query shown in Figure 8 utilises such stops to determine route starting at '*Ghuma*' and ending at '*Naroda*'. The query first determines all the transit stops that are connected to origin transit stop by the direct

```
SELECT ?origin ?trip1 ?stop1 ?stop2 ?trip2 ?destination ((?sq2 - ?sq1) + (?sq4 - ?sq3) )
WHERE {
    ?origin rdf:type transport:TransitStop .
    FILTER ( regex (str(?origin),"ghuma","i") ).
    ?st1 transport:hasTransitStop ?origin .
    ?st1 transport:hasStopSequence ?sq1 .
    ?st1 transport:isVehicleJourneyStopOf ?trip1 .
    ?trip1 transport:hasVehicleJourneyStop ?st2 .
    ?st2 transport:hasTransitStop ?stop1 .
    ?st2 transport:hasStopSequence ?sq2 .
    FILTER (xsd:integer (str(?sq2)) > xsd:integer (str(?sq1)) ) .
    ?stop1 urban:isNear ?features1 .
    ?stop2 urban:isNear ?features1 .
    ?stop2 rdf:type transport:TransitStop .
    ?st3 transport:hasTransitStop ?stop2 .
    ?st3 transport:hasStopSequence ?sq3 .
    ?st3 transport:isVehicleJourneyStopOf ?trip2 .
    ?trip2 transport:hasVehicleJourneyStop ?st4 .
    ?st4 transport:hasTransitStop ?destination .
    ?st4 transport:hasStopSequence ?sq4 .
    FILTER (xsd:integer (str(?sq4)) > xsd:integer (str(?sq3)) ) .
    FILTER ( regex (str(?destination),"naroda","i") ).
} ORDER BY ((?sq2 - ?sq1) + (?sq4 - ?sq3) )
```

Figure 8. Multimodal route query using ontology

Table 5. Output of multimodal route query

Origin	Trip1	Stop1	Stop2	Trip2	Destination	Stops
AMTS: Ghuma Bus Terminus	AMTS: Route 50 (Up)	AMTS: Shivranjani Society	BRTS: Shivranjani	BRTS: RTO To Naroda	BRTS: Naroda	59
AMTS: Ghuma Bus Terminus	AMTS: Route 49 (Up)	AMTS: Shivranjani Society	BRTS: Shivranjani	BRTS: RTO To Naroda	BRTS: Naroda	59
AMTS: Ghuma Bus Terminus	AMTS: Route 49 (Up)	AMTS: Jhansi ki Rani	BRTS: Jhansi Ki Rani	BRTS: Trip RTO To Naroda	BRTS: Naroda	60
AMTS: Ghuma Bus Terminus	AMTS: Route 49 (Up)	AMTS: Nehru Nagar	BRTS: Nehrunagar	BRTS: RTO To Naroda	BRTS: Naroda	61
AMTS: Ghuma Bus Terminus	AMTS: Route 49 (Up)	AMTS: Soni ni Chali	BRTS: Soni ni Chali	BRTS: RTO To Naroda	BRTS: Naroda	64
AMTS: Ghuma Bus Terminus	AMTS: Route 50 (Up)	AMTS: Gujarat University	BRTS: University	BRTS: RTO To Naroda	BRTS: Naroda	73

vehicle journeys, queries the urban features that are near these connected stops, determines the stops that are near these urban features, and finally determines the vehicle journeys connecting this new set of stops to the destination. Table 5 presents the result of this query. The query returns six possible routes with minimum 59 intermediate stops and maximum 73 intermediate stops.

4. Conclusion

The public transport ontology and its integration with urban features ontology, has potential to service the passenger information requirements. This paper demonstrated the capability of ontology in providing information on general service operations, itinerary planning, and multimodality, as desired by commuters during pre-trip stage of a transit trip. Ontology, not only enables sharing of data across multiple agencies, but also improves its understanding by sharing the meaning of the content of information.

The ontology thus developed, can be extended to incorporate other related concepts such as real time arrival information, weather information, road conditions etc. Moreover, the flexibility offered by RDF/OWL languages enables addition of further details to individual concept e.g. tourist attraction concept can be expanded to include details on opening hours, significance of features, etc. Furthermore, the domain ontology of geographic features may also be incorporated to enable mapping of concepts in GIS environment using Web Map Services (WMS) or Web Feature Services (WFS). The implementation of ontology based search engines however requires minimal ontological commitment between transit agencies and other information providers, and development of tools to enable translation of data from respective databases to ontology.

Acknowledgements

[To be added after peer-review]

5. References

-Agrawal, P. (2005) “Ontological considerations in GIScience.” International Journal of Geographical Information Science, Vol. 19, No. 5, pp. 501-536.

-Aifandopoulou, G., Ziliaskopoulos, A. and Chrisohoou, E. (2006) “A multi-objective optimum path algorithm for passenger pretrip planning in multimodal transportation networks.” Transportation Research Record: Journal of the Transportation Research Board, Vol. 2032, Issue 1, pp 26-34.

-Antoniou, G., and Harmelen F. (2008) A Semantic Web Premier, Second Edition, MIT Press, Cambridge.

-APTA. (2009) APTA TCIP-S-001 3.0.3 – APTA Standard for Transit Communications Interface Profiles, Version 3.0.3 Volume-III, TCIP XML Schema. American Public Transportation Association (APTA). Washington, DC.

-Berdier, C., and Roussey, C. (2007) “Urban ontologies: The Towntology prototype towards case studies.” In Ontologies for Urban Development Studies in Computational Intelligence, Vol. 16, pp. 143–155. Springer, Basel.

-Billen, R., Nogueras-Iso, J., López-Pellicer, F. J., and Vilches-Blázquez, L. M. (2011) “Ontologies in the Geographic Information sector.” in Falquet, G., Métral, C., Teller, J., and Tweed, C. (eds.), Ontologies in Urban Development Projects. Springer London.

-Casey, R. F. et al. (2000) Report No. DOT-VNTSC-FTA-99-5:Advanced Public Transportation Systems: The State of the Art - Update 2000, Final Report to the U.S. Department of Transportation, Federal Transit Administration, John A. Volpe National Transportation Systems Center, Cambridge , MA.

-Cherry, C., Hickman, M., and Garg, A. (2006) “Design of a Map-Based Transit Itinerary Planner.” Journal of Public Transportation, Vol. 9, No. 2, 45-68.

-COST Action TU0801. (2012) “Semantic Enrichment of 3D City Models for Sustainable Urban Development: Urban Ontologies.” Last modified: April 19, 2012. http://semcity.unige.ch/semcity/doku.php/urban_ontologies.

-Department for Transport (DfT). (2013) “Public Transport XML Standards.” Last modified: March 22, 2013. http://www.dft.gov.uk/publictransportdatastandards/.

-Fonseca, F., Egenhofer, M., Davis, C., and Borges, K. (2000) "Ontologies and knowledge sharing in Urban GIS.", Computers, Environment and Urban Systems, Vol. 24 No. 3, pp 232-251.

-Google Inc. (2013) "General Transit Feed Specification Reference." Last modified: July 18, 2013. https://developers.google.com/transit/gtfs/reference.

-Gruber, T. R. (1993) "A translation approach to portable ontology specifications". Knowledge Acquisition, vol. 5, pp 199-220.

-Guarino, N., and Giaretta, P. (1995) "Ontologies and Knowledge Bases: Towards a Terminological Clarification." In N. Mars (Ed.), Towards Very Large Knowledge Bases: Knowledge Building and Knowledge Sharing, IOS Press, Amsterdam.

-Horridge, M. (2009) A Practical Guide To Building OWL Ontologies Using Protege 4 and CO-ODE Tools, Edition 1.2. The University of Manchester.

-Houda, M., Khemaja, M., Oliveira, K., and Abed, M. (2010) "A public transportation ontology to support user travel planning." in proceedings of Fourth International Conference on Research Challenges in Information Science (RCIS), 19-21 May 2010, Nice, France.

-Kasturia S. and Verma A. (2010) "A Multi-Objective Transit Passenger Information System Design using GIS." ASCE Journal of Urban Planning and Development, 136(1), pp.34-41.

-Kizoom, N., and Miller, P. (2008) A Transmodel based XML schema for the Google Transit Feed Specification with a GTFS / Transmodel comparison. Kizoom Ltd., London.

-Liu, S., Brewster, C. and Shaw, D. (2013) "Ontologies for Crisis Management: A Review of State of the Art in Ontology Design and Usability." in proceedings of the 10th International ISCRAM Conference – Baden-Baden, Germany.

-Lorenz, B., Ohlbach, H. J., and Yang, L. (2005) Report No. IST506779/Munich /A1-D4/D/PU/a1: Ontology of Transportation Networks. Reasoning on the Web with Rules and Semantics (REWERSE), Munich.

-Lozano, A., and Storchi, G. (2001) "Shortest viable Path Algorithm in Multimodal Networks", Transportation Research Part A, Vol. 35, pp. 225-241.

-Modesti, P., and Sciomachen, A. (1998) "A Utility Measure for Finding Multiobjective Shortest Paths in Urban Multimodal Transportation Networks", European Journal of Operational Research, Vol. 111, pp. 495-508.

-NNRMS Standards Committee. (2005) ISRO: NNRMS: TR: 112: 2005 Committee Report, NNRMS standards: a national standard for EO images, thematic & cartographic maps, GIS databases and spatial outputs. NNRMS Secretariat, Indian Space Research Organisation (ISRO), Govt. of India, Bangalore, India.

-OGC. (2012) OGC City Geography Mark-up Language (CityGML) Encoding Standard, Document Reference Number OGC 12-019. Open Geospatial Consortium.

-Peng, Z. R., and Huang, R. (2000) "Design and development of interactive trip planning for web-based transit information systems", Transportation Research C: Emerging Technology 8: 409–425.

-Peng, Z.-R. and Kim, E. (2008) "A Standard-based Integration Framework for Distributed Transit Trip Planning Systems", Journal of Intelligent Transportation Systems, 12(1), pp 13-28.

-Peng, Z.-R., Zhao, T., and Zhang, C. (2011) "Geospatial Semantic Web Services: A Case for Transit Trip Planning Systems", in Zhao, P. and Di, L. Geospatial Web Services: Advances in Information Interoperability. Information Science Reference, Hershey.

-Pretorius, A. J. (2004) "Ontologies Introduction and Overview." Vrije Universitiet Brussels.

-Radin S., Jackson, D., Rosner, D., and Peirce, S. (2002) Trip planning state of the practice. Report No. FTA-TRI-11-02.6. Federal Highway Administration, Washington D.C.

-SAE International. (2004) SAE J2354 - Message Set for Advanced Traveller Information System (ATIS), SAE International.

-Sengar, V. et al. (2007) "Robust Location Search from Text Queries." in Proceedings of the 15th annual ACM international symposium on Advances in geographic information systems, 07 - 09, November 2007, Seattle, Washington.

-TCPO. (2006) National Urban Information Systems (NUIS) Design and Standards, Town and Country Planning Organisation, Govt. of India, Ministry of Urban Development, New Delhi, India.

-Timpf, S. (2002) "Ontologies of Wayfinding: a Traveller's Perspective", Networks and Spatial Economics, Vol. 2, pp 9-33.

-Vuchic, V. R. (2005) Urban Transit: Operations, Planning and Economics. John Wiley & Sons Inc. New Jersey.

-Wang, J., Ding, Z., and Jiang, C. (2006) "An Ontology-based Public Transport Query System." In Proceedings of the First International Conference on Semantics, Knowledge, and Grid (SKG 2005), 28-29, November 2005, Beijing, China.

-Watkins, K. E. (2010) "Explore: An Attraction Search Tool for Transit Trip Planning." Journal of Public Transportation, Vol. 13 No. 4, pp 111-128.

-Yu, L. (2011) A Developer's Guide to the Semantic Web. Springer-Verlag Berlin Heidelberg.

-Zang, C., Peng, Z.-R., Zhao, T., and Li. W. (2008) "Transformation of Transportation Data Models from Unified Modelling Language to Web Ontology Language." Transportation Research Record: Journal of the Transportation Research Board, No. 2064, pp 81-89.

-Zografos, K. G., Androutsopoulos, K. N., and Spitadakis, V. (2009), "Design and Assessment of an Online Passenger Information System for Integrated Multimodal Trip Planning", IEEE Transactions on Intelligent Transportation Systems, 10(2), pp. 311-323.