CONTEXT BASED INTEROPERABILITY TO SUPPORT INFRASTRUCTURE MANAGEMENT IN MUNICIPALITIES

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CONTEXT BASED INTEROPERABILITY TO SUPPORT INFRASTRUCTURE MANAGEMENT IN MUNICIPALITIES

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ABSTRACT

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Interoperability between Geographic Information System (GIS) of different infrastructure companies is still a problem to be handled. Infrastructure companies deal with many operations as a part of their daily routine such as a regular maintenance, or sometimes they deal with unexpected situations such as a malfunction due to natural event, like a flood or an earthquake. These situations may affect all companies and affected infrastructure companies response to these effects. Responses may result in consequences and in order to model these consequences on GIS, GISs are able to share information, which brings the interoperability problem into the scene.

The present research, aims at finding an answer to interoperability problem between GISs of different companies by considering contextual information. During the study, the geographical features are handled as the major concern and interoperability problem is examined by targeting them. The model constructed in this research is based on the ontology and because the meaning of the terms in the ontology depends on the context, ontology based context modeling is also used.

In this research, a system implementation is done for two different GISs of two infrastructure companies, which are electricity (BEDAŞ) and telecommunication (Türk Telekom) systems. On the other hand the system implemented is flexible and open to integration of other GIS systems. Maintenance and emergency situations are chosen as sample contexts for this research. The ontologies of sample infrastructures are constructed as application ontologies, which are derived from upper ontologies. On the other hand, context ontologies are used to model the maintenance and emergency. Geometric characteristics of entities are defined by another ontology which depends on ISO 19107 as a base. Together with the context ontologies and application ontologies, Semantic Web Rule Language (SWRL) is used to complete the knowledge base. “Jess”, the Rule Engine for the Java Platform, is used as a reasoner because of its SWRL and Web Ontology Language (OWL) ontology support. Jess is used to make reasoning on SWRL rules to find out necessary actions to be taken as a result of an event performed by the infrastructure companies.

Keywords: Ontology, Interoperability, Context, Semantic Web Rule Language.

ÖZ

BELEDİYE SINIRLARI İÇERİSİNDEKİ ALTYAPILARIN YÖNETİLMESİ İÇİN BAĞLAM TABANLI BİRLİKTE ÇALIŞABİLİRLİK

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Altyapı şirketlerinin oluşturmuş olduğu coğrafi bilgi sistemleri (CBS) arasındaki birlikte çalışabilirlik ele alınması gereken bir sorundur. Altyapı şirketleri, bir taraftan kesintisiz bir servis sunabilmek amacıyla bakım, onarım gibi günlük faaliyetleri gerçekleştirmenin yanısıra, bir taraftan da sel, deprem gibi bir anda ortaya çıkabilecek olayları da yönetmek durumundadırlar. Bahsettiğimiz olayların tamamı, altyapı firmaları üzerinde bir etkiye sahiptir ve her bir firma bu etkiye değişik tepkiler vermektedir. Ayrıca altyapı firmalarının vermiş olduğu bu tepkilerin de muhakkak ki bazı sonuçları vardır. Bu sonuçları CBS ortamında modelleyebilmek için, altyapı firmalarının kendi aralarında bilgi paylaşımına sahip olması gerekmektedir ki bu durum da birlikte çalışabilirlik problemi olarak tanımlanabilir.

Altyapı sistemleri bakım ve onarım çalışmaları, sel gibi durumların içerisinde normal operasyon zamanlarından farklı bir şekilde davranırlar. Dolayısıyla bu gibi durumlarda, altyapı şirketlerinin ve altyapı sistemlerinin vereceği tepki, altyapının içerisinde bulunduğu duruma göre şekillendirilmelidir. Diğer bir deyişle, her bir altyapı içerisinde bulunduğu bağlama göre değerlendirilmelidir.

Bu çalışma, farklı altyapı şirketlerinin kurgulamış olduğu CBS'ler arasında bağlam tabanlı bir birlikte çalışabilirlik modeli bulmak amacıyla yapılmıştır. Çalışmada kullanılan model ontoloji tabanlıdır ve ontolojiler içerisindeki kavramlar değişik bağlamlar içerisinde farklı anlamlar içerebileceğinden, ontoloji tabanlı bağlam modelleme yöntemi kullanılmıştır.

Çalışmada, iki farklı altyapı şirketinin CBSleri için örnek bir uygulama geliştirilmiştir. Bu şirketler elektrik dağıtım şirketi olan BEDAŞ ve telekominikasyon şirketi olan Türk Telekom'dur. Fakat kullanılan yöntemin esnek olması sebebiyle daha fazla CBS de uygulamaya dahil edilebilir. Ayrıca acil durum ve bakım onarım işlemleri ise örnek bağlamlar olarak seçilmiştir. Örnek olarak alınan altyapılar uygulama ontolojileri olarak kurgulanmış ve bakım onarım işleri, acil durum senaryoları ise bağlam ontolojileri tabanlı olarak modellenmiştir. Uygulama ontolojileri ise en üst seviye ontolojilerden türetilmiştir. Çalışmada kullanılan en üst seviye ontolojiler ise, coğrafi verilen modellenmesi için kullanılan Mekansal Gösterim Ontolojisi ve ortak kullanılan elemanları anlatmak için kullanılan Ortak Kelimeler Ontolojisidir. Mekansal Gösterim Ontolojisinin kurgulanmasında ISO 19107 standartı kullanılmıştır. Uygulama ve bağlam ontolojileri ile birlikte, Anlamsal Ağ Kural Dili (AAKD) ile oluşturulmuş kurallar bilgi tabanını oluşturmaktadır. OWL ve AAKD ontolojileri desteğinden ötürü bilgi tabanı üzerinde uslamlama yapmak için, Java platformu uyumlu bir kural motoru olan "Jess" kullanılmıştır. Jess SWRL ile yazılmış olan kuralları çalıştırarak, altyapı şirketleri tarafından gerçekleştirilen olaylar sonucunda yapılması gereken aksiyonları bulmak için kullanılmıştır.

Anahtar Kelimeler: Ontoloji, Birlikte Çalışabilirlik, Bağlam, Anlamsal Ağ Kural Dili

To my dearest wife and my family

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LIST OF ABBREVIATIONS

ACE-GIS	Adaptable and Composable E-Commerce and Geographic Information Service
API	Application Programming Interface
ASC	Aspect-Scale-Context
AYKOME	Infrastructure Coordination Headquarter
BEDAŞ	Başkent Electricity Distribution Co.
CoBrA	Context Broker Architecture
CONON	Context Ontology
COM	Context Ontology Model
CoOL	Context Ontology Language
DBMS	Database Management System
DL	Description Logic
ESCOM	Extended Specific Context Ontology Model
FTC	Feature Type Catalogue
GIC	Geo-Information Community
GIS	Geographic Information System
GML	Geography Markup Language
INSPIRE	Infrastructure for Spatial Information in the European Community
MDA	Model Driven Architecture
NSF	National Science Foundation

OMG	Object Management Group
OGC	Open Geospatial Consortium
OWL	Web Ontology Language
SDI	Spatial Data Infrastructure
SOUPA	Standard Ontology for Ubiquitous and Pervasive Applications
SWRL	Semantic Web Rule Language
TT	Türk Telekom
ULCOM	Upper-Level Context Ontology Model
UML	Unified Modeling Language
UVDM	National Geographic Data Exchange Model
WFS	Web Feature Service
XML	Extensible Markup Language

CHAPTER 1

INTRODUCTION

1.1 Interoperability and Ontology

Since invented, Geographic Information Systems (GIS) are widely used. Many systems have been established to support some decision making processes and a lot of data have been produced to make those systems work properly. Those systems have been developed on a wide scale, so new problems have been arisen. One of the most important question is that, how those systems communicate with each other? In other words, both the data exchange between these systems, and more importantly, knowledge exchange between the users of those systems have become a major problem.

Definition of an interoperability is given in Webster Online Dictionary (2010) as "ability of a system (as a weapons system) to work with or use the parts or equipment of another system." In order to make interoperability possible between systems, data exchange mechanism should be constructed and exchanged data should be understandable for all systems.

Fonseca et al. (2000) state that, knowledge exchange between users of urban GIS has several aspects. For example, data and knowledge can be shared or used within a city or between the cities. They especially underlined that, the environmental and transportational concerns should be examined in a continuous manner throughout the cities. The statement is sensible because the issues related with those concepts are not interrupted at the border of a city.

Interoperability is the well-defined problem not only in GIS but also in any kind of information system. It is defined as “the problem of bringing together heterogeneous and distributed information systems” (Stoimenov and Djordjevic-Kajan, 2005). On the other hand, Visser et al. (2002) underline the runtime aspect of interoperability in their definition.

Several interoperability problems are defined in the literature. Manso et al. (2009) state that, three of the most cited problems are schematic, syntactic and semantic interoperability. Each of the problems is handled differently. Syntactic and schematic ones are examined at the data model level. Because these problems are mostly related with the representation of the real world object in the database but semantic problems are very different by nature. Semantic, is the meaning in a language and the meaning of the same entity can be different in different systems. Therefore to overcome semantic problems, different mechanisms should be evoked. Ontologies are the most premising tools to solve the semantic problems.

The word ontology comes from the philosophy and it is concerned with the nature of existence. (Longman Online Dictionary-Ontology, 2010). The most famous and quoted definition is the Gruber’s (1993) one which is the explicit specification of conceptualization. After Gruber, Borst (1997) made another definition. He defined the ontology as a formal specification of a shared conceptualization.

Studer et al. (1998) took two definitions from Gruber (1993) and Borst (1997) and merge them. They state that an ontology is a formal, explicit specification of a shared conceptualization. In this definition, conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. Explicit means that the type of concepts used, and the constraints on their use are explicitly defined.

The representation of ontology depends on the level of abstraction. It can be represented on the computer by using a logic language and it can be stored in Extensible Markup Language (XML) based files. On the other hand, an ontology can be represented by visual languages such as Unified Modeling Language (UML). Gašević et al. (2006) give an example to clarify the concept. They are talking about the musician domain. The domain is explained by the natural language well. For example the natural language says that the musician plays an instrument. The musician ontology can be represented by a semantic network at high level of abstraction (See Figure 1).

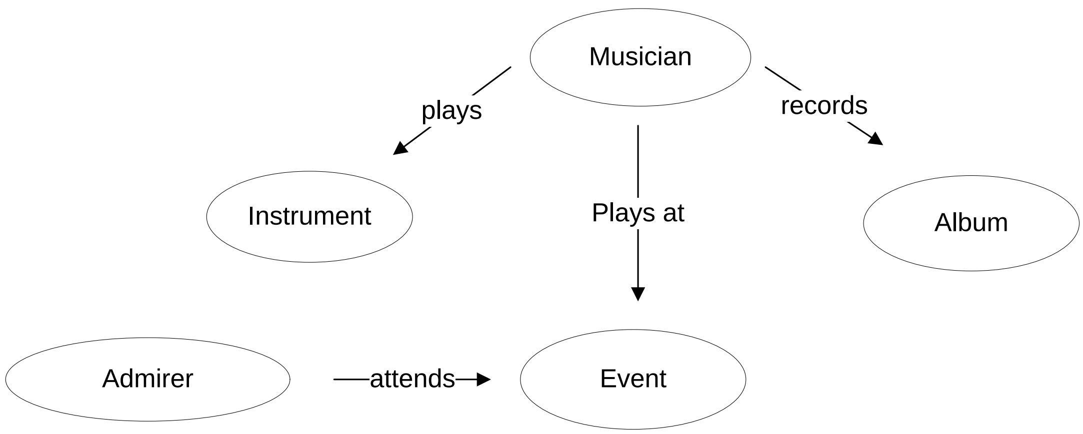

Figure 1 The semantic network of the musician ontology (Gašević et al., 2006)

As can be seen in the Figure 1, semantic network is not formal language. The attributes of the concepts and the characteristics of the relation are not explicitly shown in the figure. To provide more detail about the domain a formal visual language, UML, can be used (See Figure 2).

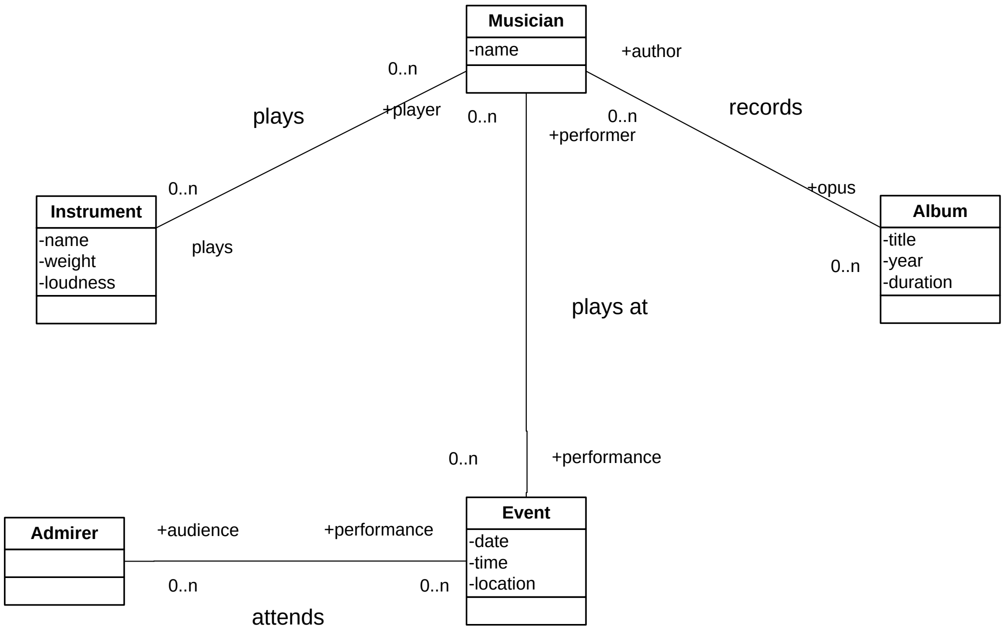

Figure 2 The UML model of the Musician ontology (Gašević et al., 2006)

The computer implementation of the musician ontology with the ontology language Web Ontology Language (OWL) is given in Figure 3.

```
<owl:Class rdf:ID="Event"/>
<owl:Class rdf:ID="Album"/>
<owl:Class rdf:ID="Musician"/>
<owl:Class rdf:ID="Admirer"/>
<owl:ObjectProperty rdf:ID="author">
        <owl:inverseOf>
                <owl:ObjectProperty rdf:ID="opus"/>
        </owl:inverseOf>
        <rdfs:domain rdf:resource="#Album"/>
        <rdfs:range rdf:resource="#Musician"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="player">
        <rdfs:range rdf:resource="#Musician"/>
        <rdfs:domain rdf:resource="#Instrument"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="loudness">
        <rdf:type
rdf:resource=http://www.w3.org/2002/07/owl#FunctionalProperty/>
        <rdfs:domain rdf:resource="#Instrument"/>
</owl:ObjectProperty>
...
```

Figure 3 The computer implementation of the musician ontology (excerpted by Gašević et al., 2006)

Mizoguchi (2001) says that, an ontology is mainly designed to be shared by many people and it has to be objective. The concept explained or modeled in the ontology can be shared between the people because the ontology has hierarchical structure and the knowledge in it can be easily decomposed. The five important qualifications of an ontology are given below (Mizoguchi (2001);

- A common vocabulary
- Explication of what has been often left implicit

- Systematic knowledge which means hierarchical definition of knowledge
- Standardization of concepts by the help of the systematic knowledge
- Meta-model functionality: An ontology helps us as a building block of a model which is used as an abstraction of real world

The current study deals with ontology as a key term. Therefore, the basic literature is covered within this literature review. On the other hand, one can refer books from Gašević et al. (2006) and Gomez-Perez (2004) for deeper knowledge on ontology concept.

1.2 Information Exchange in GIS

As spatial data production is getting cheaper than used to be, more companies started to use GIS to handle their operations. Because these companies may interact between each other, information exchange between these companies becomes one of the major problems. In order to enable information exchange between different GISs, many studies have been performed to construct spatial data infrastructure. Data standardization is beginning steps of spatial data infrastructures and it is driven by several organizations. Open Geospatial Consortium and ISO are two of the major organizations. Both organizations are contributing the problem by preparing sets of standards. These standards help to define geometric data in a way that, all data can be understandable by different GISs.

In order to establish an infrastructure for spatial information in Europe, a proposal was prepared by Commission of the European Communities at 2004 (EU Proposal, 2004). The name of the proposal is Infrastructure for Spatial Information in the European Community (INSPIRE) and it became a directive in 2007 (EU Directive, 2007). In addition many projects related with spatial data infrastructures, interoperability between different systems are supported by European Union Framework Program. These projects can be searched from Community Research and Development Information Service web site (CORDIS, 2010). Besides European Union, projects related with knowledge exchange in GIS domain are supported by National Science Foundations of United States. These projects can be searched by web site of National Science Foundations (NSF, 2010).

1.3 Situation in Turkey

A knowledge exchange is one of the problems that should be paid attention in cities. Inside the city, there are many infrastructures which have some level of interactions between each other. These infrastructures are constructed to deliver indispensible material to the public such as natural gas, water, electricity and telecommunication facilities. Naturally, all of these infrastructures are maintained by different companies. In Turkey, geographic information system construction of these infrastructures has been started in the second half of 90's. Each company has made its own design and implementation decisions. As a result of this, all GIS represents major differences. For instance, GIS are handled by using different tools, so their file formats, data handling capabilities are dissimilar. This diversity results in difficulties in making the GIS's interoperable. In fact, In Turkey, as the history of the GIS establishment for the infrastructure in municipalities is relatively recent; primary concern is not the system interoperability.

The knowledge exchange between different companies is significant because an event happened on these companies may affect each other, which results in good or bad effect on citizen living in cities. Especially if these companies have GIS to model events on it, knowledge exchange should be on GIS.

For instance maintenance operations of infrastructure companies are highly dependent to each other. The gallery system, which makes the infrastructure maintainability easier, has not been constructed in most of the cities in Turkey. Because of this reason the excavation of the ground is required to reach the targeted infrastructure. In other words, if a company needs to maintain or repair its underground element, then it is required to excavate the ground to reach the necessary elements. During the excavation, the infrastructure built by other companies may be damaged by the operator, because of lack of knowledge about the whole infrastructure. Sometimes, the damage may result in sudden interruption of the service and causes money lost. The loss of money could reach up to millions of dollars, and these damages may even result in the loss of operator life. Most of the time, in order to perform a proper maintenance operation, the service of the infrastructure should be interrupted. For example, if a mid-voltage line of the electricity network has some problems, to be able to provide a proper service, the power should be cut off. This power cut off leads to consequences on other networks, such as telecommunication network. To be able to foresee these consequences, systems that are modeled on the GIS environment must have the interoperability.

An importance of knowledge exchange is not limited by only maintenance activities. In cities, there may be some emergent events, such as flood, fire, earthquake and these events may affect the systems. These affect may also have consequences over the companies.

The information exchange between the companies is done through a different organization in Ankara-Turkey, namely, it is the Infrastructure Coordination Headquarter (AYKOME), and the maintenance planning is scheduled by that organization. The duty of AYKOME is to collect the draft maintenance and investment program of the infrastructure companies, make a final investment plan by considering all companies and give necessary permissions to the related companies considering the place where maintenance operations are to be held, especially if excavation is required. AYKOME has a web site and all the maintenance or investment plans are collected over that site. The site has mainly two user interfaces to collect the information related with the maintenance operation. In the first interface, the operator describes the job, the planning date and the steps to complete the job (See Figure 4).

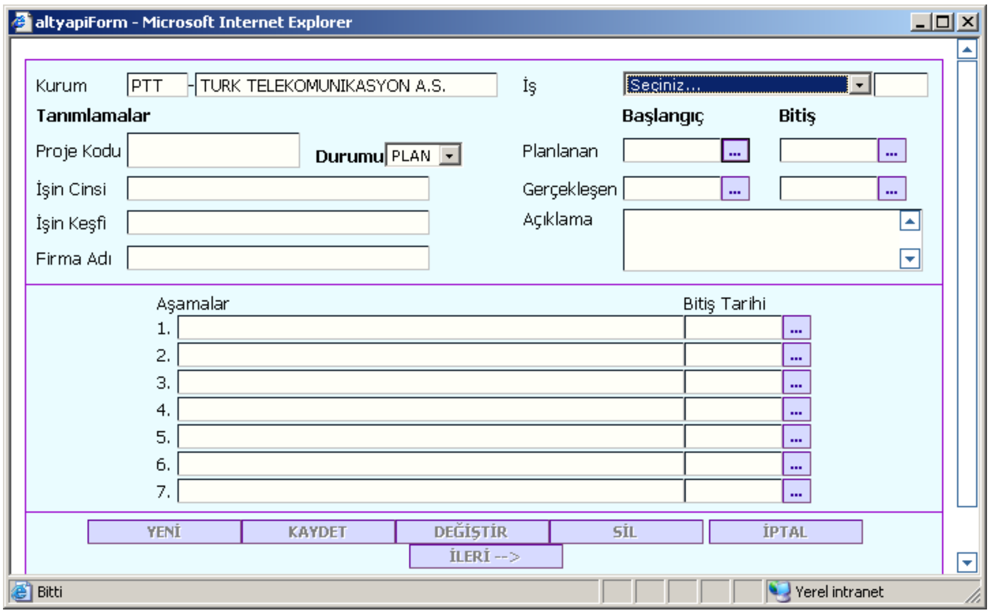

Figure 4 The plan submission interface of AYKOME

The second interface is used to submit the location of excavation. The contact person of an infrastructure company adds the location by using inter-connected drop down lists (See Figure 5).

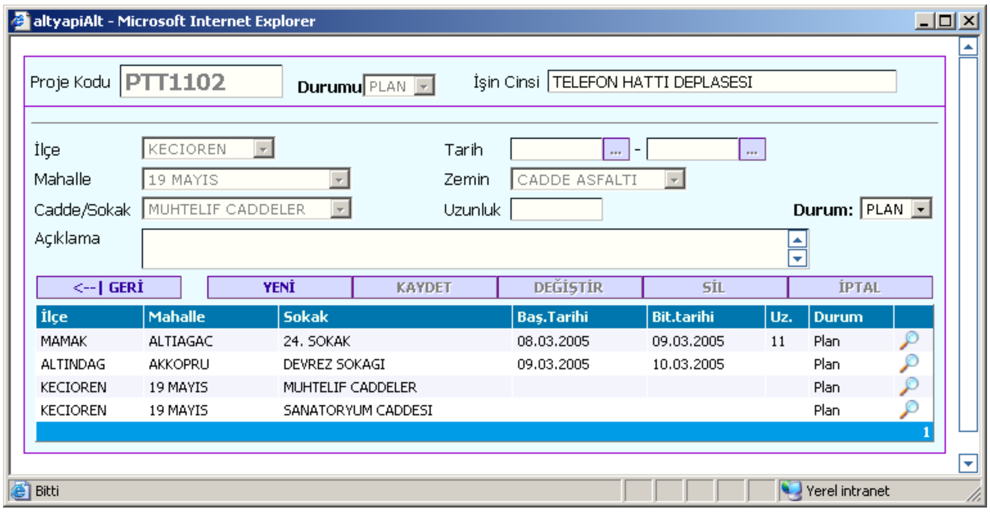

Figure 5 The location submission interface of AYKOME

The system acts like a mediator. The actual maintenance plan is prepared and finalized by the engineers in AYKOME. Therefore, the system does not provide an actual information exchange mechanism; it is rather a repository to store investment and maintenance information of different companies. Moreover, the most important defect of the AYKOME system is its non-GIS based nature.

In Turkey, studies have been performed to obey the rules in ISNPIRE and in 2005, an Action Report about construction of GIS in Turkey was published by Title Deed and Cadastral Works Directorship (Action Report, 2005). In the Action Report (2005), it is said that, the goals of INSPIRE project is to enable users in Europe to access up-to-date geographic data at real time. To make the goal possible, one of the steps that should be followed is to use common standard for geographic data. To achieve common standard, National Geographic Data Exchange Model (UVDM) is provided in the same Action Report. According to Aydinoglu et al. (2009), UVDM can be used as a base data model for different applications from different sectors.

1.4 Motivation and Scope of the Research

At the initial stage of the GIS, spatial and related data production was an important issue, since there were not much data to run those systems. Today, there are enough data to construct and maintain GISs so the main problem in the GIS field has changed. Modeling interactions of different companies on GIS is one of them. If infrastructures such as natural gas, electricity, and water within a city are of concern then it is inevitable that there shall be an interaction between these systems at the operational level. These interactions cause some consequences for both the infrastructures and the clients of those infrastructures. Modeling the interactions at the operational level on the GISs is an important problem, because the consequences may result in dramatic changes in the life of residents in the cities.

The interoperability studies in the literature, so far, have tried to answer the semantic interoperability problem. The naming heterogeneity seems to be the most delicate interoperability problem and most of the proposed solutions discussed the problem from naming heterogeneity point of view. Finding the appropriate geospatial web service and getting the necessary information from the several geospatial web services by a single query is another topic for which an attention is given. However, sometimes the meaning of a word can be changed depending on the situation which brings the contextual information into the scene. For example under normal circumstances, the electricity voltage line should be operational at any time in a day, however, for the maintenance work the voltage on the line needs to be cut off. Therefore, the semantic interoperability problem should be evolved to cover contextual information. The new approach which examines the interoperability problem at the context level has recently been emphasized in the literature.

1.5 Organization of Thesis

The current study includes six chapters. In the first chapter, brief introduction of the knowledge exchange and interoperability problem in the GIS is discussed. In addition, the fundamental knowledge about the ontology concept, which is an essential building block of the current study is provided. Lastly, the motivation behind the thesis and scope of the thesis are given.

In the second chapter, a methodology used in this study is discussed. Aims and objectives of the study, method of data collection, method of analysis, method of ontology construction and expected outcome and contribution of the study are presented.

In the third chapter, detailed information about the GIS interoperability is presented. The solution provided in the literature is discussed and how the context modeling has been handled so far is examined in detail.

In the fourth chapter, the system structure is discussed. First, the electricity and telecommunication networks are demonstrated. The network elements of these infrastructures are presented. Subsequently, the ontologies developed to model these networks are discussed. In addition, the context ontology is explained. Eventually, the rule bases which are used to model the actions to be taken as a result of a maintenance event and emergency event are examined.

In the fifth chapter, the details of the implementation of the study are demonstrated. The three web services, which are for AYKOME, BEDAŞ and Türk Telekom (TT) are discussed. The interactions of these web services with the ontologies are examined. In addition, the add-ons for the GISs and how the GIS's interact with the web services are explained. Last, three sample scenarios are demonstrated.

Finally, in the sixth chapter, the results of the current study are discussed. The importance of the study for the interoperability concept is explained. The place of the study within the seven layer interoperability framework is given. The advantages of the proposed architecture are identified.

CHAPTER 2

RESEARCH METHODOLOGY

In this chapter, aims and objectives of the present research are given. Additionally, data collection procedures and construction of system architecture based on the collected data are discussed. Finally expected outcomes and contribution of the research to both industry and literature are addressed.

2.1 Aims and Objectives

In this study, the interoperability problem is examined from the infrastructure management point of view and dynamic level of interoperability has been tried to be fulfilled at the conceptual and implementation level. To accomplish this aim, system architecture is proposed and implementation of the architecture is performed. The sample location is identified as a district inside the Ankara Metropolitan Municipality; seeing that the infrastructure companies in Ankara Metropolitan Municipality suffer from the consequences of not having interoperable systems at its disposal while performing their maintenance operations and during emergency situations. Currently, the action that should be taken as a result of a maintenance operation is depending on an operator or engineer in the companies and the GIS has no ability to guide the responsible person about the necessary actions. In addition, if any company has a maintenance operation on some location, the company needs to find out if there is any other existing infrastructure. The required answer could not be provided by either the current GIS systems in Ankara or system in AYKOME. Moreover, the interaction of the systems during the emergency case could not be examined on the existing system.

Consequently, in this study, an interoperability model is developed and implemented for the sample infrastructures. These sample infrastructures are determined as Electricity and Telecommunication networks. The sample area has been selected as a small district in Çankaya Subprovince of the Ankara Metropolitan Municipality. The ontology approach is adopted to model both networks, and the maintenance operations and emergency situations are modeled by using context ontologies.

2.2 Method of Data Collection

Two types of information are required for implementation of the current study. The first type is the sample geographic data and the second one is the domain knowledge from the professionals of the field.

The first types of data, sample geographic data, used in this study are gathered via contact people from the infrastructure companies. MapInfo is the GIS tool used in both Electricity and Telecommunication Infrastructure Companies. Therefore to access necessary data, the first connection is made with the distributor company of MapInfo, namely, Başar Computer Systems (www.basarsoft.com.tr) in Turkey. Contact people in both electricity and telecommunication companies are introduced by Başar Computer Systems.

GIS construction for Telecommunication Company has not been completed at the time, when the research was begun. Therefore, before receiving data, 5 months have passed for data production to be completed for at least one of the district in Ankara Metropolitan Municipality. When required telecommunication data were obtained for specific district, the data belonging to the same district were requested from Electricity Company. Both companies do not share attribute data. Especially, client data is kept private by the companies. For this reason, although, the client data would have been used in the study, they were not received from the infrastructure companies. As a result, they are not used for the current study.

Second type of information, domain knowledge about electricity and land based telecommunication networks were acquired by conducting series of interviews made with contact people. During these interviews, building blocks of both networks and details regarding service distribution were received from contact people. In addition, actions taken by companies during maintenance operations and emergency situations were discussed in these interviews. The interviews were not structured. Throughput the process of designing of system architecture, a new interview is scheduled and performed when it is necessary. In other words, when a new question is appeared, new interview is performed.

The detailed explanation about data is given in Section 4.1 and Section 4.2.

2.3 Method of Analysis

No attribute data were acquired in this research; therefore interoperability problem is studied from geometric data point of view.

After examining data belonging to both companies, commonalities are tried to be decided for both networks. Therefore, similar things on both networks are revealed. Because we do not have an attribute data, these similarities are examined from the non-attribute or geometric data point of view. Especially, behavior or duties of network elements are stressed while exploring similarities. These behavior and duties are explained in detail in Section 4.3.1.

2.4 Method of Ontology Construction

Construction methodology of ontologies used in this study follows ontology development guide given in Protégé web site (Noy and McGuinness, 2010). Spatial representation ontology is based on ISO 19107 and is downloaded from Drexel

University web site (ISO 19107 Ontology, 2008). Therefore, it is based on reuse of existing ontology. Construction of other ontologies is started by defining classes and class hierarchy. The next step is definition of properties of classes. During property definition, types of properties are also defined as either object type or data type properties. Finally, for each property, domain and range are defined.

2.5 Expected Outcomes and Contributions

Outcomes expected in this study can be analyzed in terms of two perspectives as literature and industry.

Although, contextual interoperability is frequently addressed in information systems research, semantic interoperability and context based interoperability studies are relatively new in GIS domain. Therefore, this study expected to extent the context-based interoperability literature in GIS domain. Additionally, new and further research would build upon the system architecture and sample implementation that supports context-based interoperability conducted in this study.

In the same way, the results of the study will contribute to the industry. For instance, the architecture proposed in this study will shed light on the interoperability projects of infrastructure companies and municipalities in the future. Another contribution will be regarding GIS privacy in which the details of each GIS are concealed from each other. As the system architecture for interoperability and implementation used in this study ensures GIS privacy, prospective projects can take the advantage of that. With the help of this study, solutions to real life interoperability problems become more possible if desired.

CHAPTER 3

INTEROPERABILITY PROBLEM IN GIS

3.1 What is Interoperability?

By the word interoperability, we don’t only emphasize sharing of data among different information communities. The shared data should be understood and processed or interpreted by all information communities. Bishr (1998) has noted six levels of interoperability between different systems (See Figure 6).

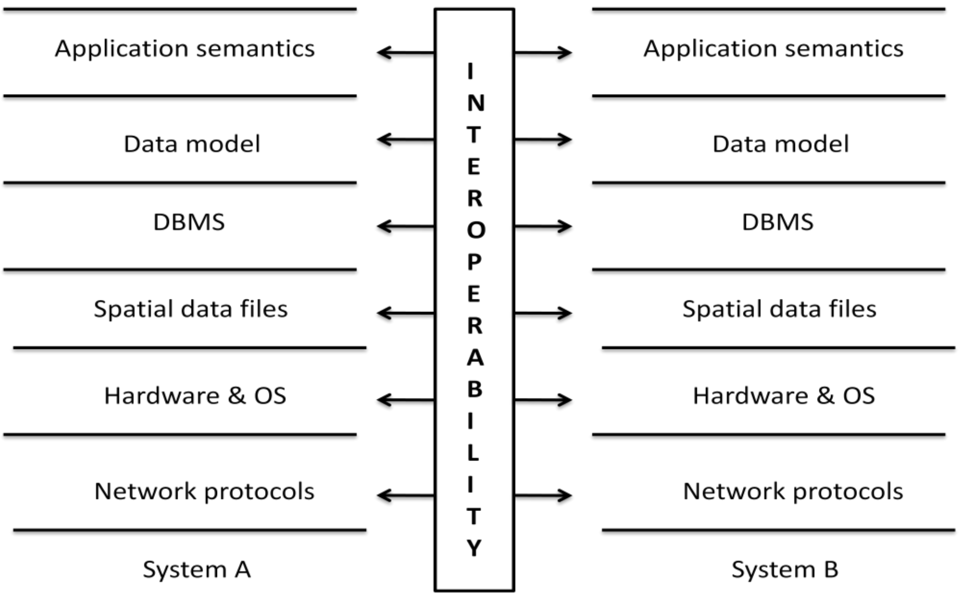

Figure 6 Levels of interoperability in GIS (Bishr, 1998)

The lowest four levels are very much related with the technological background of the systems except for the spatial data files. The very basic prerequisite of the interoperability is the communication of the system over the network, which means that the interoperating systems should be aware of their operating systems and network protocols. On the other hand, for spatial data files level interoperability, the system users can access and use the spatial data files that reside on the other systems. In order to connect the DBMS which is the 4th level of interoperability some common protocols has been invented, such as Microsoft Open Database Connectivity (ODBC). By the help of the ODBC, one user can query different database management systems.

The 5th and the 6th levels are different from the other four levels. Many researchers in the literature pay attention to especially these two levels since 2000. The top two levels are different from the other four levels. On the fifth level, Bishr (1998) mentioned about the virtual global data model which is an abstraction of databases of interoperating system. On the other hand, semantic differences are discussed at the sixth level. Bishr (1998) has divided "Application Semantics" and "Data mode" levels into 3 sub-levels which are Syntactic, Schematic and Semantic. In addition Stuckenschmidt et al. (2000) approached the interoperability problem similar to Bishr (1998). They stated that, to achieve interoperability, syntactic, structural and semantic integration problems should be solved.

3.1.1 Syntactic Heterogeneity and Interoperability

Syntactic heterogeneity problems are related with the data format. In other words, it carries the non-contextual problem. Bishr (1998) has classified the syntactic heterogeneity problem under two parts. One of them is the logical data model and its underlying database management system (DBMS) such as a DBMS having relational data model and object oriented data model. Other one is the representation of the spatial objects in the database.

Much of the commercial systems implement relational data model and object-relational data model. The things or entities in geographic information system are represented in two ways: The raster data structure which is defined as array of regular cells and object data structure in which entities can be point, line or polygon.

3.1.2 Schematic Heterogeneity and Interoperability

Schematic heterogeneity is the structural heterogeneity and related with the homonyms, synonyms, different attributes in database tables. Stuckenschmidt et al. (2000) have described the problems as "different information systems store their data in different structures". Therefore main problem is the different database schema in different systems. For example, a table name can be different in different systems. In addition, the same attribute can be named differently on different systems. A table related with one real world entity can have four columns in one system and ten columns in another system.

In addition to schema conflicts, there can also be data conflicts. For instance, the same data can have different representations such as, same data can have different measurement unit on different systems. In Figure 7, the possible schematic heterogeneities are represented.

I. **Schema Conflicts**
- A. Table-versus-table conflicts
  - 1. One-to-one table conflicts
    - a. Table name conflicts
      - 1) Different names for equivalent tables
      - 2) Same name for different tables
    - b. Table structure conflicts
      - 1) Missing attributes
      - 2) Missing but implicit attributes
    - c. Table constraint conflicts
  - 2. Many-to-many table conflicts
- B. Attribute-versus-attribute conflicts
  - 1. One-to-one attribute conflicts
    - a. Attribute name conflicts
      - 1) Different names for equivalent attributes
      - 2) Same name for different attributes
    - b. Default value conflicts
    - c. Attribute constraint conflicts
      - 1) Data type conflicts
      - 2) Attribute integrity-constraint conflicts
  - 2. Many-to-many attribute conflicts
- C. Table-versus-attribute conflicts

II. **Data Conflicts**
- A. Wrong data
- B. Different representation for the same data (Same representation for different data)
  - 1. Different expressions
  - 2. Different units
  - 3. Different precisions

Figure 7 Schema and data conflict classification (Kim and Seo, 1991)

3.1.3 Semantic Heterogeneity and Interoperability

In Webster online dictionary, semantic is defined as the "meaning in a language" (Merriam-Webster, Semantic). It is very clear that, the meaning can be changed depending on the context. Therefore, the shared understanding of a word is important if we talk about interoperability. Bishr (1998) states that there are two types of semantic heterogeneity. One of them is the cognitive heterogeneity and the other one is the naming heterogeneity. In the cognitive type, the same entity is viewed differently. He gives an example from the road network. For a pavement management group, the number of lanes, the direction of traffic flow is important. However, the same road network can be used for address information for marketing group. On the other hand, in the naming heterogeneity, the same real world entities can be named differently. For example, the words "watercourse" and "river" describe the same entity.

Semantic heterogeneity may emerge from the representation of the object. Harvey et al. (1999) have given a very good example of the situation. Researchers underline the existence of several standards for transportation definition in Europe. One of the standards is the Official Topographic-Cartographic Information System (ATKIS) of Germany and the other one is Geographic Data Files (GDF) which is a European standard. In GDF the term "road" consists of road, railways, waterways, junctions, but in ATKIS waterways is not a "road". In GDF two flow directions of the traffic are represented by double line but in ATKIS single line is used for traffic flow. So if the query is sent to both systems for a Baker Street, then the responses will be very different (See Figure 8).

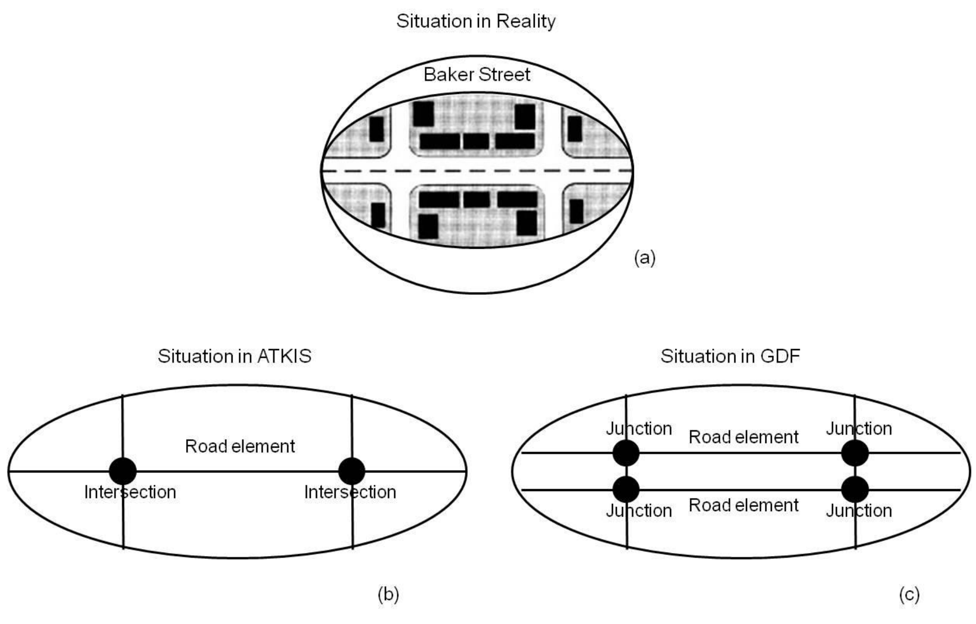

Figure 8 ATKIS-GDF comparison (Harvey et al., 1999)

Similarly, Lutz and Clein (2006) have conducted research on semantic heterogeneity. They have intended to identify the water level of the Elbe River at a given instance at the given location. There are three organizations which offer the water level in the rivers. The organizations give the information as World Feature Service (WFS). Different keywords are used to define the same entity such as water level and depth. The keywords in the metadata used in WFS are provided in Table 1.

Table 1 The keywords used in the metadata of the three organizations WFS (Lutz and Clein, 2006).

Organization	Keyword
Federal Agency for Hydrology	Water level, measurement, Elbe
Electronic Information System for Waterways	Control point, tide scale, river, depth
Czeeh Hydrometeorological Institute	Watermark, measurement gauge, Elbe

To solve the semantic issue, Kuhn (2005) has stated that, there must be shared understanding of the message which two systems exchange. Bittner et al. (2005) have suggested two different ontology based approaches to solve the semantic interoperability. One of them is to share the common terminology by all the systems. In this approach, the shared common terminology is specified by the metadata standards. If a system has a terminology different from the common terminology then a transformation mapping is needed. In the other approach proposed by Bittner et al. (2005) the systems are using the terminology whose semantic is explained by logic-based ontology. In addition, there is a reference terminology which has also based on the logic based semantic.

3.2 Metadata

The prefix meta in epistemology is used to mean about (its own category), so metadata is meaning data about data (Wikipedia-Meta, 2010). In other words, metadata explains the data in the information store. For example, if you have a geographic data, its lineage information which can be the date of creation, its accuracy and the analysis applied to produce the data are part of the metadata about the geographic data you have.

Sheth (1999) states that, using metadata brings two major advantages:

- The content of the data in the information store can be captured independently from its representation

- The domain knowledge which describes the information domain to which the data belongs can be represented.

Kashyap et al. (1995) have classified metadata into three major subgroups;

- Content Dependent Metadata: The metadata describes content dependent information. For example, the size of some text.
- Content Independent Metadata: The metadata describes content independent information. For example, the sensor used to record the image.
- Content Descriptive Metadata: This kind of metadata is used to describe the content of the data. For instance, the textual annotations describe the contents of an image.

Metadata is a major component of any heterogeneity solving mechanism. Therefore, many metadata studies have been performed so far in the geographic information world. One of them is the ISO 19115 (2003) standard. ISO 19115 defines;

- Mandatory and conditional metadata sections, metadata entities and metadata elements

- The minimum set of metadata required to serve the full range of metadata applications (data discovery, determining data fitness for use, data access, data transfer, and use of digital data)

- Optional metadata elements – to allow for a more extensive standard description of geographic data, if required

- A method for extending metadata to fit specialized needs.

The information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference and distribution of geographical data are provided with that standard. Each of the items above is provided as UML Metadata packages (See Figure 9).

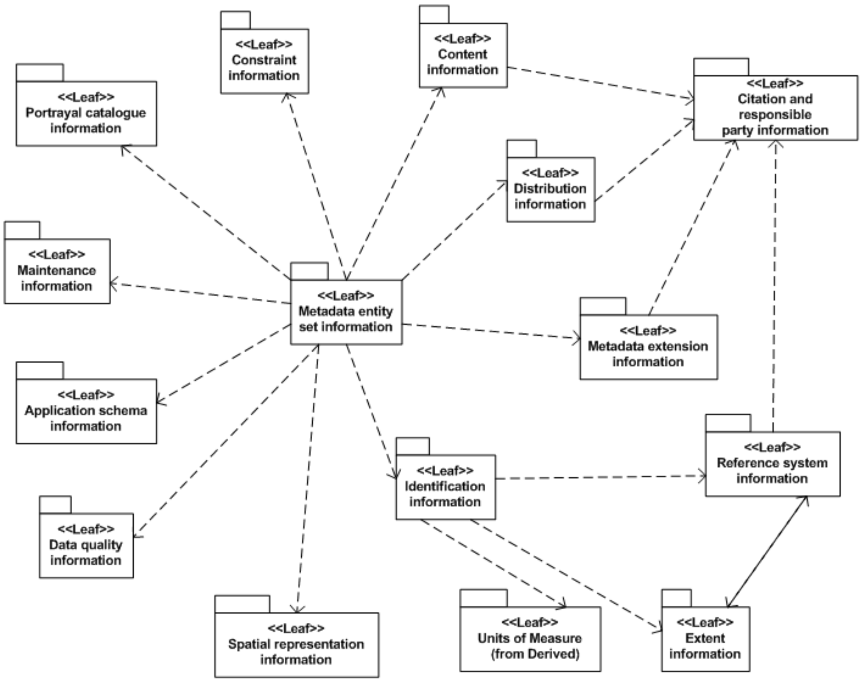

Figure 9 The metadata packages in ISO 19115 (ISO 19115, 2003)

Each package in Figure 9 is composed of classes and they are represented by UML class diagrams. In Figure 10, the content of the metadata set information package is presented. Similar to Metadata entity set information package, other packages are covered in detail in the ISO 19115 standard.

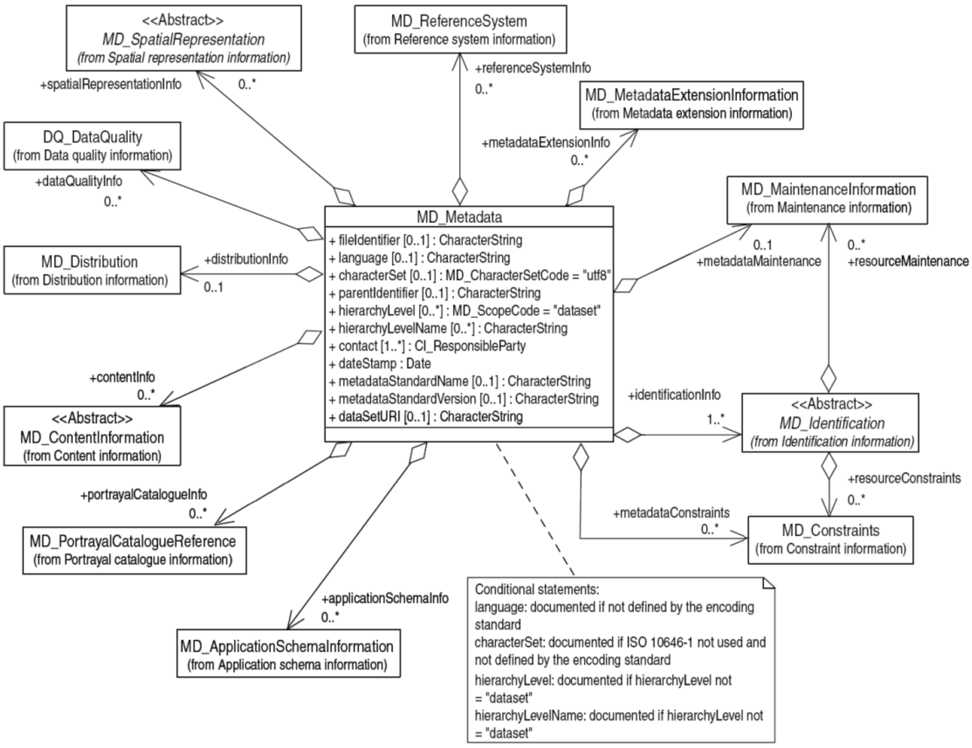

Figure 10 The metadata entity set information (ISO 19115, 2003)

3.3 Semantic Registry and Feature Type Catalogue

Stock et al. (2010) define Feature Type Catalogue (FTC) as "Feature Type Catalogues are formal structures for representing the categories of geographic features or geographic concepts, and may provide support for any geographic information system or data sharing exercise, because they identify the concepts with which the system deals”. Therefore it can be used as a key element in data sharing studies.

In their study, Stock et al. (2010) research about using semantically-reach FTC in a geospatial registry for Spatial Data Infrastructures (SDI). Semantically-reach FTC contains information about feature types, their attributes and operations. In addition various types of relationships between feature types are also included in semantically-reach FTC. In other words, attributes, associations and operations of feature types form the semantic of a feature and called as Semantic Registry (See Figure 11). In the figure operations and attributes are linked by three mechanisms.

- “trigerredBy” mechanism is used to make an operation possible when an attribute value is changes.
- “affects” mechanism explains a possible effects of an operation to a value of an attribute.
- “observes” mechanisms explains an observation of an attribute value.

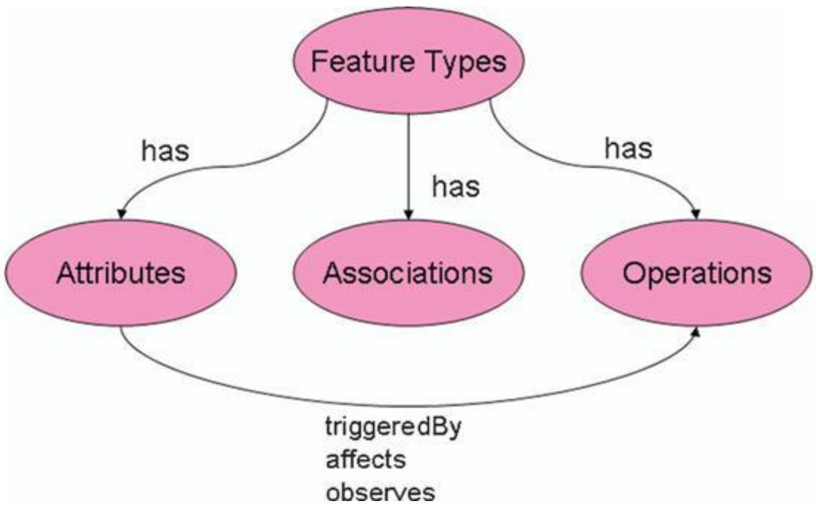

Figure 11 Semantic Registry (Stock et al., 2010).

Authors define that, FTC can be considered as lightweight ontologies and state, it is not considered to be as full-weight because it does not have ability to define axioms and does not have formal language (Stock et al., 2010).

The study of Stock et al. (2010) based on the ISO 19110. ISO 19110:2005 is Geographic Information- Methodology for Feature Cataloguing and the way for cataloguing feature types is defined by ISO 19110:2005. In addition, it also specifies how the classification of feature types is organized into a feature catalogue (ISO 19110, 2010).

In addition to content of a Semantic Registry, Stock et al. (2010) define also registry interface. The duty of interface is to allow users to access and navigate the Semantic Registry by telling users what format they should use and what response to expect. Therefore, Semantic Registry can be used from different systems and users.

There are two major drawbacks of the Stock et al. (2010) study which are stated by authors also. First, the semantic description of an object is expressed by mechanism that contains reasoning. Reasoning mechanism is not possible by their current research and authors are searching for the reasoning possibilities for future works. Users implementing FTC may add new attributes to the FTC for their systems, which can be a problem for the interoperability with other systems.

3.4 GIS Interoperability Studies

The use of metadata in GIS has become very popular, especially after the release of ISO 19115 standard in 2003. However, metadata standard is not sufficient for all types of implementation, since, there are lots of fields which are not defined in the metadata. These fields especially include non-spatial attributes and should be added to the metadata specification. There are various methods of adding non-defined fields to the metadata. Schuurman and Lescczynski (2006) report adding the additional metadata into ISO 19115 as ontology based fields.

In the Elbe River example mentioned in Semantic Heterogeneity and Interoperability section, Lutz and Clein (2006) have reported solving the problem by using an ontological approach. In solution, domain ontology, application ontology and ontology based reasoner are used to formulate user queries and retrieve the desired information from the systems.

Another study about the rivers is done by Pundt and Bishr (2002). One of European Union projects, namely, GIPSIE is relevant with a framework discussed in their study. They have examined the stream surveying whose data are used by many organizations. It is clear that, each of the organizations has its own understanding about the domain. Therefore, Pundt and Bishr (2002) have presented a design of domain ontology for the category stream to achieve the shared understanding.

Similarly, Visser et al. (2002) have also developed a methodology, to integrate two land cover catalogues which are CORINE and ATKIS. Authors have reported two aims in their study. The first is to provide the integrated views of the two catalogues, and the second is to verify one catalogue against other. To accomplish the aims, for each catalogue, they have defined the ontology by defining catalogue concepts hierarchically, such as plants, forest plants, and forest trees. For each concept, they also have defined necessary and sufficient conditions to define membership prerequisites of that concept. For example, in ATKIS, a forest has to be at least 10 ha in size. By defining ontology, they have offered a methodology to solve the semantic conflict between two catalogues.

Stoimenov and Djordjevic (2005) have proposed GeoNis framework to overcome the interoperability problem. To handle the schematic and syntactic heterogeneity, they have used the Open Geospatial Consortium (OGC, 2010) metadata standards about spatial data. In addition, they have also used an ontology-based approach for semantic interoperability. For each Geo-Information Community (GIC), a local ontology is constructed. The local ontologies interoperate with each other by using the translator/wrapper and mediator. The main tool to enable the framework correctly is the GeoNis server which contains top level ontology. The top level ontology consists of a shared database which results in the common understanding of the data for each GIC. The integration mentality of the GIC through GeoNis framework is shown in Figure 12.

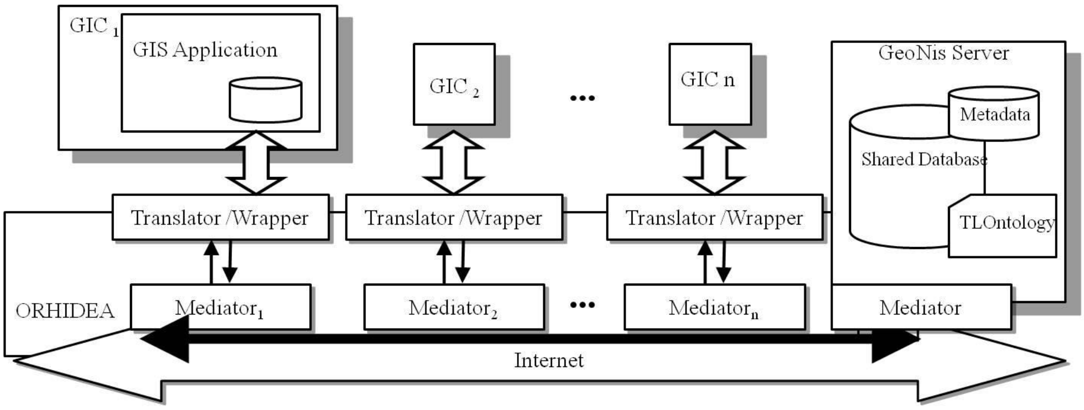

Figure 12 The GeoNis integration framework (Stoimenov et al., 2005)

Lutz et al. (2009) have proposed a solution to semantic heterogeneity problem, which is based on ontologies and logical reasoning. They have examined the layering and corresponding age of rocks, called stratigraphy, as a problem area. As different authors use different stratigraphic classification at different time in history, different types of heterogeneity exists in the problem area. In addition, Lutz et al. (2009) have also dealt with the discovery and retrieval of the proper information from the data sources. The shared vocabulary and application ontologies are used to setup ontology structure and the schemas of the data sources and application ontologies are mapped. In the study, subsumption reasoning has recruited to find a concept that matches specific query concepts, because the vocabularies from different classification systems are all derived from the shared vocabulary. A user query is transformed to the description logic (DL) concepts by the function implemented by the authors. After converting user query to a DL query, ontology based reasoner finds a matching concept and then the map of the desired rocks is retrieved from the web map service.

Kuhn (2003) talks about importance of semantic reference system to achieve semantic interoperability. His study is supported by European Commission in the ACE-GIS (IST-2002-37724) and BRIDGE-IT (IST-2001-34386) projects. He defines three semantic interoperability problems between information providers and requesters:

- Service providers need to be able to determine whether a data source offers useful semantics for a planned service

- Client services need to be able to determine whether a given service offers useful semantics as input to their processing

- Human users need to be able to determine whether a service provides useful semantics to answer a question

Author addresses semantic reference system for both requester and providers for the solution.

Poveda et al. (2004) state that ACE-GIS (Adaptable and Composable E-Commerce and Geographic Information Service) is European Union supported project and provides service infrastructure to provide better tools for discovery, development, deployment and composability of distributed web service. These web services are combination of geographic information and e-commerce services. In the project, semantic interoperability tools are provided to help developers find semantically appropriate web service and correct usage of them. The key part of the project for solving semantic heterogeneities is Semantic Reference Systems. To make search facilities easier for appropriate web service, services are tagged with concepts defined in application ontologies. The meaning of service operators and input and output data types are explained by these concepts. Semantic Reference Systems make tagging web services and data types.

There are semantic interoperability studies awarded by National Science Foundation (NSF). One of them is Spatial Ontology Community of Practice: an

Interdisciplinary Network to Support Geospatial Data Sharing, Integration, and Interoperability which has an acronym INTEROP (INTEROP, 2010). In this study, an interdisciplinary network is used as glue between geospatial communities to come up with well designed formal ontologies relying on agreement between communities. Therefore, common ontologies constructed for different communities are thought as a solution for semantic interoperability problem.

Another NSF awarded project is Geoscience Information Network (GIN) (GIN, 2008). In this project, geospatial data interoperability is aiming between different geo databases. Allison et al. (2008) state that, one of the key components of GIN is common interchange formats to encode information for transmission which makes geospatial data interoperability possible.

Differently, Fallahi et al. (2008) have concentrated on the geo-services. Geo-services contain field-based geospatial data. In the study, the properties of each geo-service have been described by ontologies and the DL queries have been used to find the desired geo-service. Similarly Bernard et al. (2005) propose geographic information services based architecture for European Spatial Data Infrastructure. In their study, one of services is Thesaurus Service and it provides a functionality needed for semantic interoperability.

Geographical database integration and spatial data integration are another research field with interoperability requirements. Boucher and Zimanyi (2009) have reported about establishing conversion between different geographic file formats. Their study was based on OWL and semantic translation. They have used ontology for deciding on a map between the source and target formats. Cruz et al. (2007) have proposed an agreement maker by which the global (source) ontology and local (target) ontologies are mapped and an agreement document is produced. By the help of the agreement document, more than one spatial database is queried by single query. Another study about integrating different database schemas from different GIS application has been conducted by Suryana et al. (2009). They have suggested using a global concept that represents two different classes from two different schemas but representing the same entity. They have used ontology to understand the similarity of concepts from different database schemas. In addition, XML and Geography Markup Language (GML) have been used to perform data transformation.

Mohammadi et al. (2010) have also examined spatial data integration. They have proposed a tool to deal with both technical and nontechnical issues of spatial data integration. The nontechnical issues include institutional, policy, legal and social issues. The tool collects information from different spatial data sources and processes them. During processing, the criteria or measures about data integration are given by the operator which is used to extract the data on different systems and metadata of those data. Then an integration report has been extracted by the tool. If there is no incompliancy, then the display method of the tool is invoked to display the integrated data.

Another important aspect of the semantic interoperability is to use the context information. Bouquet et al. (2004) have stated that “contexts are local models that encode a party’s subjective view of a domain”. Therefore, there can be more than one point of view of the same domain which means that the context information should be considered while defining semantics.

Cai (2007) have applied context-based approach in the geospatial domain. He has used context alignment and common contextual knowledge instead of common ontological commitment to reach the semantic interoperability. But he has not abandoned to use the ontology approach. Instead, the ontology is surrounded by contextual knowledge. Figure 13 provides an example of the context space related with shopping given by Cai (2007). In the figure C_1/O_1 represents the “Shopping”, $C_{1,1}/O_{1,1}$ is for “Grocery Shopping” and $C_{1,1,1}/O_{1,1,1}$, $C_{1,1,2}/O_{1,1,2}$ represent “Grocery Shopping by car” and “Grocery Shopping by walking” respectively. Therefore each context contains also ontological knowledge.

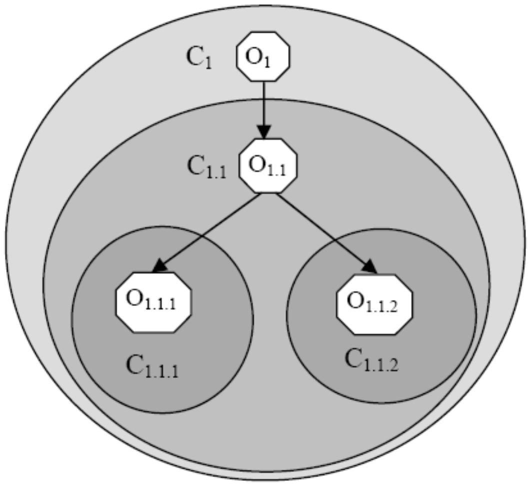

Figure 13 Cai’s use of context (Cai, 2007)

For the interoperability of the information systems, Tolk et al. (2009) have proposed a framework. They have defined 7 levels of interoperability between complex systems. These levels are shown in Figure 14.

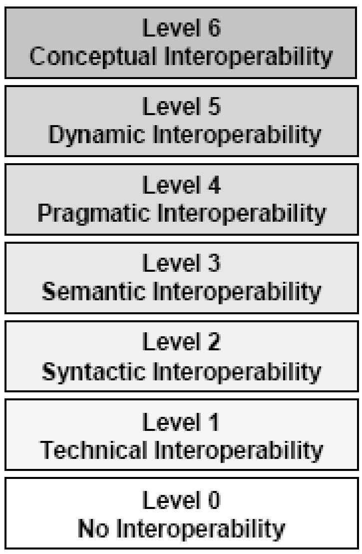

Figure 14 Levels of interoperability (Tolk et al., 2009)

Tolk et al.'s (2009) framework extends the Bishr's (1998) study remarkably. Technical Interoperability level Tolk et al. (2009) covers first two levels of Bishr's (1998) levels. These two levels are Network Protocols and Hardware & OS levels. At the syntactic level, Tolk et al. (2009) mention about exchanging data by using correct protocol and forming elements into a format satisfying the correct protocol. In other words, in this level, data level heterogeneity is solved. Therefore in Spatial Data Files and Data Model Level of Bishr's (1998) framework covered in the Syntactic Interoperability Level. The Semantic level of Tolk et al.'s (2009) is corresponding the highest level of Bishr's (1998) study. The DBMS layer of Bishr's (1998) is mentioning about the communication of different Database Management Systems used by different protocols. Therefore DBMS Level is partly related with Level 1 and Level 2 of Tolk et al.'s (2009) framework.

In Tolk et al.'s (2009) framework, semantic interoperability itself is not the end point to be reached. There are three interoperability levels over semantic one and these levels start with the context information. The pragmatic interoperability is reached when the interoperating systems are aware of the context and the meaning of the information exchanged between each other. Therefore, context information should be defined clearly. In addition in dynamic level, systems can sense the context changes. In another study, Tolk et al. (2008) have defined the concepts of ontological width and depth. As the focus of ontology extends from a single system to all societies of systems within a domain, the width of ontology extends from low to high. In other words, the width of the ontology is related with the number of interoperating systems. On the other hand, the depth is related with the level of data exchange happening within the interoperating systems. As the level of data exchanges increases from system level to domain level, then the depth also increases. The exchanging entities can be data, processes, and assumptions while the systems are interoperating. The width and depth concepts are illustrated in Figure 15.

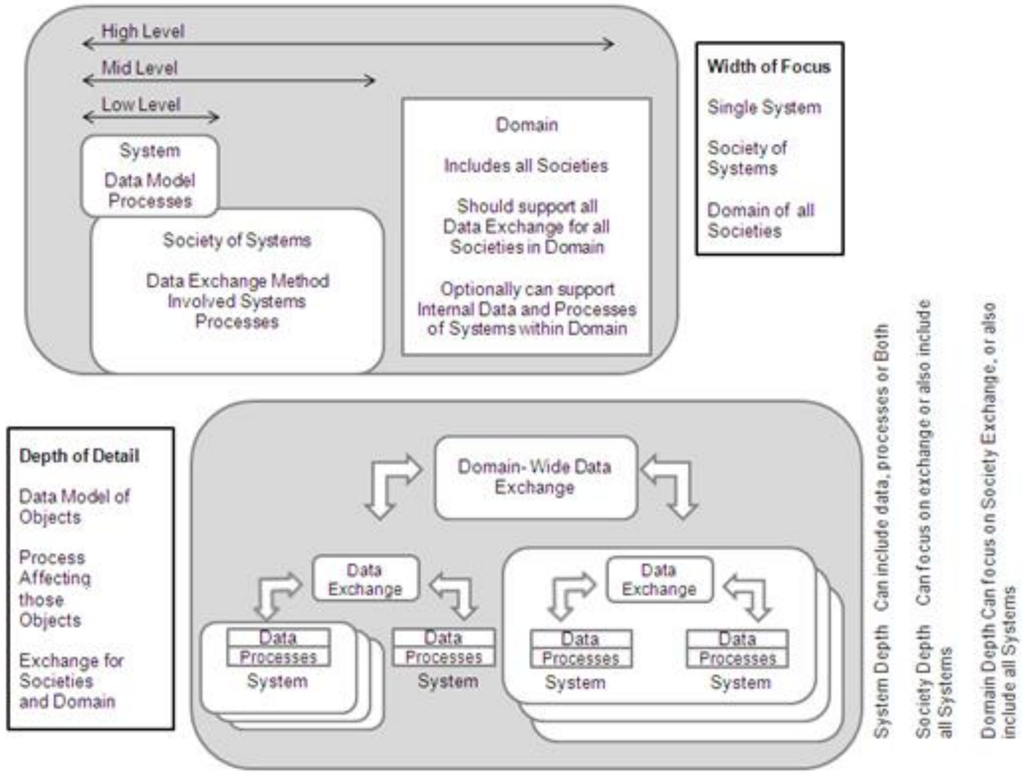

Figure 15 The width and depth of ontology (Tolk et al., 2008)

As the width and depth of the ontologies increase, the ontological rules help interoperation. These rules can be internal or external. Internal rules are determined within the formal ontology; while, external rules define the interaction between the systems.

The seven layers interoperability model proposed by Tolk et al. (2009) is a hierarchical interoperability model. In other words, to reach the 4^{th} layer, the first three layers should be accomplished to a large extent. In the same way, Manso et al. (2009) have proposed a 7 layer interoperability model for the spatial data infrastructure. The layers are technical, syntactic, semantic, pragmatic, dynamic, conceptual and organizational and there is no hierarchy between these layers (See Figure 16). Manso et al. (2009) define the definition of layers different from Tolk et al. (2009). In pragmatic level, they talk about capability of different systems to use application or service interfaces to invoke methods or procedures. In addition, in dynamic interoperability level, they talk about system awareness. They think that, in this level, systems should monitor each other and can respond to changes in the transfer of information. However they do not mention about the context changes in both levels. Authors have used the elements of metadata standards ISO 19115 (2003) and ISO 19139 (2007) to relate the different interoperability levels to each other.

As interoperability aims information exchange between different systems and meaning of information varies depending on context in which a system exists, context handling is an important part of an interoperability study.

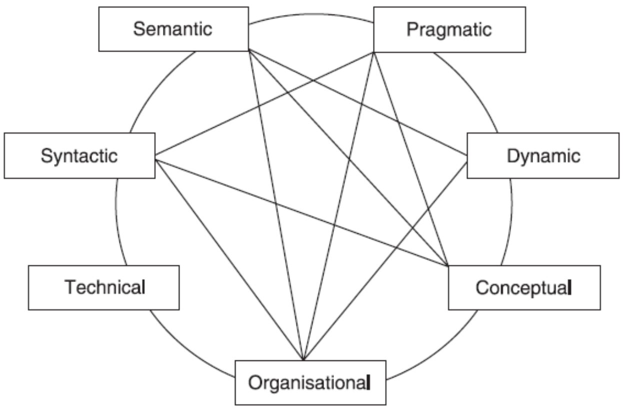

Figure 16 The interoperability model of Manso et al. (2009)

3.5 Geographic Data Sharing

GIS softwares have different data formats from each other. In order to use geographic data on different GIS softwares, either a data should be converted or common data format should be used. Geography Markup Language (GML) of the OGC has an XML grammar and used in a geographic system as a modeling language. In addition, it is an open interchange format for geographic data on the Internet (Geography Markup Language, 2010).

The Web Feature Service (WFS) is an important alternative for sharing geographic data, as in WFS the geographic data is defined based on the GML (Vretanos, 2005). In addition, it is web based which means regardless of where the GIS reside, it can be reached.

3.6 Context Modeling

Studies of Tolk et al. (2008) and Manso et al. (2009) have proven that context awareness is important for information system interoperability. Consequently, context modeling is a significant issue. There are different types of context models in the literature. First, the Web Ontology Language (OWL) based models are described. The model used the extension of the OWL schema is described afterwards. The third approach for the context modeling is the one using a representation language other than OWL.

3.6.1 Context Model Based On OWL

3.6.1.1 CONON Model

Wang et al. (2004) identify location, user activity and computational hold entity as the fundamental context information. They said that the information about the executing situation can be captured by the help of that context information. They divide their context model into two parts as the upper ontology and the specific ontology. As shown on the Figure 17, the upper ontology captures the general features of the fundamental context entities, and it is called as context ontology (CONON).

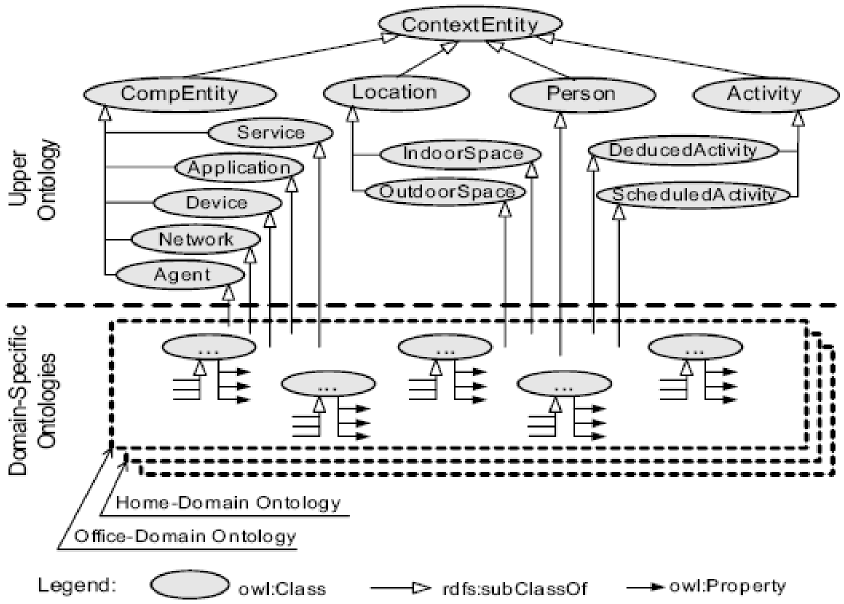

Figure 17 Partial definition of the CONON upper ontology (Wang et al., 2004)

The specific ontology explains the details of the general concepts. For each domain, there is one specific ontology. Figure 18 explains the partial definition of the specific ontology for home domain.

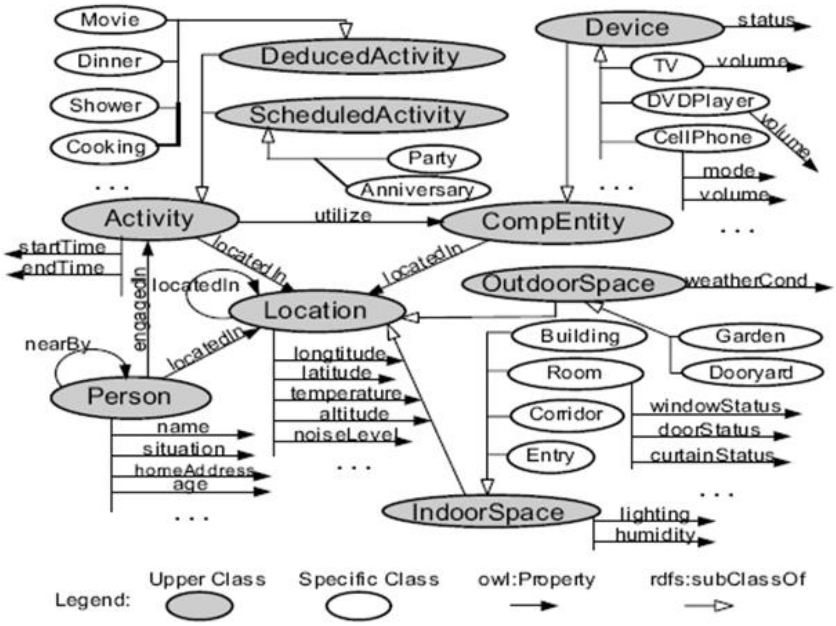

Figure 18 Partial definition of the specific ontology for home domain (Wang et al., 2004)

The study of Wang et al. (2004) supports two types of reasoning. One of them is for testing the consistency of the context information in the ontology, and the other one is for deriving the higher level context information from existing information. In addition, reasoning is based on CONON and specific ontology of the domain and additional user defined context reasoning rules whose examples are given in Figure 19.

Situation	Reasoning Rules
Sleeping	(?u locatedIn Bedroom) ∧ (Bedroom lightLevel LOW) ∧ (Bedroom drape Status CLOSED) ==> (?u situation SLEEPING)
Showering	(?u locatedIn Bathroom) ∧ (WaterHeater locatedIn Bathroom) ∧ (Bathroom doorStatus Closed) ∧ (WaterHeater status ON) ==> (?u situation SHOWERING)
Cooking	(?u locatedIn Kitchen) ∧ (ElectricOven locatedIn Kitchen) ∧ (ElectricOven status ON) ==> (?u situation COOKING)
Watching TV	(?u locatedIn LivingRoom) ∧ (TVSet locatedIn LivingRoom) ∧ (TVSet status ON) ==> (?u situation WATCHING TV)
Having Dinner	(?u locatedIn DiningRoom) ∧ (?v locatedIn DiningRoom) ∧ (?u owl:differentFromT ?v) ==> (?u situation HAVINGDINNER)

Figure 19 The user defined context reasoning rule (Wang et al., 2004)

3.6.1.2 mySAM Model

Another study for context modeling comes from Bucur et al. (2005), and called mySAM. In this study, context aware applications are based on the agent based architecture and agents are working on the handheld devices like PDA. Context management, acquisition and reasoning are separated, because, the processing power of these kinds of devices are not powerful enough to perform all these operations. The context awareness in the Bucur et al. (2005) is handled in four layers (See Figure 20).

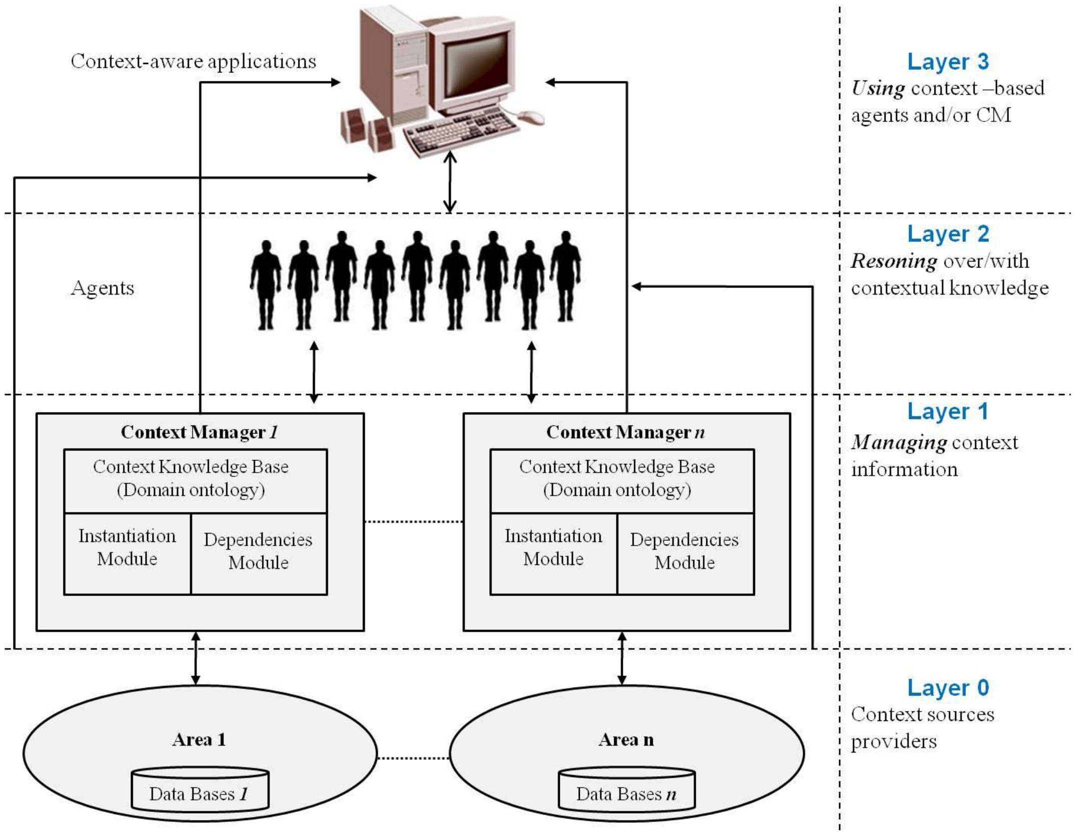

Figure 20 Global architecture for context aware applications (Bucur et al., 2005)

At Layer 0, the context is retrieved from the sensors in the environment. At Layer 1, context information is managed. The agents are placed on the Layer 2 and they reason about the context. At Layer 3, there are context aware applications which use agents at the Layer 2. In the architecture of the study, agents are interacting with other agents, environment and the users. Environment, interaction, organizational and user related context are defined, so agents can sense the environments and reason about these contexts while make decisions.

Instead of defining context as the properties of an entity (e.g. property “status of a meeting” and entity meeting), Bucur et al. (2005) define context attribute concepts. Context attribute explains the information which defines one element of the context such as ActivityLocation, NamePerson and ActivityDuration. While defining each attribute, the #ContextAttribute class is defined. This class contains information;

- The name of the attribute
- The necessary parameters for instantiation
- The value domain of the attribute.

In addition to the #ContextAttribute class, the domain ontology covering all the concepts is also provided in the study. In the domain ontology #Entity is the top class. The #Person, #Group, #Room, #Activity classes are all derived from the #Entity class. The attributes of these classes are subclasses of the #ContextAttribute class. In addition the restrictions for each attribute are also defined. For instance, the context attribute RoleOfPersonInGroup is described as follows:

- Name = "RoleOfPersonInGroup";
- NoEntities = 2 = { #Person; #Group}
- valueType = #Role (value for this attribute is an instance of the class #Role);
- multipleValues = "false" (a person can only play one role in a group).

3.6.1.3 CoBrA Model

Another context modeling approach is CoBrA which is a "context broker architecture" to support context aware computing in "intelligent spaces" (Chen et al., 2003). The major responsibilities of the broker are;

- Get context information from various sources
- Reason about the acquired context information

- By using common ontologies, share the context information among the distributed agents

- Protect the privacy of the users.

By considering these responsibilities, there are four functional components defined in the study;

- Context Knowledge Base which is a persistent data store for context knowledge

- Context Reasoning Engine which make inference about the context knowledge base

- Context Acquisition Module which is used to acquire context from the external sources

- Privacy Management Module which is a set of communication protocols and behavior rules to protect the privacy of the user.

The CoBrA ontology has four distinctive but related themes. These are the concepts that define physical places and their associated spatial relations, the concepts that define agents, the concepts that describe the location contexts of an agent and the concepts that describe the activity contexts of an agent. The classes and properties of the ontology are given in Figure 21.

CoBrA Ontology Classes		CoBrA Ontology Properties	
“Place” Related	Agents’ Location Context	“Place” Related	Agents’ Location Context
Place AtomicPlace CompoundPlace Campus Building AtomicPlaceInBuilding AtomicPlaceNotInBuilding Room Hallway Stairway OtherPlaceInBuilding Restroom Gender LadiesRoom MensRoom ParkingLot	ThingInBuilding SoftwareAgentInBuilding PersonInBuilding ThingNotInBuilding SoftwareAgentNotInBuilding PersonNotInBuilding ThingInRoom SoftwareAgentInRoom PersonInRoom	latitude longitude hasPrettyName isSpatiallySubsumedBy spatiallySubsumes accessRestricted- ToGender lotNumber	locatedIn locatedInAtomicPlace locatedInRoom locatedInRestroom locatedInParkingLot locatedInCompoundPlace locatedInBuilding locatedInCampus
“Agent” Related	Agents’ Activity Context	“Agent” Related	Agents’ Activity Context
Agent Person SoftwareAgent Role SpeakerRole AudienceRole IntentionalAction ActionFoundInPresntation	PresentationSchedule EventHappeningNow RoomHasPresentationHappeningNow ParticipantOfPresentation- HappeningNow SpeakerOfPresentationHappeningNow AudienceOfPresentationHappeningNow PersonFillsRoleInPresentation PersonFillsSpeakerRole PersonFillsAudienceRole	hasContactInformation hasFullName hasEmail hasHomePage hasAgentAddress fillsRole isFilledBy intendsToPerform desiresSomeone- ToAchieve	participatesIn startTime endTime location hasEventHappeningNow invitedSpeaker expectedAudience presentationTitle presentationAbstract presentation eventDescription eventSchedule

Figure 21 The classes and their properties in the CoBrA ontology (Chen et al., 2003)

“Place” class represents the physical location on a university campus. It has longitude, latitude and hasPrettyName attribute. In addition, it participates in the spatiallySubsumed and isSpatiallySubsumedBy relation. Places are also having activities and events and have two subclasses, namely, AtomicPlace and CompoundPlace.

“Agent” class has two subclasses, namely, Person and SoftwareAgents. The Person is for human agents. Agent class has property hasContactInformation which is also has subproperties hasFullName, hasEmail, hasHomePage and hasAgentAddress.

“Role” class is an abstract class which represents the all possible roles that an agent can play. It has two subclasses which are SpeakerRole and AudienceRole and has two properties which are fillsRole and isFilledBy.

“IntentionalAction” class explains the all defined actions. The instances of this class can be associated with either an instance of the Role class or Agent class. This association is performed by the help of the object properties intendsToPerform or desiresSomeoneToAchieve.

In CoBrA ontology, some of the classes explain the agents’ location context which means a collection of dynamic knowledge that describes the location of an agent. The location property of an agent is modeled by the property locatedIn whose range is Place. In addition, locatedIn property has two sub-properties, namely, locatedInAtomicPlace and locatedInCompoundPlace.

Activities in which the agents participates, eg. meeting and presentation are described by the Agents’ Activity Context. These activities are assumed to have a schedule. For instance, a presentation’s schedule is defined by PresentationSchedule class. To specify the place of a presentation, PresentationSchedule class is related with the locatedInAtomicPlace and locatedInCompoundPlace classes. In addition, in order to represent invited speaker and audience, invitedSpeaker and expectedAudience properties are also defined. Moreover, PresentationSchedule class has also presentationTitle and presentationAbstract properties.

By these classes and properties, the dynamic conditions that happen on the university campus can be modeled. For example, if a person has a presentation in one of the rooms in the campus, and save it on his PDA’s calendar, then sensors on the campus can obtain this schedule information from his PDA. In addition, if person is in the presentation room at the time of presentation, the agents take an action for adjusting the light level in the room and for starting the presentation from computer.

3.6.1.4 SOUPA Model

Another interesting work on context modeling is the SOUPA (Chen et al., 2004). SOUPA stands for the standard ontology for ubiquitous and pervasive applications and it consists of two related set of ontologies. SOUPA Core contains generic vocabularies that are valid for different applications. SOUPA Extension is derived from generic concepts and defines additional vocabularies to support specific applications. The SOUPA ontology is given in Figure 22.

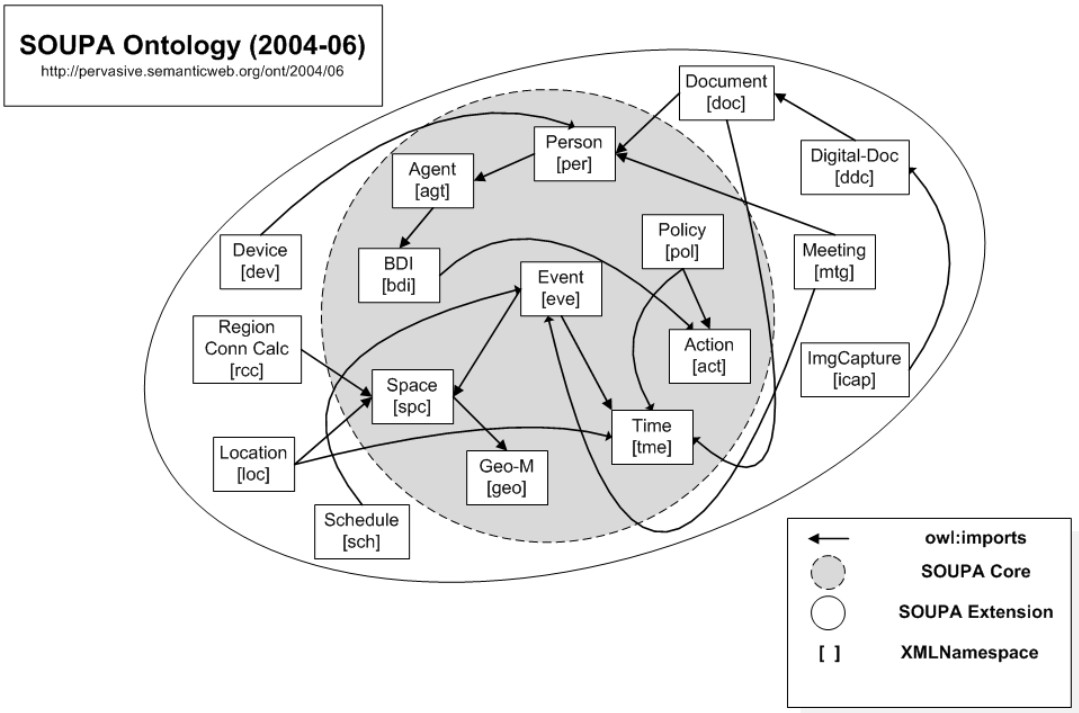

Figure 22 The SOUPA ontology (Chen et al., 2004)

SOUPA Core is a set of ontologies consists of vocabularies for expressing concepts that are associated with

- Person
- Policy and action

- Agent and belief-desire-intention (BDI)
- Time
- Space
- Event

Person class describes contact information and profile of a person.

Policy and action defines vocabularies for representing security and privacy policies. In addition they also define description logic based mechanisms for reasoning about the defined policies. The execution of an action is guided and/or restricted by the policies which are set of rules. The ontology representation of an action is defined in the action ontology document. The class act:Action represents a set of all actions. This class can have a set of properties;

- act:actor – the entity that performs the action
- act:recipient – the entity that receives the effect after the action is performed
- act:target – the object that the action applies to
- act:location – the location at where the action is performed
- act:time – the time at which the action is performed
- act:instrument – the thing that the actor uses to perform the action

In addition to action ontology, the policy is defined in the policy ontology. The pol:Policy class represents all the policies. The properties of this class are pol:permits and pol:forbid and the ranges are the pol:PermittedActions and pol:ForbiddenActions. Policy ontology defines also meta information for individual policies such as author of a policy (pol:creator), the entity that enforces a policy (pol:enforcer), the creation time of a policy (pol:createdOn), and default reasoning mode of a policy (pol:defaultPolicyMode)

Agent and BDI define the agents, beliefs, desires and intentions. In SOUPA both computational entities and humans can be modeled as agents. All agents are represented by agt:Agent class which has properties in order to characterize agents' mental state. These properties are;

- agt:believes whose range is bdi:Fact class which is subclass of the rdf:Statement class

- agt:desires whose range is bdi:Desire class which defines a set of world states that agents desire to bring about

- agt:intends whose range is bdi:Intention class which represents a set of plans that agents intend to execute

In addition to these three properties, agt:hasGoal property defines the goal of the agent.

In SOUPA, there is also set of ontologies that are used to express time and temporal relations. There are mainly two classes, namely, tme:TemporalEntity and tme:TemporalThing. Tme:TemporalEntity is the union of tme:TimeInstant and tme:TimeInterval classes. Moreover, tme:TemporalThing is the union of the tme:InstantThing, tme:IntervalThing classes. In order to describe the order relations between two different time instants, the ontology defines following properties: tme:before, tme:after, tme:beforeOrAt, tme:afterOrAt, and tme:sameTimeAs. On the other hand, tme:startsSoonerThan, tme:startsLaterThan, tme:startsSameTimeAs, tme:endsSoonerThan, tme:endsLaterThan, tme:endsSameTimeAs, tme:startsAfterEndOf, and tme:endsBeforeStartOf properties are defined for describing the order relations between two different temporal things.

In SOUPA, spatial entities are also represented by space ontology. Two ontology documents are related to space ontology: space and geo-measurement. The symbolic representation of space and spatial relations are defined by the first ontology document; whereas the second document defines typical geospatial vocabularies such as longitude, latitude, altitude, distance, and surface area.

The last ontological definition of the SOUPA core is an Event Ontology. It is used to explain the occurrence of different activities and schedules. Eve:Event class is the main class of the event ontology. Event ontology has eve:SpatialTemporalThing class which is used to describe things that has spatial and temporal characteristics.

3.6.1.5 OWL-C Model

Another OWL based study on context modeling is about specifying web services. In this study Maamar et al. (2006) define the context as common meta-data about current execution status of a web service. The study has three major components I-Context, W-Context and C-Context. In the study, web service instances are binding to appropriate ontology so that the data management task can be easily performed.

When web services accept an invitation of participation in composite services, composite services inform the web services about the ontology to which instance of that web services adapt. During adaptation, to monitor the composite and web services from temporal perspective the context of composite services (C-Context) and context of web services (W-Context) are used respectively. In addition, web service instances rely on their respective context of web services instance (I-Contexts) to collect and submit details to W-Contexts of their web services.

Certain context provider would deliver all types of contextual information so, contexts will have a different granularities and structures. To manage these granularities, there are two mechanisms called consolidation and reconciliation. Consolidation is occurred at the web service level. When a web service accepts an invitation, web service instance and I-context are created. The transfer of details from I-Contexts to W-Context is featured by a consolidation of these details. On the other hand, the reconciliation occurs at the composite service level and transfer of details from I-Contexts to C-Context is featured by a reconciliation of these details. For example, from one web service “location of execution” argument and from another web service “site of execution” argument are considered to be the same in the reconciliation process (See Figure 23).

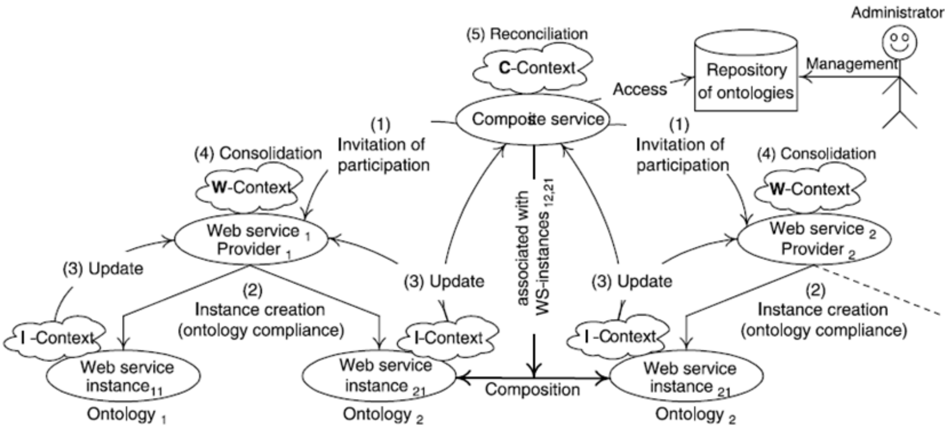

Figure 23 Context and ontology use in web service composition (Maamar et al., 2006)

After consolidation and reconciliation process and before updating the related context, the heterogeneity problem is solved by OWL-C, which has two parts:

- The first part is about the arguments that define the structure of context.
- The second part is about the capabilities associated with context

In the first part, context is an additional argument of a web service. By using OWL-C, semantics of the arguments can be defined (eg. identifier, execution cost), so common representation of the content of context of Web services is satisfied. In the second part, a service needs to be embedded with awareness mechanisms. These mechanisms gather any contextual raw data from sensors and detect any change in the environment. The OWL-C is given in Figure 24

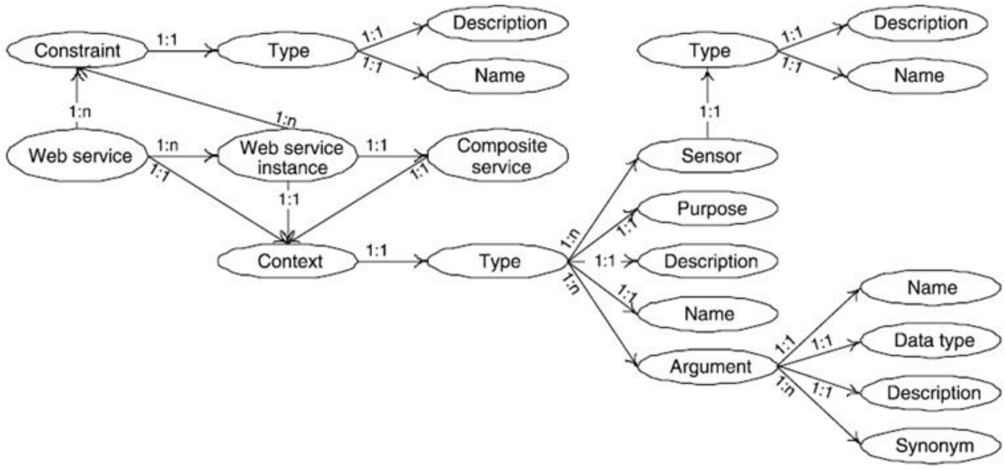

Figure 24 Ontology based description of context of web services (Maamar et al. 2006)

3.6.2 Context Model Based on Extension of OWL

3.6.2.1 C-OWL Model

Bouquet et al. (2004) state that ontologies are shared models of a domain whereas context is local or un-shared model. Therefore, communication can be performed by explicit mappings between these local models. In their study, Bouquet et al. (2004) extend or enrich the ontology because they believe that, the OWL ontology has problems on following points:

- The directionality of information flow. Bouquet et al. (2004) explain the problem as follows: consider ontology O_1 and has axioms $A \subseteq B$ and $C \subseteq D$. If we define another ontology, namely, O_2 which is derived from O_1 and O_2 has axiom $B \subseteq C$ then we can infer in O_2 that $A \subseteq D$ but not in O_1

- Local domains. Bouquet et al. (2004) assume that ontology O_{WCM} is the ontology of the word wild car manufacturer. In that ontology, the constraints, "a car can only have one engine" is specified and car manufacturer Ferrari and Porche import the ontology. $O_{Ferrari}$ ontology has axiom: WCM:car $\subseteq$ ∀hasEngine.{F23, F34i} and O_{Porche} ontology has axiom: WCM:car $\subseteq$ ∀hasEngine.{P09, P98i}. According to the global semantics, any interpretation of the OWL space containing O_{WCM}, $O_{Ferrari}$ and O_{porche} is such that, either $(F23)^{IFerrari} = (P09)^{IPorche}$ or $(F34)^{IFerrari} = (P98i)^{Iporche}$. This interpretation is not wanted as Ferrari does not produce Porsche's engines and neither vice versa.

- Context Mapping. Sale:Car is from vendor point of view and FIAT:Car is from manufacturer point of view. These two concepts coincides at the instance level.

These three problems are handled by extending the OWL. In Figure 25, the approach used in extension is provided.

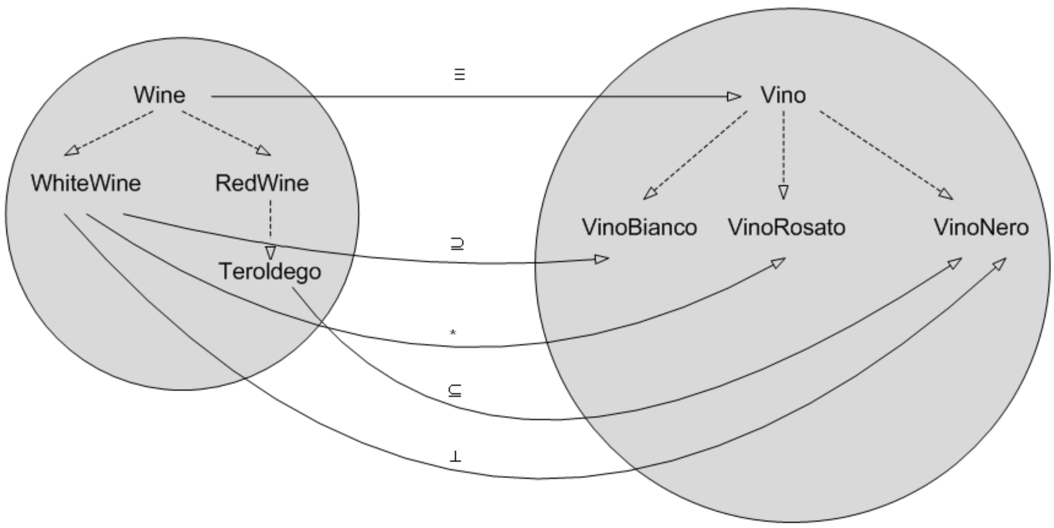

Figure 25 A C-OWL mappings from the ontology wine to the ontology vino (Bouquet et al., 2004)

Figure 25 shows an example mapping of two ontologies about wines. In order to represent this mapping, Bouquet et al. (2004) capture the following aspects:

- a unique identifier for referring to mapping;
- a reference to the source ontology;
- a reference to the target ontology;
- a set of bridge rules relating classes from two ontologies, each described by:
  - (a reference to) the source concept;
  - (a reference to) the target concept;
  - type of bridge rule, which is one of $\equiv$, $\subseteq$,$\supseteq$, $\perp$, $*$.

The representation can be seen in Figure 26.

```
<?xml version=”1.0” encoding=”UTF-8”?>
<rdf:RDF
        xmlns:rdf=”http://www.w3.org/1999/02/22-rdf-syntax-ns#”
        xmlns:rdfs=”http://www.w3.org/2000/01/rdf-schema#”
        xmlns:cowl=”http://www.cowl.org/”
        xmlns:owl=”http://www.w3.org/2002/07/owl#”
        <cowl:Mapping rdf : ID=”myMapping”>
                <rdfs:comment>Example Mapping for Web Semantics Journal Paper</rdfs:comment>
                <cowl:sourceOntology>
                        <owl:Ontology rdf:about=”http://www.example.org/wine.owl”/>
                </cowl:sourceOntology>
                <cowl:targetOntology>
                        <owl:Ontology rdf:about=”http://www.example.org/vino.owl”/>
                </cowl:targetOntology>
                <cowl:bridgeRule>
                        <cowl:Equivalent>
                                <cowl:source>
                                        <owl:Class rdf:about=”http://www.example.org/wine.owl#wine”/>
                                </cowl:source>
                                <cowl:target>
                                        <owl:Class rdf:about=”http://www.example.org/vino.owl#vino”/>
                                </cowl:target>
                        </cowl:Equivalent>
                </cowl:bridgeRule>
                <cowl:bridgeRule>
                        <cowl:Onto>
                                <cowl:source>
                                        <owl:Class rdf:about=”http://www.example.org/wine.owl#RedWine”/>
                                </cowl:source>
                                <cowl:target>
                                        <owl:Class rdf:about=”http://www.example.org/vino.owl#VinoRosso”/>
                                </cowl:target>
                        </cowl:Onto>
                </cowl:bridgeRule>
                <cowl:bridgeRule>
                        <cowl:Into>
                                <cowl:source>
                                        <owl:Class rdf:about=”http://www.example.org/wine.owl#Teroldego”/>
```

Figure 26 The C-OWL extension (Bouquet et al., 2004)

3.6.3 Context Model Based on Other Representation Language

OWL is not the only representation language for modeling context in pervasive computing environment. In Aspect-Scale-Context (ASC) model, Strang et al. (2003) use F-Logic as representation language. They define the context information as any information which can be used to characterize the state of an entity concerning a specific aspect. In addition, an entity is a person, a place or in general an object and an aspect is a classification, symbol or value range. Strang et al. (2003) use ontology to achieve shared understanding and propose Context Ontology Language (CoOL) for both knowledge representation and querying in their study.

CoOL is divided into two parts as core and integration. Core is defined by ASC model. The ASC model is given in Figure 27.

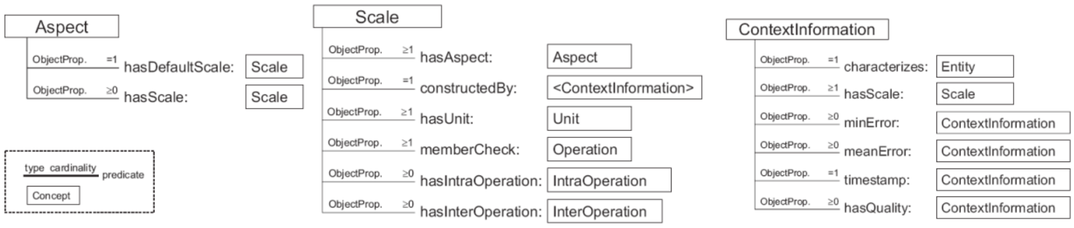

Figure 27 The ASC model (Strang et al., 2003)

In the model, each aspect aggregates one or more scales, and each scale aggregates one or more context information. These core concepts are interrelated via hasAspect, hasScale and constructedBy relations. For example an aspect GeographicCoordinate has two scales, namely, WGS84 and GaussKruger and valid context information may be an instance, created in one of the object oriented programming language like Java with new GaussKruegerCoordinate(“367032", "533074").

In the model, scales are sets of context information and constructed by one class of context information, so scale mapping is necessary which is called as operations (See Figure 28).

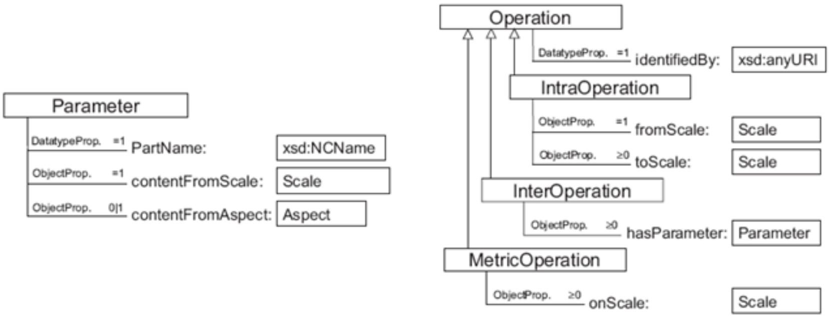

Figure 28 Scale mapping or operations in CoOL(Strang et al., 2003)

IntraOperations relate two scales from the same aspect (for example from meter to kilometer). On the other hand, "InterOperations" relates two scales from different aspects. For instance Kilometerperhour scale of speed aspect is related with delta_t of duration aspect and delta_s from spatial distance aspect. In addition MetricOperation may be used to compare two context information instance objects of the same scale.

In the study, Strang et al. (2003) use OntoBroker as inference engine and it can work on the ASC model and able to determine knowledge about entities, aspects, scales and context information.

3.6.4 Other Context Modeling Studies

The context modeling by using ontologies is also performed by using Model Driven Architecture (MDA) of Object Management Group (OMG) in the literature. The remarkable study is performed by Ou et al. (2006). In their study, they propose Context Ontology Model (COM) which is divided into two as Upper-Level Context Ontology Model (ULCOM) and Extended Specific Context Ontology Model (ESCOM). ULCOM captures ontology of concepts, those are essential for generically characterizing context in pervasive services domain. Whereas ESCOM defines specific concepts and it is an extension of ULCOM.

ULCOM includes three core concepts;

- Entity. Its type is OWLClass and represents five types of context concepts, namely, person, device, communication-channel (ComChannel), function, and event
- EntityProperty. Its type is OWLProperty and used to characterize general attributes, such as, time, identity, activity, and location.
- EntitySpecification. It is an instance of OWLRestrictions and specifies the constraints.

A part of context ontology model defined in the study is given in Figure 29.

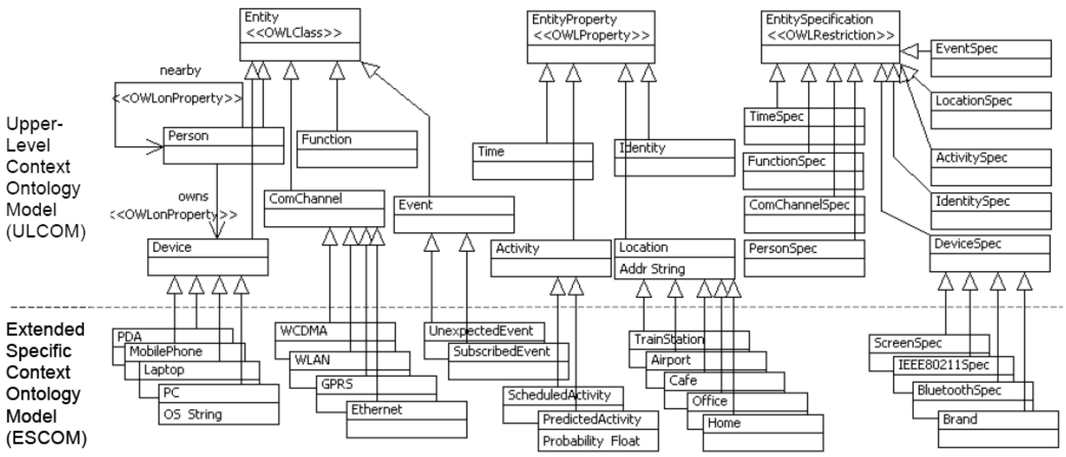

Figure 29 A part of the context ontology model (Ou et al., 2006)

Context modeling study related with spatial object comes from Park et al. (2007). In their research, they divide the context information into two as Generic Context Information which are fact and Specific Context Information. The latter one related to specific object in specific time point, and can provide private and intelligent services. This kind of context information is called situation.

In the study, Park et al. (2007) state that the process of information generation for context-awareness has four steps;

- Data Step in which objects are generated by using the data acquired from sensors
- Context Step; the values of objects generated in the data step are interpreted by domain knowledge which is fact set represented using ontology
- Semantic Step; in which the inference mechanisms are applied on fact set in order to get derived facts.
- Situation Step; in which the rule of each application are derived by using domain knowledge facts. Situation interpreter is used to interpret a rule and recognize a current situation (See Figure 30).

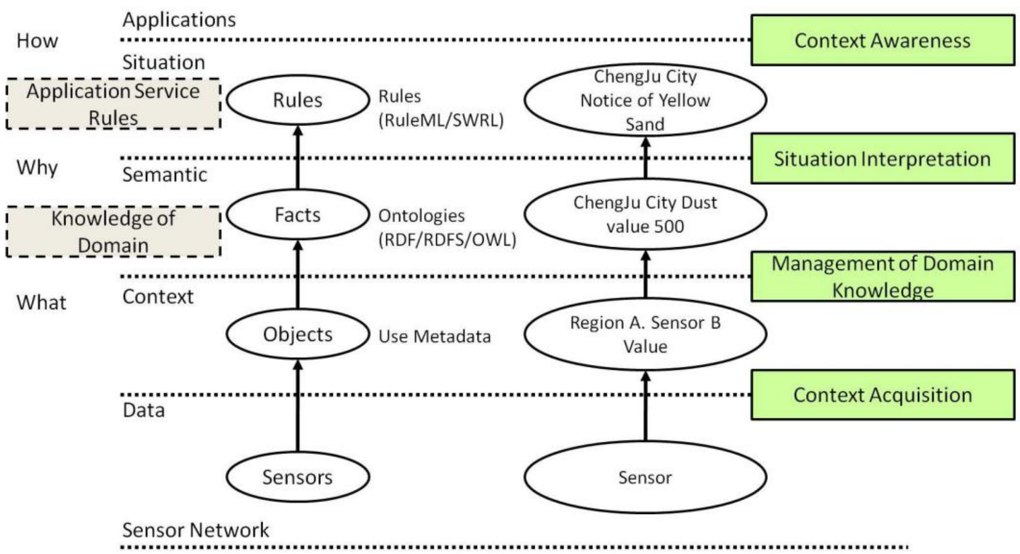

Figure 30 Representation of context information in processing context-awareness (Park et al., 2007).

In the Park et al. (2007) study a set of the same kind of geographic objects is defined as Theme and these geographic objects are classified into:

- a general attribute description with character, figures, and symbols
- a spatial-part attribute which is set of point, line, and polygon, and spatial topology (See Figure 31).

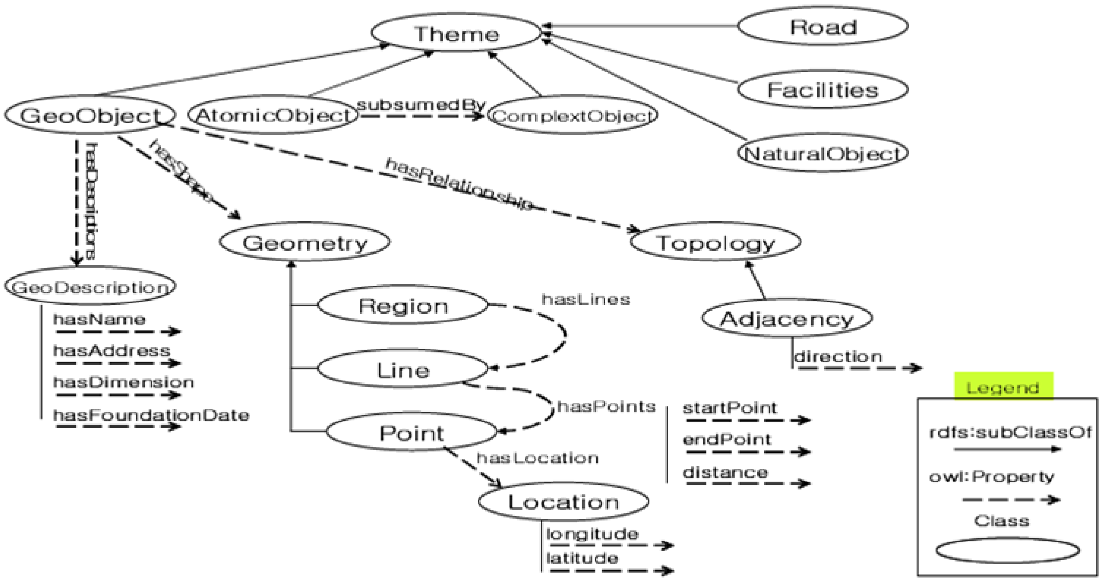

Figure 31 The spatial information ontology for spatial object (Park et al., 2007)

In Figure 31 geographic topology are represented by OWL as disjointWith, subClassof, sameAs, equivalent-Class, differentFrom and so on.

Park et al. (2007) represent the situation by using rules which are composed of conditions and conclusions. Conditions are the mix of facts and conclusions are facts. Rules are defined by Semantic Web Rule Language (SWRL) which is compatible rule of OWL ontology based on RuleML of XML. In Figure 32, a rule of “If the sensor is measuring fine dust and density of the dust is greater or equal than 500 and less than 1000 and duration of sensor value greater than 60 unit in Cheongju city, there will be a yellow sand warning.” is represented.

If FineDust(?s) and value(?s, ?v) and [?v >=500] and [?v < 1000] and duration(?v, ?t) and [t >= 60] and locatedIn(?s, ?r) then NoticeYellowSand(?r)

Condition : FineDust(?s) : Sensor is fine dust.
locatedIn(?s, ?r) : Sensor's location (Cheongju City)
value(?s, ?v) : Sensor's value(500 μg/m3)
duration(?v, ?t) : Duration of sensor's value(greater than 1 hour)

Conclusion : NoticeYellowSand(?r) : Notice of Yellow sand at sensor's location
s is sensor, v is measurement value, t is time, and r is area or place

Figure 32 A rule sample from Park et al.'s study (Park et al., 2007)

SOUPA, which is explained in Section 3.6.1.4, was an inspiring context modeling technique for the present study. The context used in this study is designed by the help of the Organization, Event and Action ontologies which are similar to Event, Action and Person in the SOUPA. A maintenance operation is handled by an infrastructure organization and designed as an event. In addition, in the maintenance context, the consequences of events produce actions and these actions are found out by using Semantic Web Rule Language (SWRL).

3.7 Semantic Web Rule Language

O'Connor et al. (2005) state that, Semantic Web Rule Language (SWRL) aims to be the standard rule language of the Semantic Web and it has an ability to express the horn-like rule in terms of OWL concepts.

Horrocks et al. (2010) state that SWRL is combination of OWL DL and OWL Lite which are two version of OWL with Rule Markup Language (RuleML). SWRL rules are composed of two parts, namely, antecedent (body) and consequent (head). When a condition specified in the body of a rule is true then a condition specified in the head must also be true.

Both the body and head consist of zero or more atoms and atoms in SWRL rules can be of the form C(x), P(x,y), sameAs(x,y), or differentFrom(x,y) (Horrocks et al., 2010). In these formation:

- C is an OWL description
- P is an OWL property
- x,y are either variables, OWL individuals or data values.

SWRL has human readable syntax and in this syntax rules have a form as follows:

Antecedent =>Consequent.

For example if an uncle is tried to be explained in SWRL, the rule should be written as:

Parent (?x,?y) ^ brother (?y,?z) =>uncle(?x,z?)

In this example rule, x and y are related to each other with parent property and y and z are related to each other with brother property. In other words, y is parent of x and z and y is brother. Therefore z is an uncle of x. as consequent states.

There are several built-ins defined in SWRL. These are used for comparisons, math, boolean values, strings, date, time, duration, URIs and lists. For example swrlb:lessThanOrEqual is used for comparisons. In addition, SWRLTab of the Protégé Ontology Editor has SWRL Query built-in. The built-ins in this library is used to have SWRL as a query language (SWRLQueryBuiltIns, 2010).

In order to find all person whose age is less than 25, following query can be used:

Person(?p) ^ hasAge(?p, ?a) ^ swrlb:lessThan(?a, 25) → query:select(?p, ?a)

3.8 ISO 19107:2003 Geographic Information – Spatial Schema

In order to describe spatial characteristics of geographic features, ISO published a standard ISO 190107:2003 in 2003 (ISO 19107:2003, 2003). It describes vector geometry and topology up to 3 dimensions. In standard geometry is described by different Unified Language (UML) packages. These packages are describing the set of related types. The package of the standard and their dependencies are given in Figure 33.

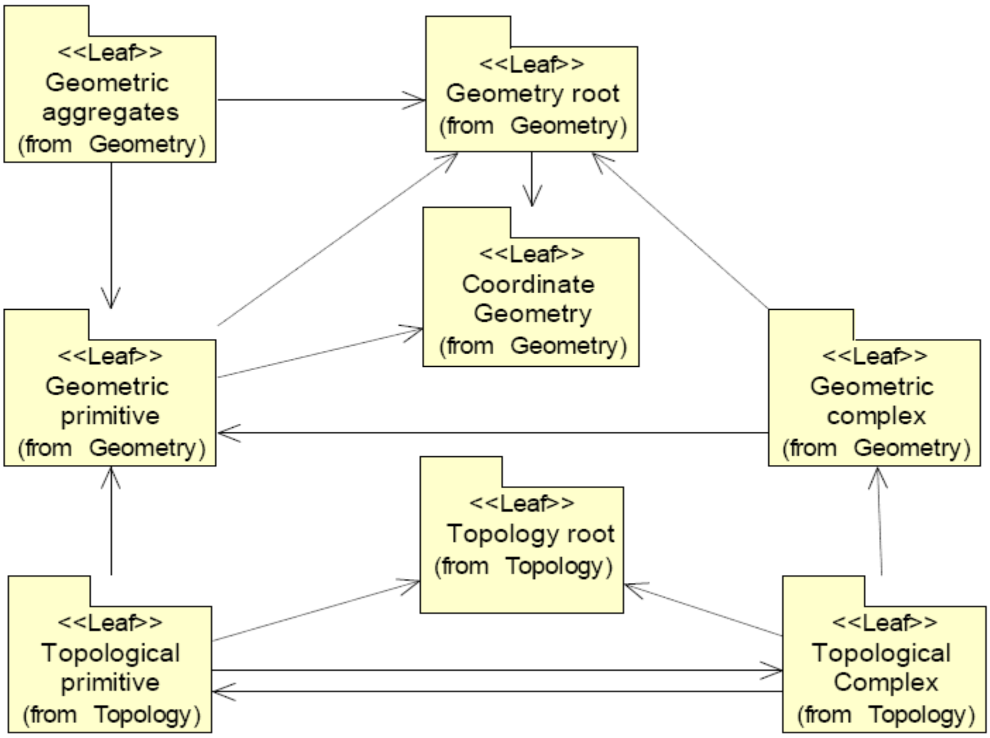

Figure 33 UML package and their dependencies in ISO 19107 (ISO 19107:2003, 2003)

Five of the packages in Figure 33 define the geometric characteristics of the spatial objects. These are geometric aggregates, geometry root, and geometric primitive, geometric complex and coordinate geometry (See Figure 34).

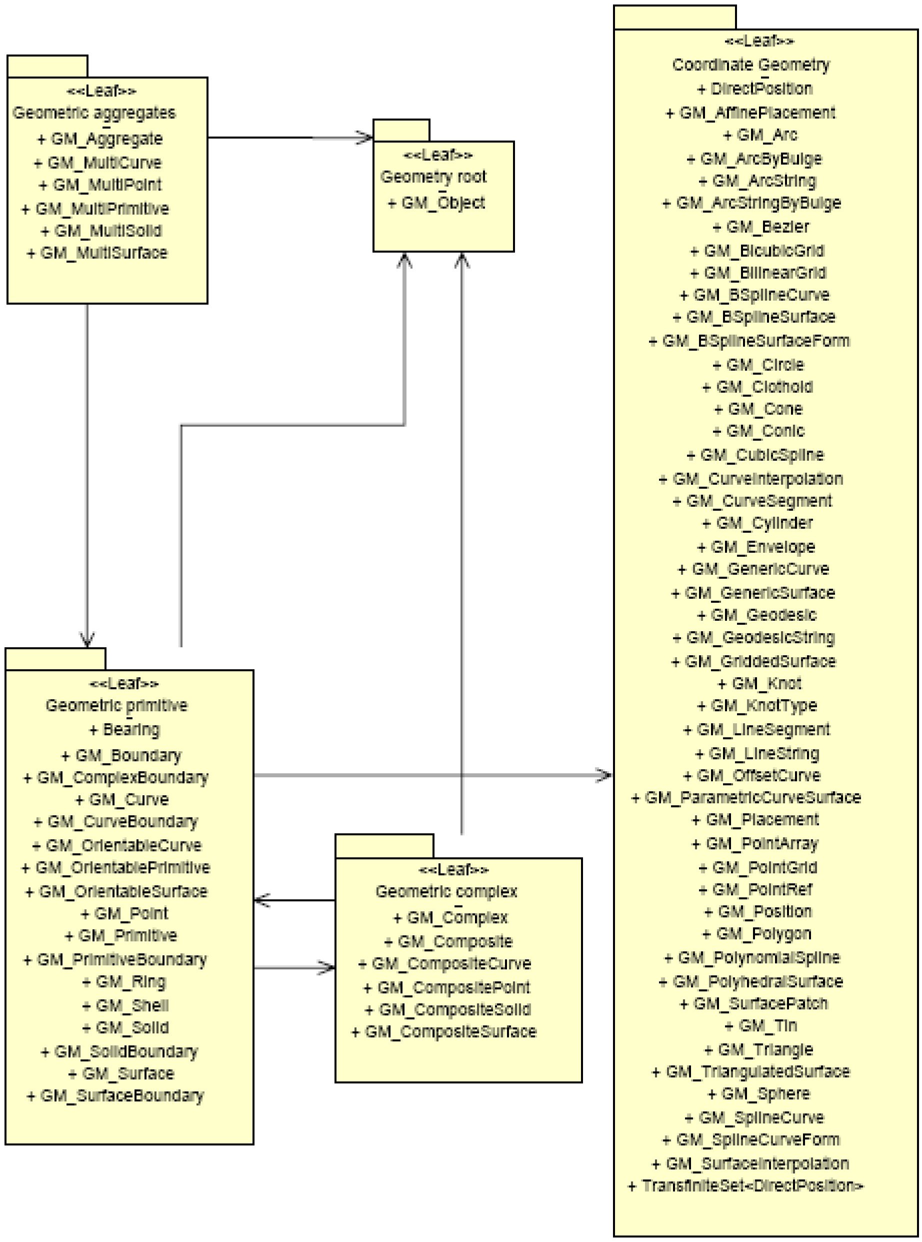

Figure 34 Geometry Package: Class content and internal dependencies (ISO 19107:2003, 2003)

3.8.1 Geometric Primitive Package

ISO 19107:2003 (2003) has a strong class hierarchy. All the geometric classes are derived from GM_Object. There are basically three branches in the class hierarchy. These are the GM_Primitive, GM_Complex and the GM_Aggregate. GM_Complexes are always made of GM_Primitive. In addition, point, line and polygon objects which are used to represent the real geographic features in the world are represented by the GM_Primitive. These primitives are basically, GM_Point, GM_Curve and GM_Surface (See Figure 35).

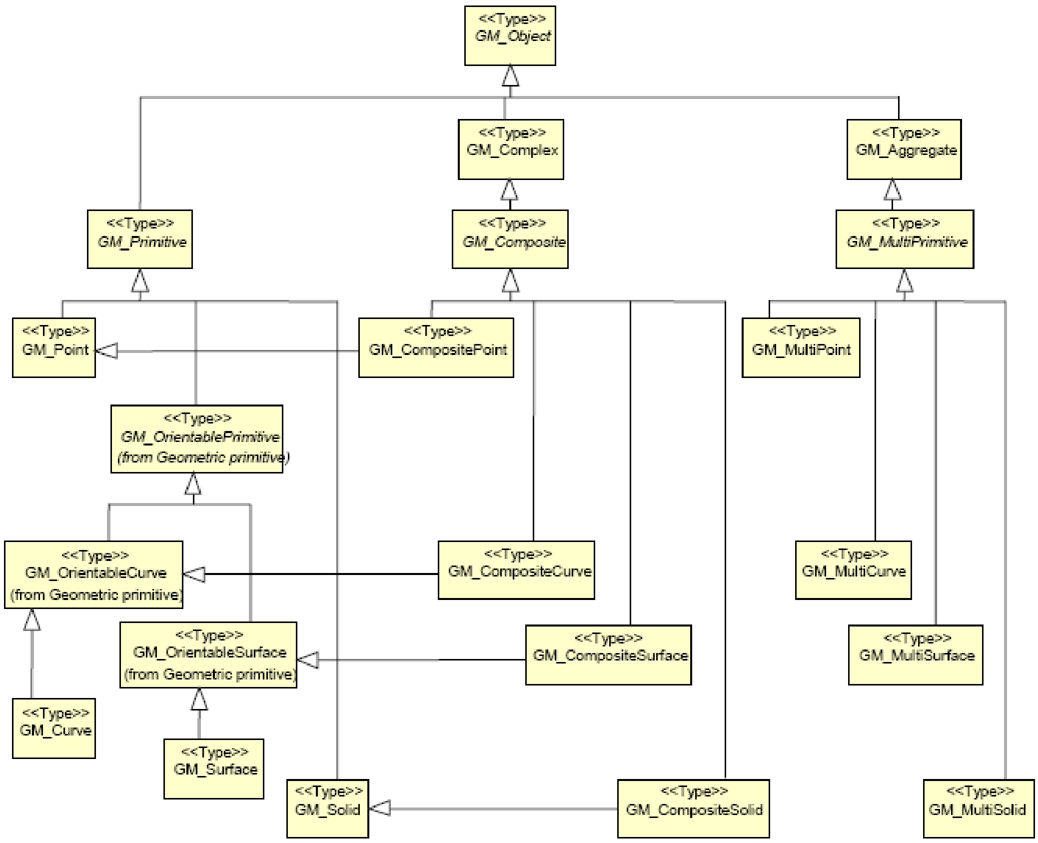

Figure 35 Basic classes of geometry with specialization relations (ISO 19107:2003, 2003)

3.8.2 Coordinate Geometry Package

Coordinate geometry package contains set of classes which are needed to define the geometric objects. The classes of the package are also the primary constructs of the classes of the geometric primitive package.

3.8.2.1 Direct Position Class

The direct position class defines the coordinate of a position within specific coordinate reference system. It has two properties which are coordinate and dimension. Coordinate is the sequence of numbers that hold the coordinates of the given position for a specific reference system. Dimension is the number of entries.

3.8.2.2 GM_CurvementSegment Class

It defines a homogenous segment of a GM_Curve. Each GM_CurveSegment shall be in, at most, one GM_Curve (See Figure 36).

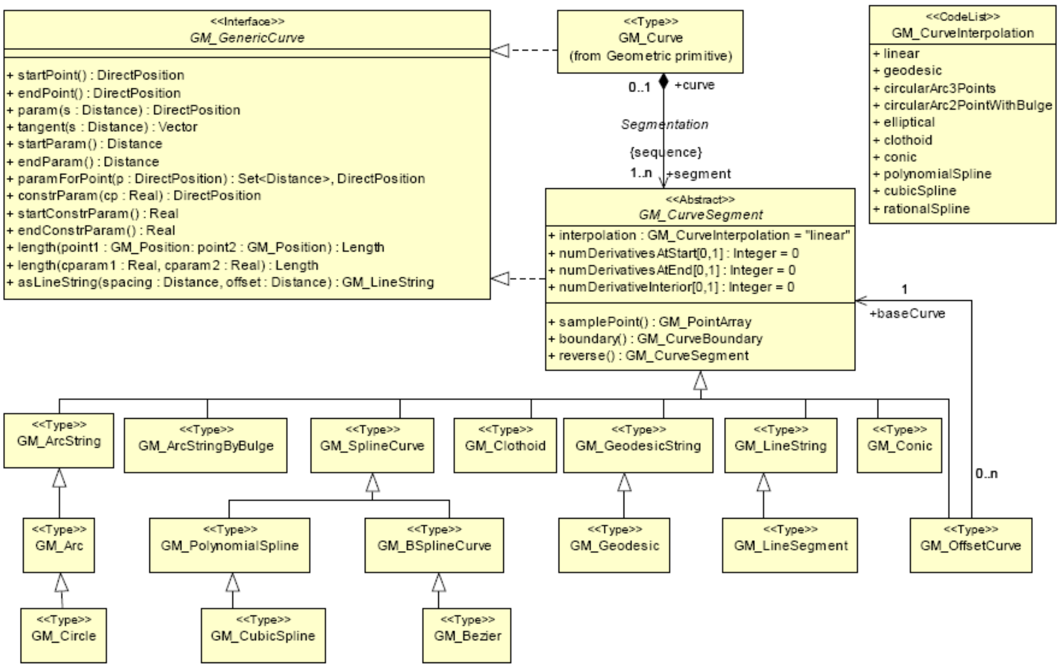

Figure 36 GM_CurveSegment class (ISO 19107:2003, 2003)

3.8.2.3 GM_LineString Class

A GM_LineString consists of sequence of line segments. The class essentially combines a Sequence<GM_LineSegments> into a single object (See Figure 37).

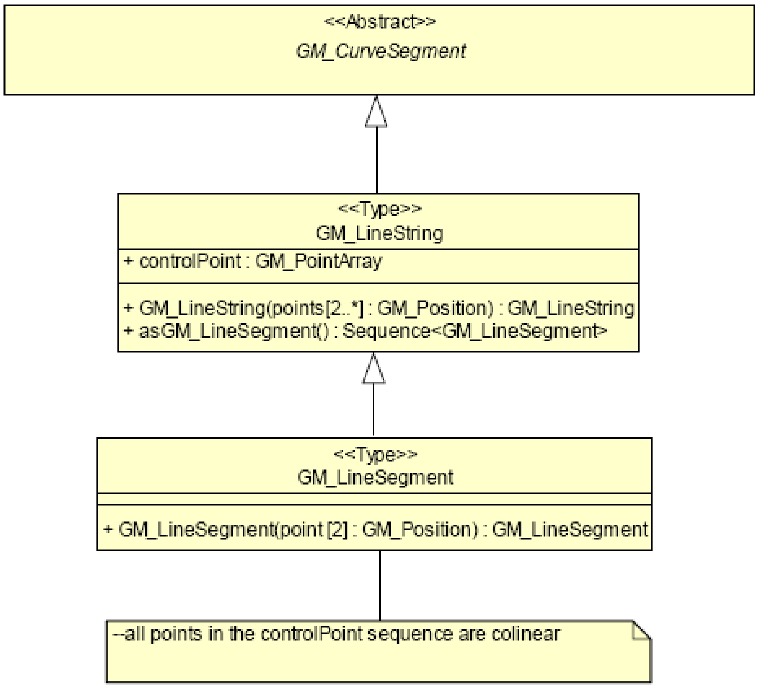

Figure 37 The GM_LineString and GM_LineSegment classes (ISO 19107:2003, 2003)

3.8.2.4 GM_LineSegment Class

It is the line that has a two distinct DirectPositions (the start and end point) joint by straight line.

3.9 Summary

In summary, the literature review reveals that multi-level interoperability studies have been proposed recently. One of the multi-level interoperability studies belong the Tolk et al. (2009). In the study, writers underline the importance of context awareness and handling of context changes. On the other hand, they discussed the problem at the theoretical level and sample systems are not demonstrated in the study. In addition, system interoperability is discussed rather than the GIS interoperability.

Additionally, the reviewed literature points out that GIS interoperability studies are more concentrated on the semantic level interoperability rather than the upper levels handled in Tolk et al.'s (2009) study. Therefore this study aims to fill the gap in context based interoperability in GIS domain in the by introducing an application of context based interoperability in the pragmatic and dynamic levels. Lastly, in this literature context modelling studies are investigated to decide how contexts can be modelled for this study. Although several techniques about context modelling are handled in this literature review, contributing to the context modelling literature was not an aim for this study. The reviewed studies gave inspiration while modelling the context used in this study.

CHAPTER 4

SYSTEM DESCRIPTION

In this study, the Electricity and the Telecommunication GIS systems are selected as sample GISs. The sample area was selected as one of the districts of Çankaya Municipality, which is within the boundaries of Ankara Metropolitan Municipality.

In Ankara, the electricity network is managed by Başkent Electricity Distribution Co. (BEDAŞ) and the telecommunication network is managed by Türk Telekom (TT). The major reasons behind the use of BEDAŞ and TT GIS's are twofold. As for the first reason, the construction of BEDAŞ and TT GIS systems has almost been completed. And the second reason is the effects of networks on each other. Any maintenance event in one network may have effects on the other network. Especially on the BEDAŞ maintenance, the effects can become serious. On a face to face interview with the T. Küçükpehlivan (May 2008), he stated that, the penalty paid by the BEDAŞ to the TT is in million dollars scale in a year as a result of the damages in the TT network during the maintenance operations. Therefore, the infrastructure companies suffer from having non-interoperable systems especially when they plan to maintain their infrastructures. This is the motivation for choosing maintenance as the primary research subject.

The possible consequences as a result of an emergency like flood, earthquake on both BEDAŞ and TT are also tried to be modeled in this study. The reason why emergency situations are included in this study is to explore how systems react to these situations affected from each other during emergency situation.

The knowledge related with the infrastructures is acquired by personal communication with the BEDAŞ and TT employees. The details of the infrastructure, how maintenance operations are handled are given from the Maltepe BEDAŞ Transformation Center Headquarter and Akköprü Local Exchange of TT.

4.1 Electricity Infrastructure

There are three firms in Turkey that maintain the electrical service. These are Electrical Production Company (EÜAŞ), Electrical Transformation Company (EİAŞ) and Electrical Distribution Company (EDAŞ). EÜAŞ is responsible for the generation of electricity. When the electricity generated (in power plants, dams etc.), it is transmitted to the interconnect system of Turkey. On this system, electricity is transmitted in 380kV voltage. The duty of the EÜAŞ ends when the electricity is given on this system.

EİAŞ is responsible for taking the electricity from the interconnect system and transmitting it to the cities. During the transmission, the voltage of the electricity is reduced from 380kV to 34.5 kV. The reduction is performed at two steps. In the first step, the voltage is lowered from 380kV to 154kV at the auto-transformation centers and at the second step the 154kV voltage is reduced to 34.5kV at the electrical transformation centers.

The 34.5kV of electricity is submitted to the distribution center in the cities. The distribution center is the first element of the EDAŞ system. From this point, EDAŞ is responsible from the transmission of the electricity to the clients. The voltage of the electricity, after the distribution center is still 34.5kV and this voltage is reduced to the 0.4kV at the distribution transformation units. Through that point the electricity is transmitted to the boxes which are last elements of the electricity network before clients. Each box generally feeds one or two buildings in the network. The brief representation of the explained process of electricity transmission is provided in Figure 38.

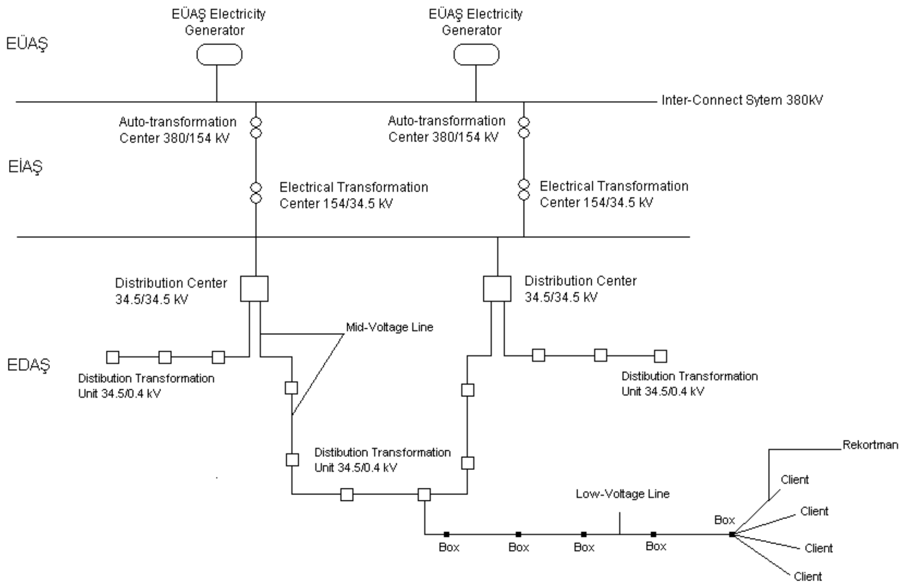

Figure 38 Electricity infrastructure representation

As shown in Figure 38, the network is making a loop after the Distribution Center. The aim of the structure is to feed the line from different directions so that the effect of a line break can be minimized. The feeding system is not automatic, which means if a line is broken, the line is not automatically fed from reverse direction. The manual intervention is necessary. The structure below the Distribution Transformation Unit is tree. Therefore, if the line breaks at that location, then the clients after breaking point will not get power. The realization of an electricity network demonstrated in Figure 38 on GIS is given in Figure 39.In this figure, the network elements from Distribution Center to Rekortman is marked.

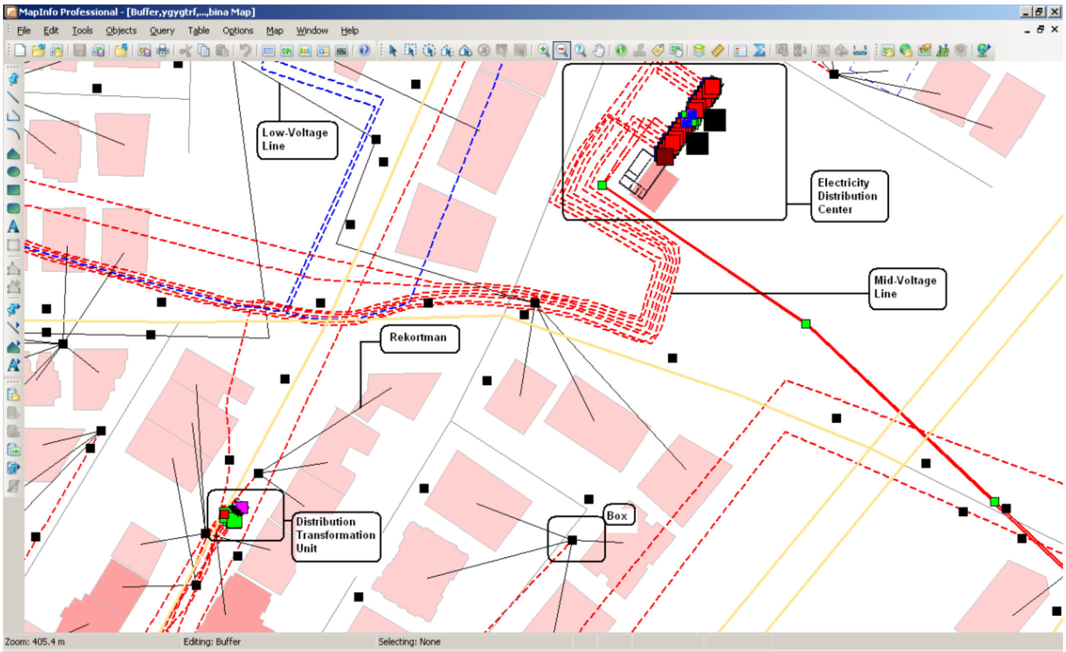

Figure 39 Sample screenshot from BEDAŞ GIS (MapInfo screenshot)

4.2 Telecommunication Infrastructure

One of the most widespread land-based telecommunication infrastructures is established and maintained by TT in Turkey. In TT network, tandem exchanges are the main exchanges that enable local exchanges communicate with each other. They are connected to each other by fiber cable, which is called junction or trunk, and the connection between them forms a loop. Therefore, if the fiber cable between two tandem exchanges is broken, the communication can be possible from the other side of the loop. Generally tandem exchanges are province based and each province contains one tandem exchange.

Clients take communication services from local exchanges, which are connected to the tandem and each other by fiber cable (junction or trunk). Two different local exchanges located on different cities communicate with each other over tandem exchanges.

Below local exchange, the next network element is the field cabinet. A field cabinet is connected to a local exchange by a bunch of copper cables (containing 1800 individual cables). These bunches of cables are called as principal cables. The field cabinets are connected to the building boxes or cabinets by local cables which are copper also. The clients receive communication lines over apartment cabinets. A representation of the explained telecommunication network is provided in Figure 40.

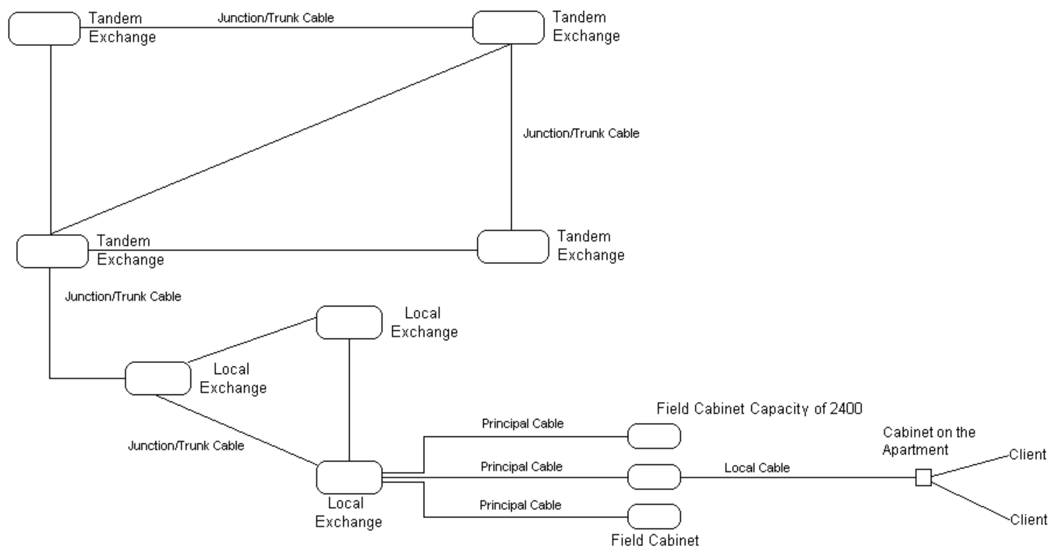

Figure 40 The telecommunication network representation

Realization of TT network demonstrated in Figure 40 is given in Figure 41 and Figure 42. A data related with client is not given by TT because of privacy of subscription data. Therefore cabinet on the apartment and client data cannot be shown on these figures.

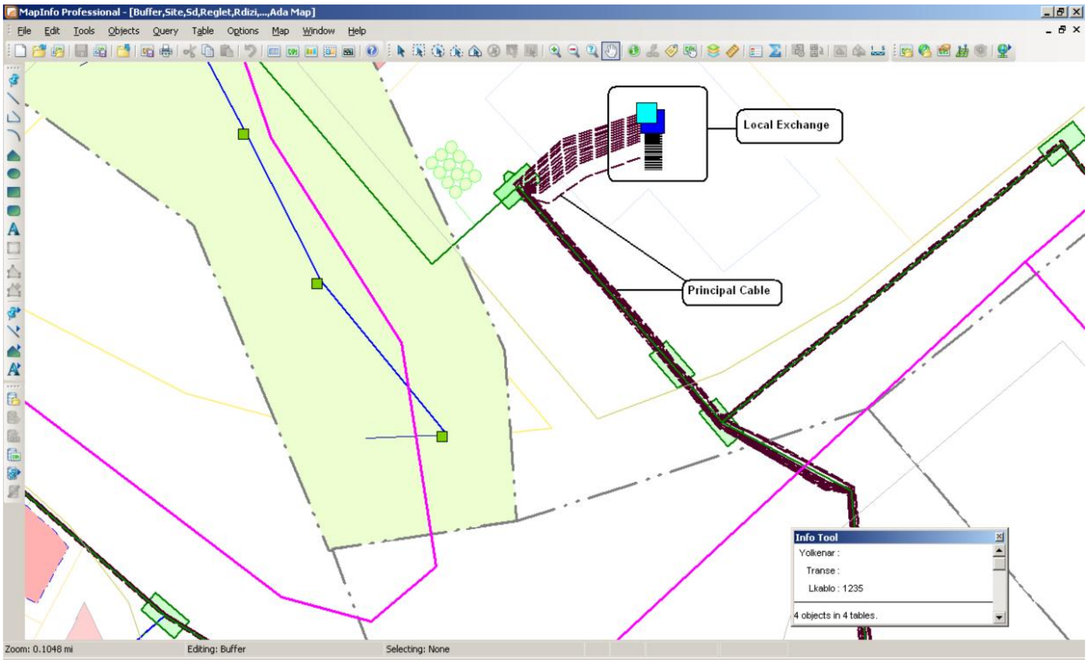

Figure 41 Realization of local exchange and principal cable in TT GIS (MapInfo screenshot)

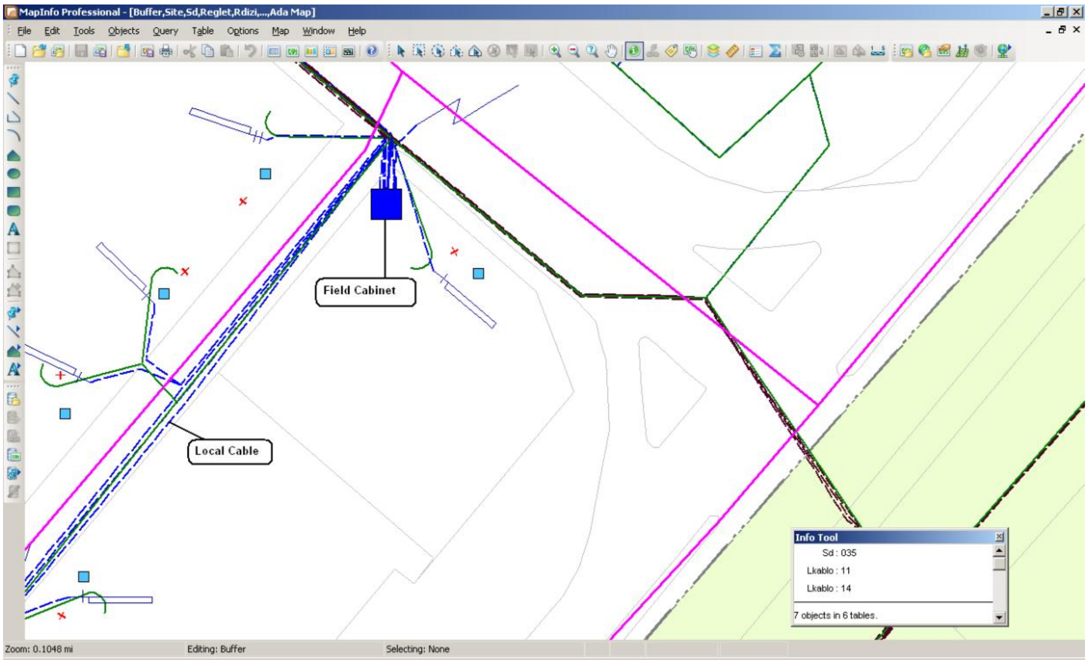

Figure 42 Realization of field cabinet and local cable (MapInfo screenshot)

4.3 Knowledge Base

The knowledge base used in this study is composed of mainly 3 ontologies, rule bases and inference engine. Three ontologies are Upper Ontology, Application Ontologies and Context Ontologies. There are two context ontologies defined in this study, namely, Maintenance Context Ontology and Emergency Context Ontology. The representation of knowledge base is given in Figure 43.

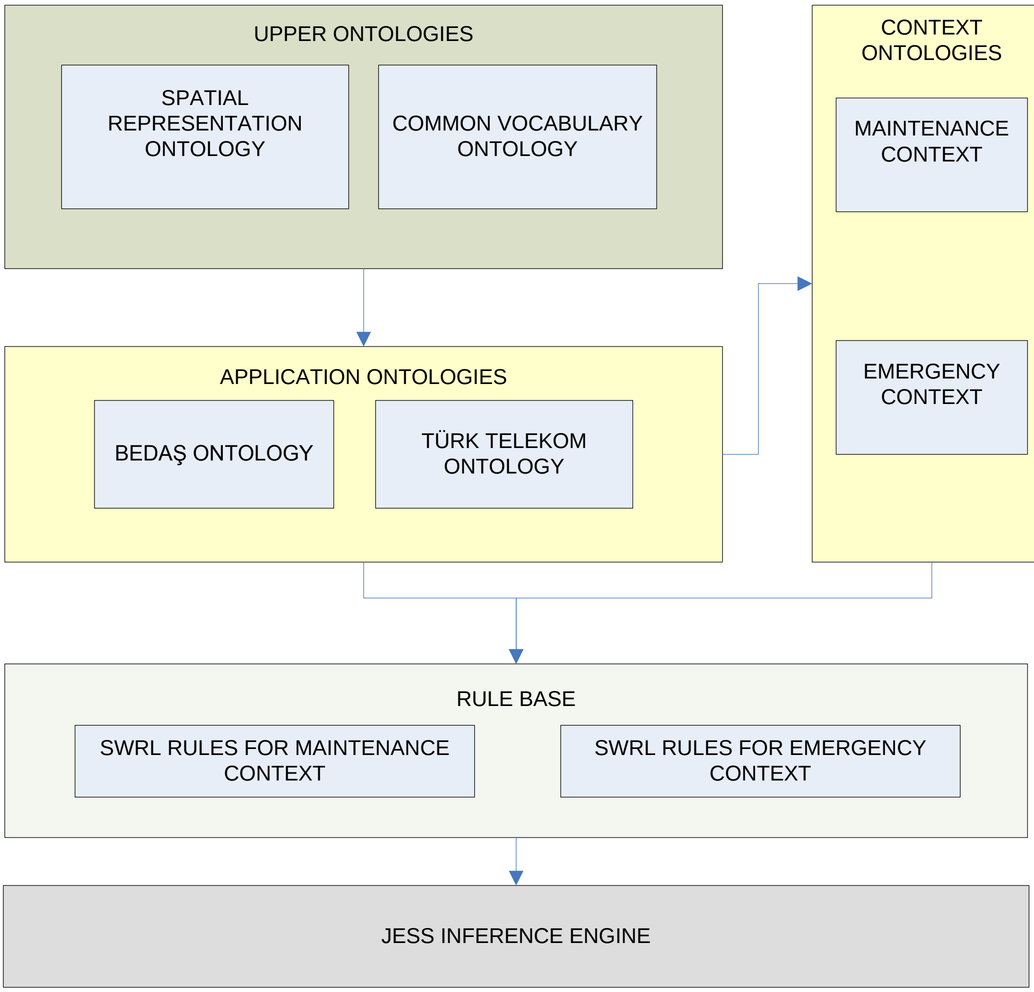

Figure 43 The knowledge base

In order to explain the deriving and usage hierarchy, the arrows are used in Figure 43. The Application Ontologies are deriving by using the Upper Ontologies. In addition the Context Ontologies are using the Application Ontologies. Similarly, the Rule Base is constructed over both the Application Ontologies and the Context Ontologies. Finally, Jess Inference Engine is reason about rules in the Rule Base.

Context based interoperability can be possible by knowledge base proposed in Figure 43. TT and BEDAŞ application ontologies are derived from Upper Ontologies. Therefore the semantic level heterogeneity between TT and BEDAŞ can be overcome by using concepts in TT and BEDAŞ ontologies whose ancestor is from Common Vocabularies ontologies. In addition, different contexts are handled by Context Ontologies. Together with the Rule Base, in context ontologies, behavior changes of network elements in BEDAŞ and TT GIS can be defined. Therefore how specific elements on BEDAŞ or TT network change its behavior depending on the context is answered by context ontologies and rule base. In Tolk et al.'s (2009) framework Level 4 and Level 5 are Pragmatic and Dynamic Level respectively. Level 4 is achieved by Context ontologies in the proposed knowledge base. In this study, context changes are tried to be captured by ontology individuals. When an emergency event or maintenance event is created, the individual is created in context ontologies. By checking the individual, GIS systems can sense which context they should adopt. Therefore systems can interoperate dynamically.

4.3.1 The Upper Ontologies

The Upper Ontologies consist of Spatial Representation Ontology and Common Vocabularies Ontology. Spatial Representation Ontology defines the geometric entities and the relationship between them. ISO 19107 (2003), which is the spatial schema standard of ISO, is used as guidance to form the spatial representation ontology. In the infrastructure network, most elements are defined by lines and points, therefore, in the Spatial Representation Ontology, the lines and points representation is stressed. Therefore, whole ISO 19107 ontology is not used in the architecture. The lines are represented by GM_Curve class in the ontology (See Figure 44).

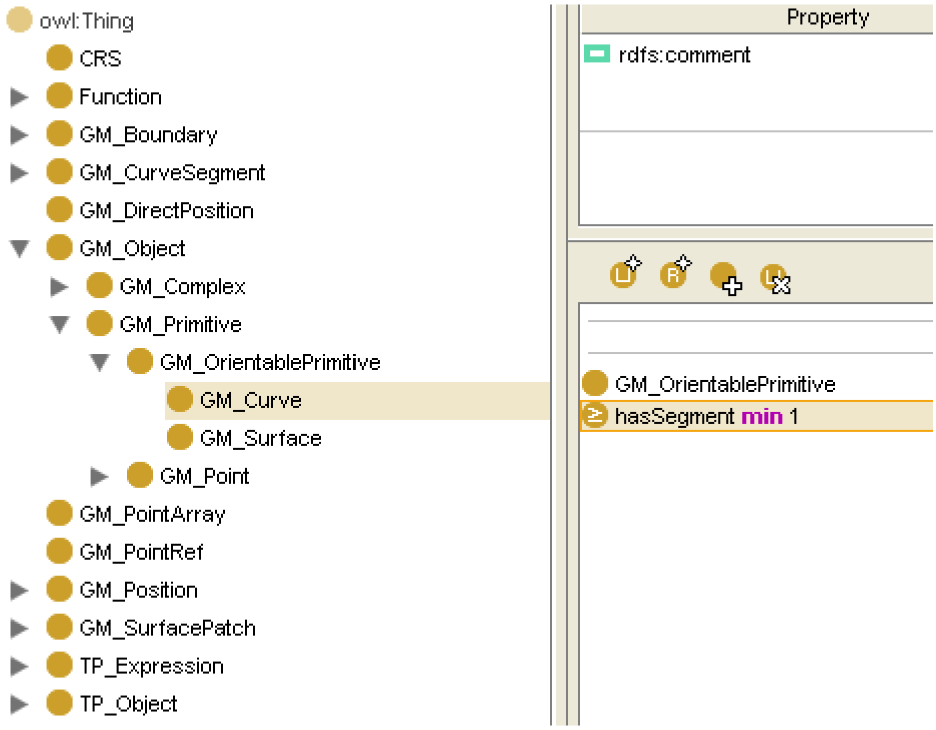

Figure 44 GM_Curve class in spatial representation ontology (Protégé screenshot)

The GM_Curve class is a GM_OrientablePrimitive and has at least one LineSegment. Nodes on the line segment are represented by control points which are GM_PointArray class (See Figure 45).

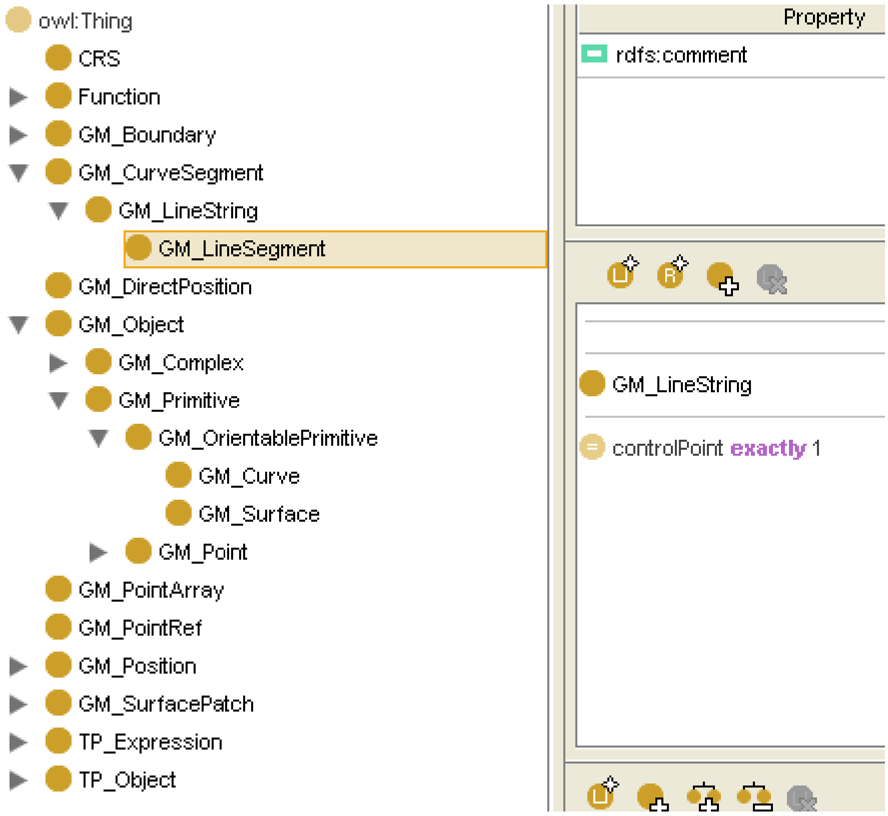

Figure 45 GM_LineSegment class in spatial representation ontology (Protégé screenshot)

The GM_PointArray class has at least one column and the column is the direct position. The direct position is represented by GM_DirectPosition class and has at least two and at most three coordinates. The GM_PointArray and GM_DirectPosition classes are presented in Figure 46 and Figure 47, respectively.

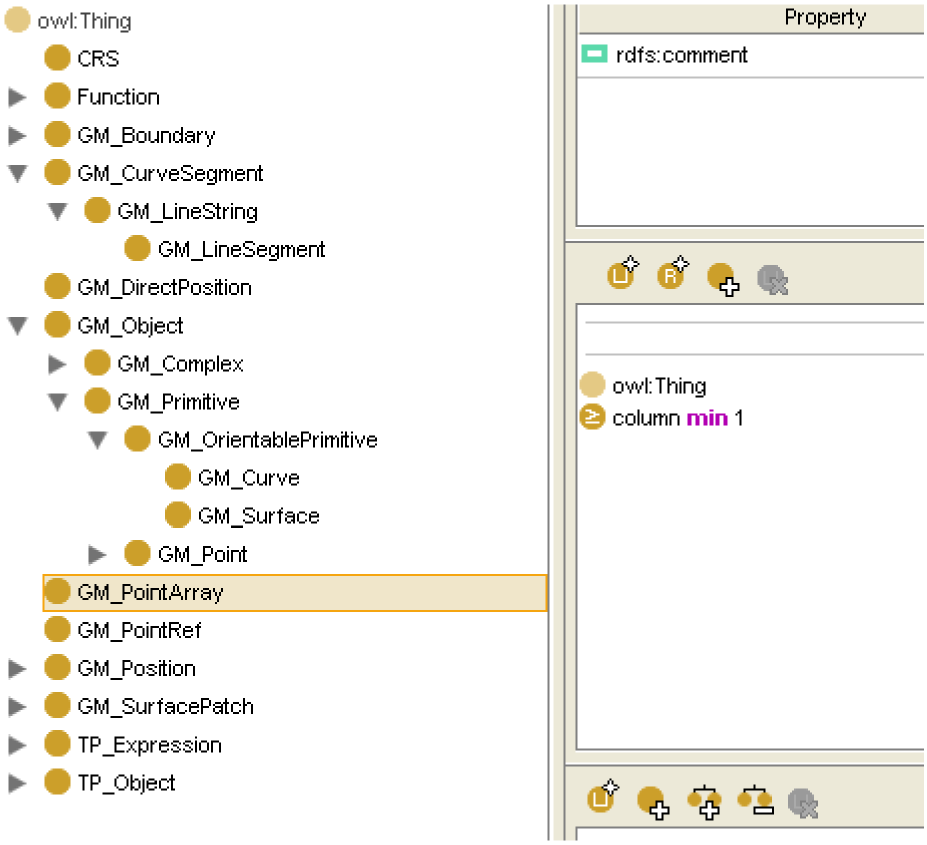

Figure 46 GM_PointArray class in spatial representation ontology (Protégé screenshot)

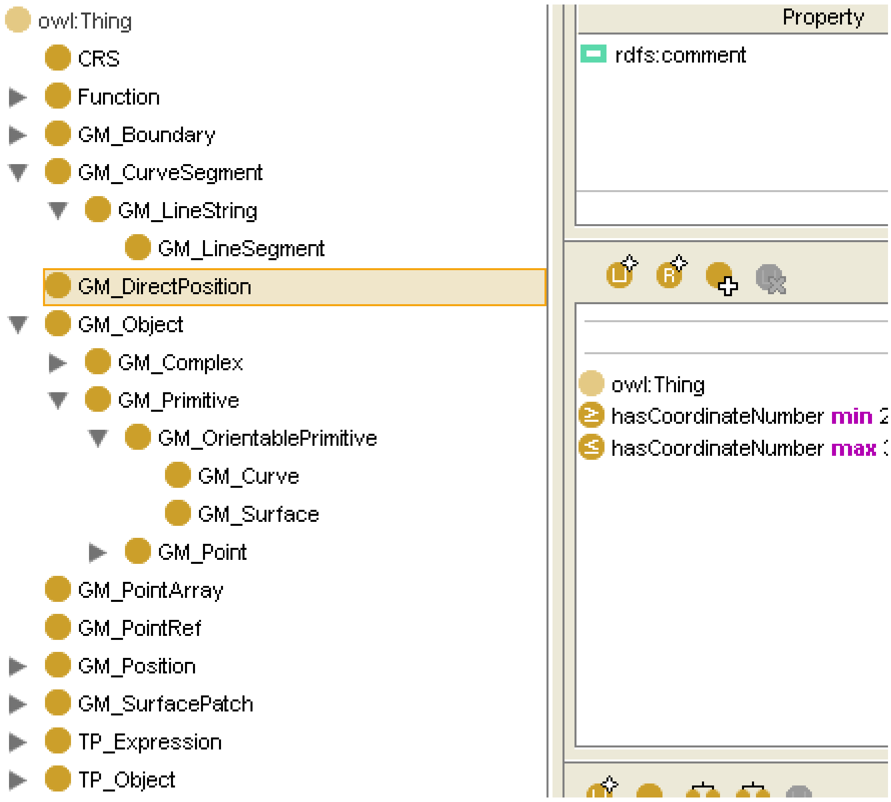

Figure 47 GM_DirectPosition class in spatial representation ontology (Protégé screenshot)

Therefore a line is represented by the help of the GM_Curve, GM_LineSegment, GM_PointArray and GM_DirectPosition. Similarly, the point objects are defined by the help of the GM_Point class. Each GM_Point has at least one position whose value is expressed by GM_DirectPosition (See Figure 48).

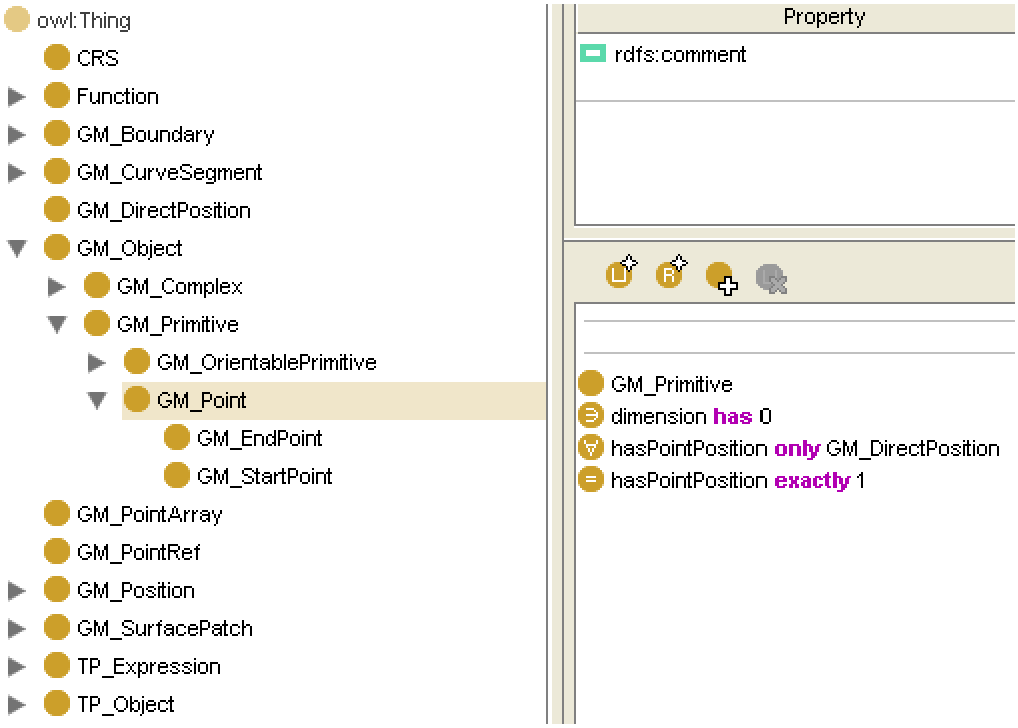

Figure 48 GM_Point class in spatial representation ontology (Protégé screenshot)

The other upper ontology is the common vocabularies ontology and it explains the commonalities between the BEDAŞ and TT GIS. If two networks are examined on the municipality scale, then the main elements are defined as electrical transformation center, distribution center, distribution transformation unit, box, low voltage line, mid voltage line and client for the electricity network and local exchange, field cabinet, apartment cabinet, local cable, principal cable, client cable and client for the telecommunication network (See Figure 38 and Figure 40). All these elements can be thought as network nodes and edges, so the common vocabularies ontology is constructed in terms of network nodes and edges. The nodes are called as DistributionPoints and edges are called DistributionLines. At the leaves of the network, there are clients. The closest distribution unit to a client is named first order distribution unit. Similarly, the closest distribution line is the first order distribution line. Therefore, clients are connected to the first level distribution unit by first level distribution lines. In ontology, the first level distribution line is called as ToClient_DL meaning that a class represents distribution line attached to a client. Similarly, the first level network node is called as ClientLevel_DU, which means a class explains the distribution unit responsible for delivering the service to a client. The whole commonalities are designed by the same approach in the common vocabularies ontology which is presented in Figure 49.

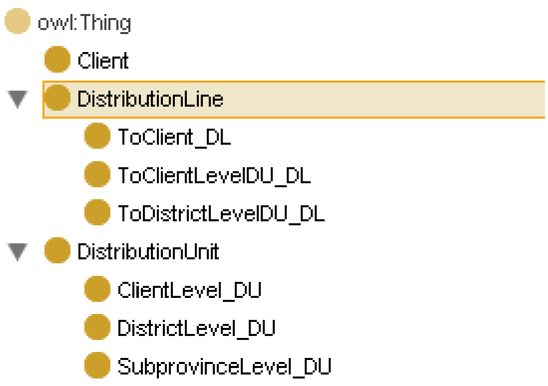

Figure 49 The common vocabularies ontology (Protégé screenshot)

In Figure 49, ToClientLevelDU_DL is expressing the distribution line connecting to the client level distribution unit. In addition DistrictLevel_DU is for distribution unit that serves the district in the sub province. The detail of each class is given in Appendix A.

4.3.2 Application Ontologies

Application Ontologies are used to express the structures of the BEDAŞ and TT networks. To construct the BEDAŞ ontology, each element is produced by using terms of Common Vocabulary Ontology. In addition, the spatial characteristics of the elements are defined by using Spatial Representation Ontology. For instance, Rekortman is first level network edge in BEDAŞ network and connecting the client and box so it is specializing the ToClient_DL class from the Common Vocabularies ontology. In addition, it is a distribution line that means it is distributing electricity to network nodes and its spatial characteristic is explained by GM_Curve from the Spatial Representation Ontology (See Figure 50). The critical class definitions of the BEDAŞ ontology are given in Appendix B.

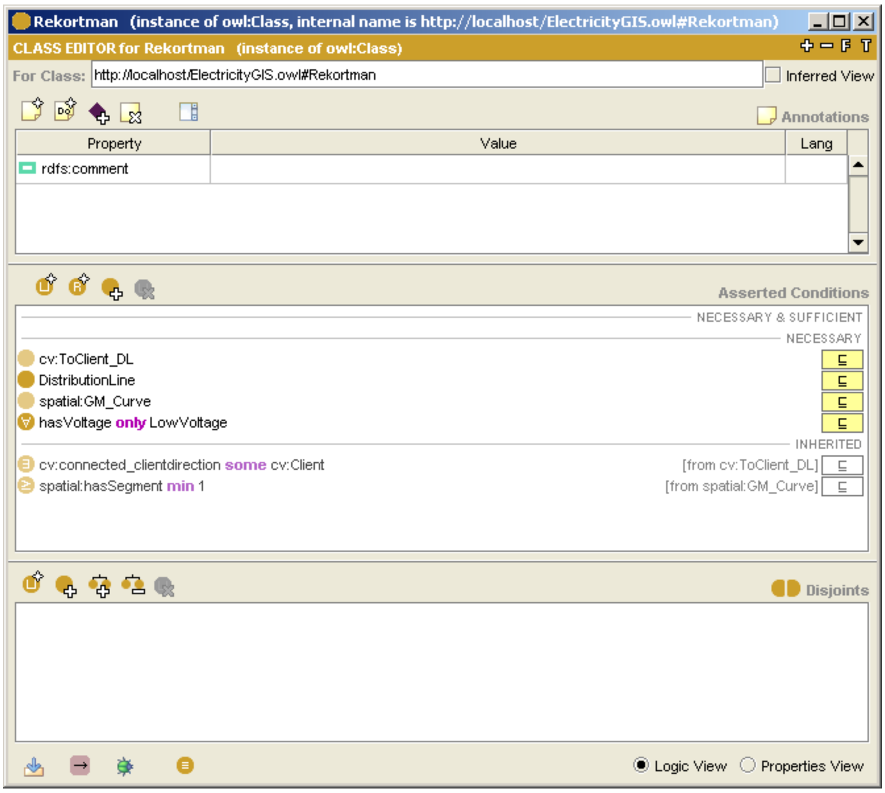

Figure 50 The representation of Rekortman in BEDAŞ ontology (Protégé screenshot)

The TT ontology is constructed by the same approach, which means the Upper Ontologies are used to constitute the TT ontology. The critical class definitions of TT ontology are given in Appendix C.

4.3.3 Context Ontology

In maintenance operations, the behavior of the network elements of the GISs may differ from those in regular operation. For example, in regular service time, a mid-voltage electricity line is expected to be operational, which means it has 34.5 kV energy. However to repair a mid voltage electricity line, the electricity should be cut off. Therefore during the maintenance time, all electricity network elements can show different characteristics than its regular operational time, so the maintenance is evaluated as contextual information. Similarly the same behavior change can be occurred during emergency events. For example, during flood or earthquake, electricity may need to be cut off. Therefore an emergency context is added to the knowledge base as a second context.

In this study, SOUPA is the inspiring context modeling technique. The context used in this study is designed by the help of the Organization, Event and Action ontologies. A maintenance operation is handled by an infrastructure organization and modeled as an event. When an event happens, some consequences will occur and these consequences are interpreted as actions. Therefore the Context Ontology has three sub-ontologies: Event, Action and Organization. The event ontology is explaining the possible emergency situations and maintenance and repair activities on the BEDAŞ and TT network. Three different variations of the event are the construction of new network element due to infrastructural investment, maintenance and malfunction. These are specialization of InfrastructureCompanyEvent class. In addition emergency situations are defined as EmergencyEvent class. There are three subclasses of EmergencyEvent class, namely, Earthquake, Fire and Flood. The classes of the Event ontology are listed in Figure 51.

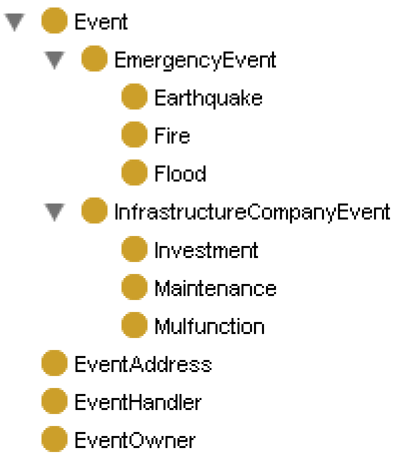

Figure 51 Event Ontology (Protégé screenshot)

The event belongs to or affects either BEDAŞ or TT. In addition, an event may be implemented through a contractor. Therefore, the infrastructure companies and contractors are modeled by the Organization Ontology (See Figure 52).

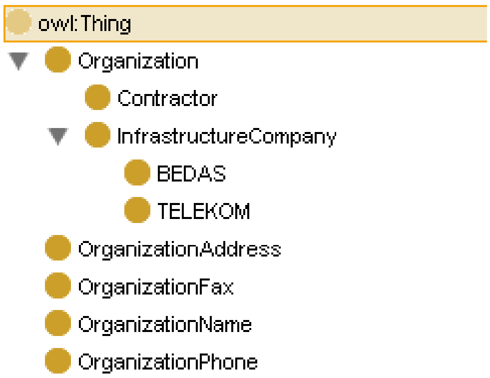

Figure 52 Organization ontology (Protégé screenshot)

Moreover, an event has some consequences in the networks. For example, if there is maintenance on some mid voltage electricity line and the estimated duration of the maintenance operation is longer than 30 minutes, then BEDAŞ makes an announcement on the local media about the maintenance and the location of the districts where electricity cannot be provided. So this announcement should be modeled as an action. The action is modeled under the Action Ontology which is shown in Figure 53.

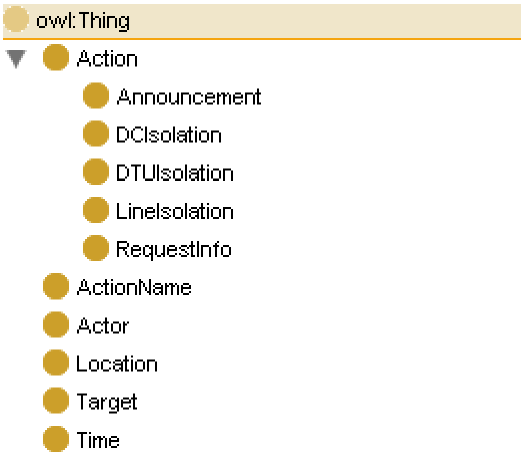

Figure 53 The Action ontology (Protégé screenshot)

In addition to these three ontologies, some properties are defined in the Context Ontologies. These properties have a duty to relate different concept from different ontologies. For example in Maintenance Context Otology, an object property called as hasObjectType is defined. Domain of the property is InfrastructureCompanyEvent from Event Ontology and range of the property is DistributionLine or DistributionUnit from Common Vocabularies Ontology. Therefore by the help of the property defined in context ontology, different concepts are related.

4.4 Rule Base

The required actions that should be taken as a result of the events are decided by semantic rules. The actions depend on some conditions and these conditions are defined by Semantic Web Rule Language (SWRL) (Horrocks et al., 2004).

SWRL is preferred because of its high expression capability, easy programmability and the Protégé Ontology Editor support. The rules are defined by using the SWRL tab of the Protégé.

The rule base contains definition rules and query rules and for each context, separate rules are constructed in the system. The definition rules are used to define the action caused by an event. For example, for the maintenance context the local media announcement is determined as a kind of action and is caused by having greater than 30 minutes maintenance event on mid voltage line. The action is defined by SWRL rule reproduced in Figure 54.

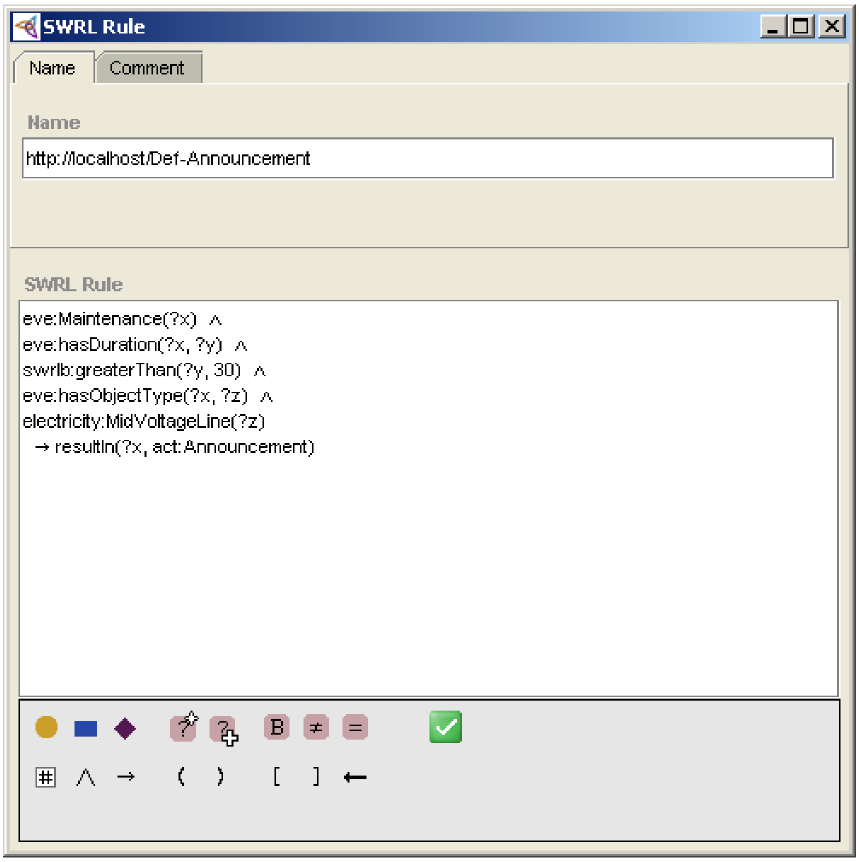

Figure 54 The definition of Announcement by SWRL in Maintenance Context (Protégé Screenshot)

An important duty of definition rules is to define behavior changes of network elements. For example if a consequence of event required to isolation of distribution center from the BEDAŞ network, then we can understand that, behavior of that distribution center is changed from “power on” to “power off”. Therefore all the network elements connected to that distribution center changed their behavior.

The query rules are for determining the whole actions generated in the BEDAŞ or TT network as a result of the event. For example in Figure 55, the select statement from Maintenance Context picks the possible actions when there is an event which

- has type Maintenance and
- has owner BEDAŞ and
- has duration greater than 30 minutes and
- has object type mid voltage line

The other rules used in this study are given in Appendix D.

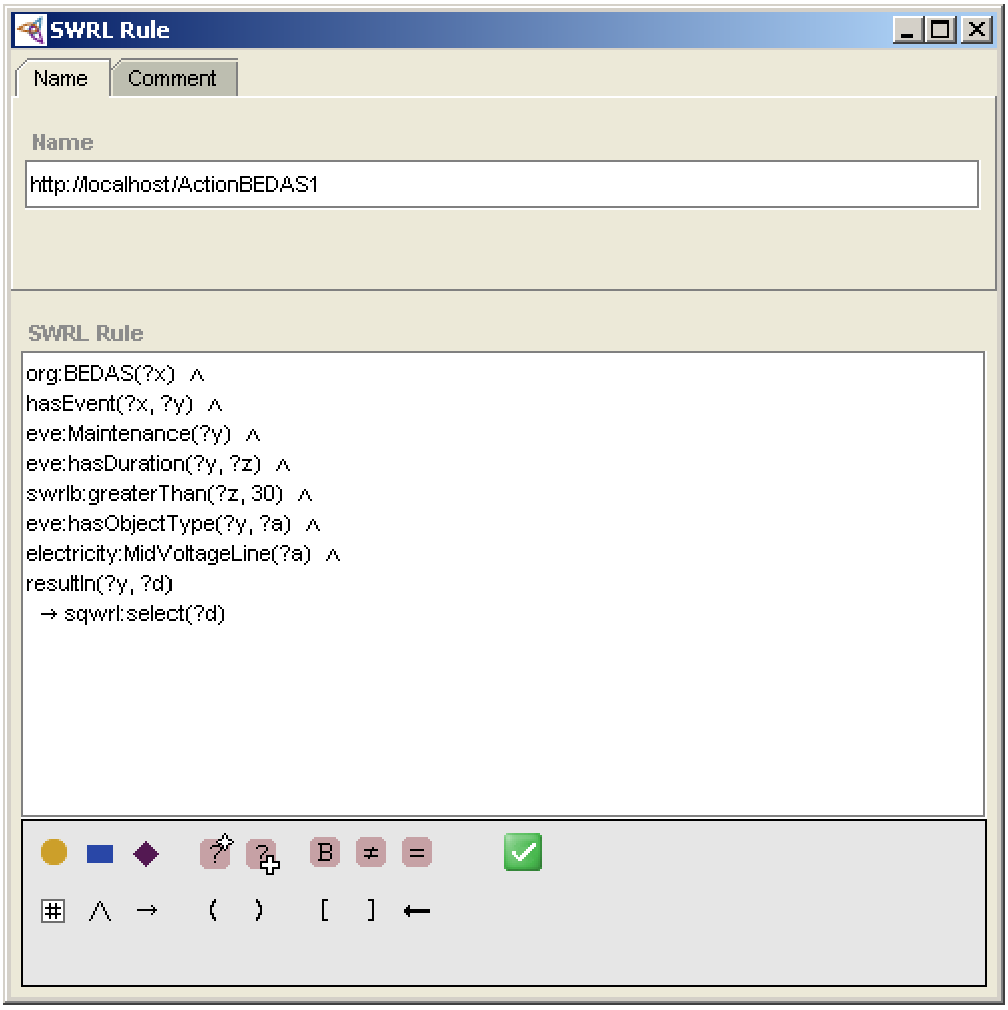

Figure 55 An action selection rule for the BEDAŞ network from Maintenance Context (Protégé Screenshot)

Jess is employed as the rule engine in this study, because of its capability to run SWRL rules and its good Java interfaces. In addition, the SWRL Tab of the Protégé has integration with Jess. Therefore, the rules are run within the SWRL Tab of Protégé and can be tested if they are successfully defined.

We have defined the several ontologies to provide interoperability in the GIS infrastructure on maintenance context. However, the problem of sharing geographic data is still present. The GML by the Open GIS Consortium (OGS) is a good choice for defining geographic data because all the important GIS companies are supporting the format. Other than WFSs, three web services have been developed, namely, the AYKOME, BEDAŞ and TELEKOM services, which are discussed in the next chapter. The system architecture is depicted in Figure 56.

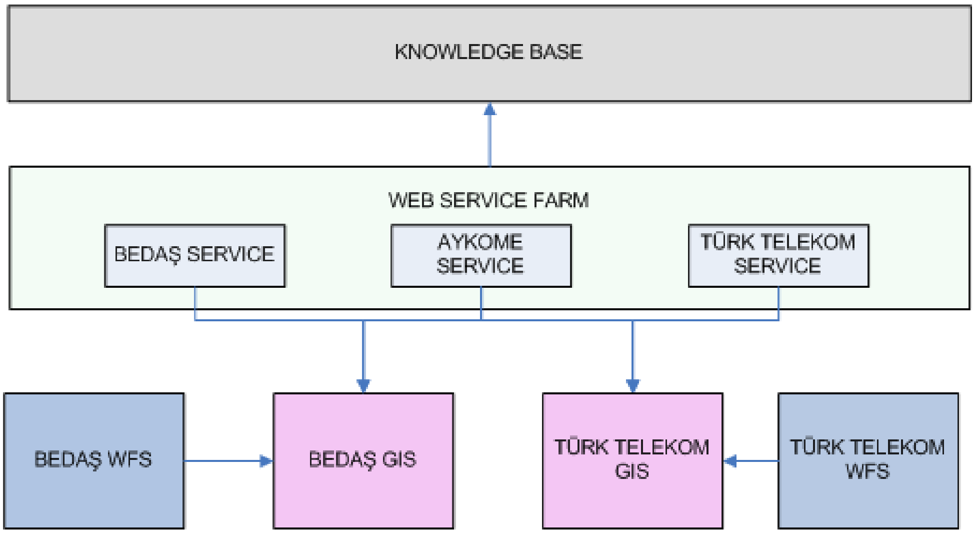

Figure 56 The system architecture

The arrows in Figure 56 are used similar to Figure 43. The three web services are using the knowledge base for both deciding an action as a result of an event and querying an ontology structure. The BEDAŞ and TT GISs are using three web services to implement interoperability. Finally, data of the GISs are served by two WFSs.

CHAPTER 5

IMPLEMENTATION DETAILS

To enable interoperability, add-ons to GISs and web services have been implemented. The main purpose of the add-ons is to communicate with the web services of the corresponding infrastructure company and query the ontological structure. Web service of the infrastructure company is responsible for responding the queries coming from the GIS. The major mission of AYKOME web service is to handle the semantic queries. All the software components and their duties are explained by three scenarios in this chapter.

5.1 First Scenario: Information Request

The first scenario involves information request from the other GIS. For example, if BEDAŞ has maintenance on some point in the network and if the maintenance requires excavation, then the operator at BEDAŞ should know whether there is an infrastructure which belongs to other infrastructure company. Therefore, the operator should send an information request and receive the required information. The process can be summarized as follows:

1. The operator at BEDAŞ adds an event at some location.

2. The system responses whether there is a necessity to know about network element belonging to other companies.

3. If there is a necessity then the system queries the BEDAŞ Web Service to get the top level common vocabularies element which is type of BEDAŞ element at the location where the event is added.

4. BEDAŞ operator sends an information request.

5. The request is created at Common Vocabularies Ontology.

6. The location is created at Spatial Ontology.

7. The TT operator checks whether there is a request.

8. If there is a request, TT GIS finds those GIS elements that are a type of common vocabulary element.

9. TT operator sends appropriate information.

10. BEDAŞ operator checks for response.

11. If there is a response, BEDAŞ operator requests from system to show the available element on the map.

12. The system shows the element on the map.

The flow diagram of the scenario is given in Figure 57.

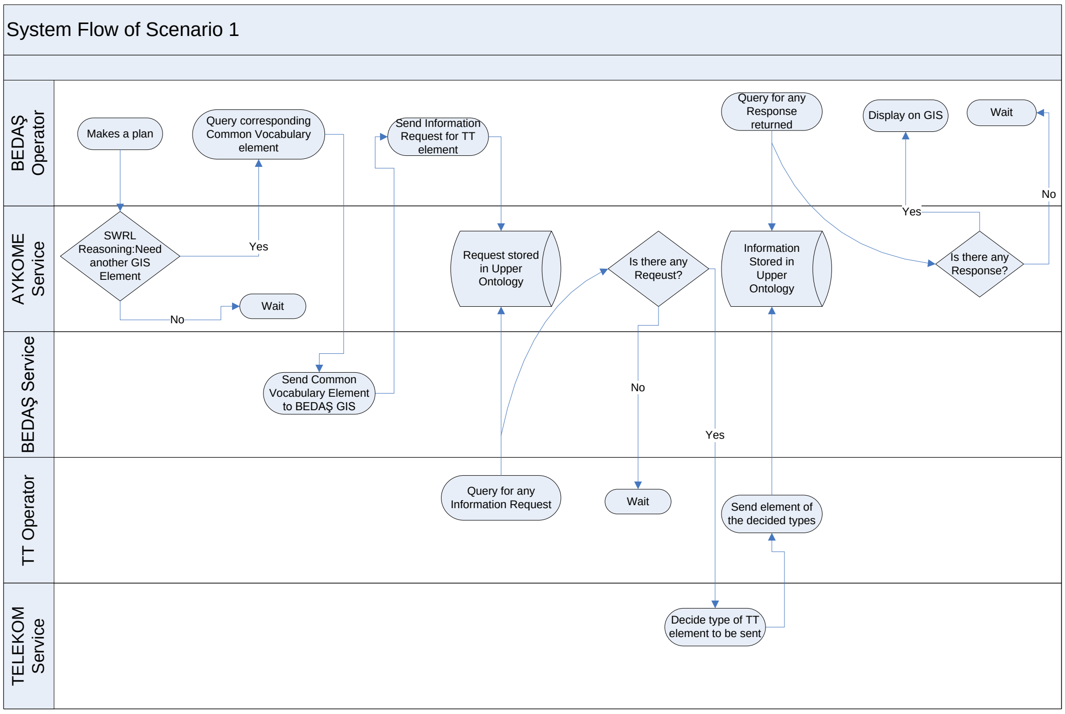

Figure 57 Flow chart of the business for Scenario 1

To make the scenario possible AYKOME, BEDAŞ and TELEKOM web services and add-ons for these GISs are developed. The AYKOME web service is designed to mediate the BEDAŞ and TELEKOM system. The AYKOME has following responsibility:

- Create and get distribution line individual in common vocabularies ontology.
- Create and get curve individual in spatial representation ontology.
- Create and get point individual in spatial representation ontology.
- Create and get event individual in context ontology.
- Create and get organization individual in context ontology.

- Make inferences on the context ontology by using SWRL rules and Jess rule engine.

Having these capabilities, AYKOME Service has ability to create information requests and responses between two GIS Systems.

The other web services are responsible for;

- Mapping between GIS and ontology of that GIS which means that the corresponding element of the GIS and ontology are determined in the web services of TELEKOM and BEDAŞ.

- Get sub and super classes of the corresponding organization ontology.

All the web services are created by using Java. The reason why we are using Java is that Protégé and Jess has an API for only Java.

The add-ons to GIS are developed by two different platforms. The first one is MapBasic which is scripting platform for MapInfo program. This platform is used to call add-ons which are developed in the Microsoft .NET environment. The MapBasic add-ons written for BEDAŞ GIS are composed of menu and tool button, which can be seen in Figure 58.

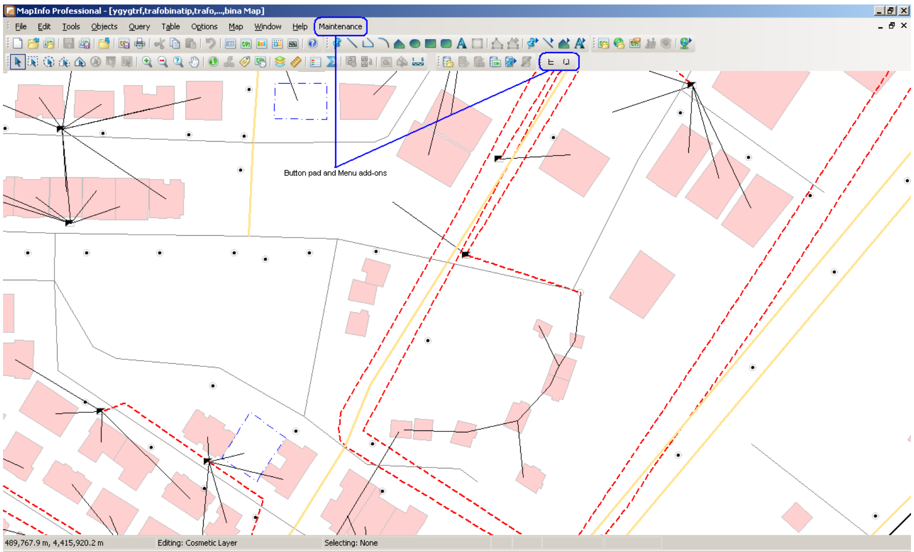

Figure 58 MapBasic add-ons to the BEDAŞ GIS (MapInfo screenshot)

The operator at the BEDAŞ needs to use button pad if he wants to add an event in the GIS. After picking some point on the map, a new dialog box is displayed to provide the event details to the system (See Figure 59).

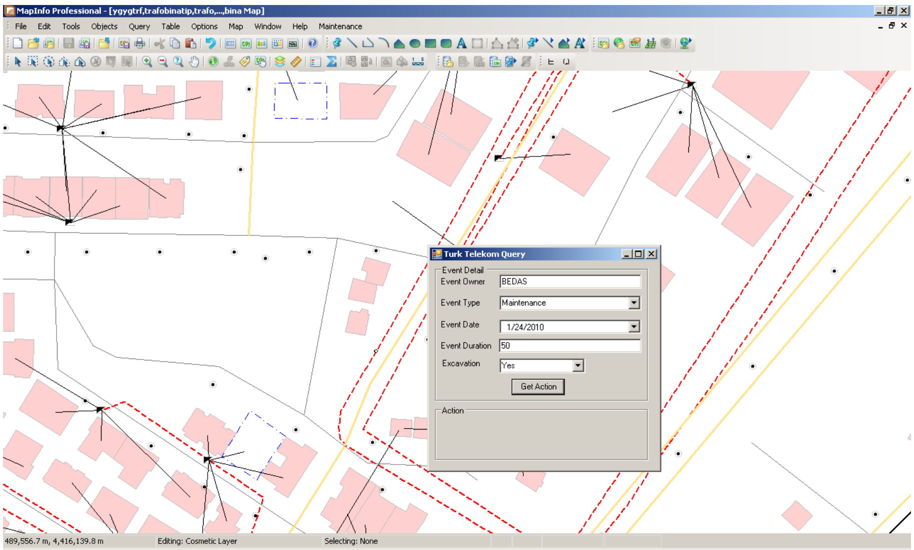

Figure 59 The Event details dialog box (MapInfo screenshot)

The operator provides the required information and presses the Get Action button. The information is sent to the AYKOME Web Service to come up with an appropriate action. The appropriate action is based on inference. Because the operator adds a maintenance event to perform a query, BEDAŞ GIS knows that it should be adopted to maintenance context. Therefore inference is made according to rule base for maintenance context. The SWRL rules defined in the maintenance context decide the right action to be taken. Execution of SWRL rules are performed by application programming interface (API) of Jess. The API provides two methods, namely, runSQWRLQueries and getSQWRLResult, which are used to execute and obtain results of a SWRL rules. The result is displayed on the same dialog box (See Figure 60).

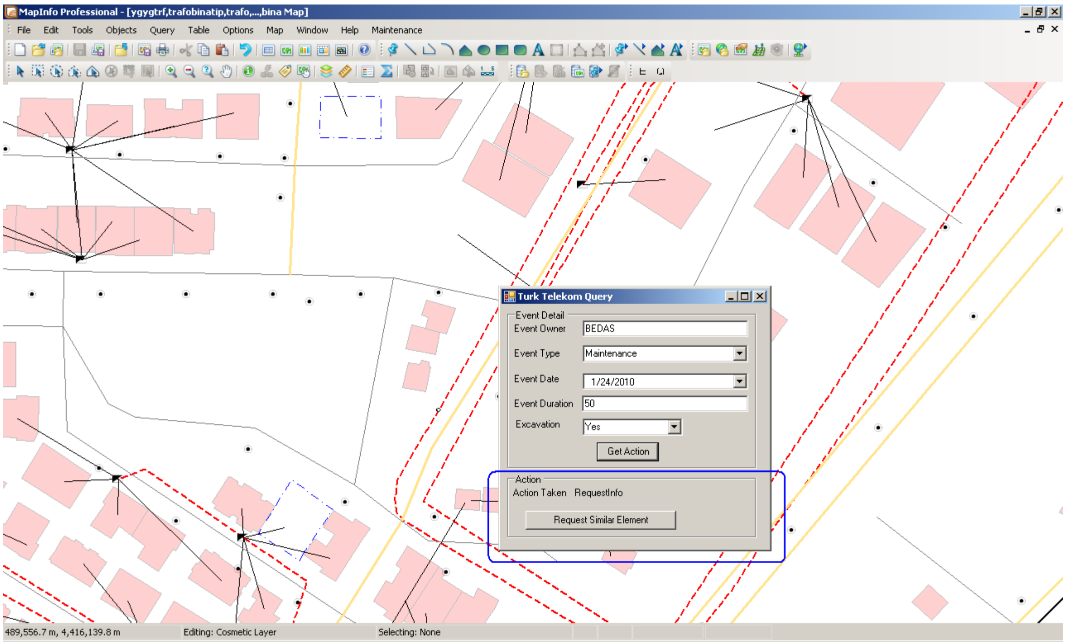

Figure 60 Correct action that should be taken (MapInfo screenshot)

If the right action is returned to be the RequestInfo, then the Request Similar Element button is appeared (See Figure 60). By pressing the button, the element request is sent to the AYKOME Web Service, which is the mediating component between the two GISs. Before sending request, the BEDAŞ GIS finds the BEDAŞ network element at the point the event is associated with and searches BEDAŞ web service for corresponding top level common vocabulary ontology element. The reason why we are searching for the common vocabulary element is that the BEDAŞ operator does not know the structure of the TT GIS, so he is requesting the element in terms of common vocabularies terms. If corresponding common vocabulary element is distribution line, the distribution line individual from Common Vocabularies Ontology is created at the end of the request sending. Creation is performed by Protégé API. The API provides a method createOWLIndividual for any classes (See Figure 61).

```
 @WebMethod
public void createDLIndividual(@WebParam(name="DistributionLineInstance") String dlIndividual)
        throws OntologyLoadException, URISyntaxException, Exception
{
    String u="file:///E:/Doktora-PhD/Thesis/OntologyWorks/CommonVocabularies/CommonVocabularies.owl";
    JenaOWLModel cvOwlModel=ProtegeOWL.createJenaOWLModelFromURI(u);
    URI uri=new URI(u);

    OWLNamedClass distributionLineClass=cvOwlModel.getOWLNamedClass("http://localhost/CommonVocabularies.owl#DistributionLine");
    OWLIndividual m_DistributionLine=distributionLineClass.createOWLIndividual(dlIndividual);
    cvOwlModel.save(uri);
 }
```

Figure 61 createDLIndividual method and usage of createOWLIndividual method of Protégé API (NetBeans screenshot)

In addition GM_Point individual from Spatial Representation Ontology is also created for the location of the event (See Figure 62 and Figure 63).

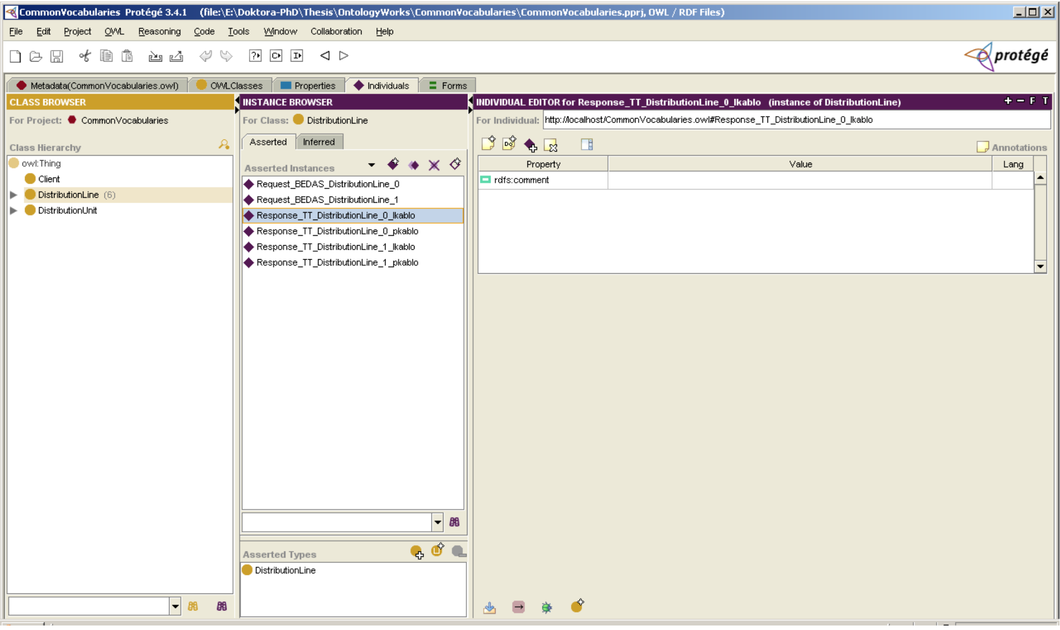

Figure 62 The distribution line instance created in the common vocabularies ontology (Protégé screenshot)

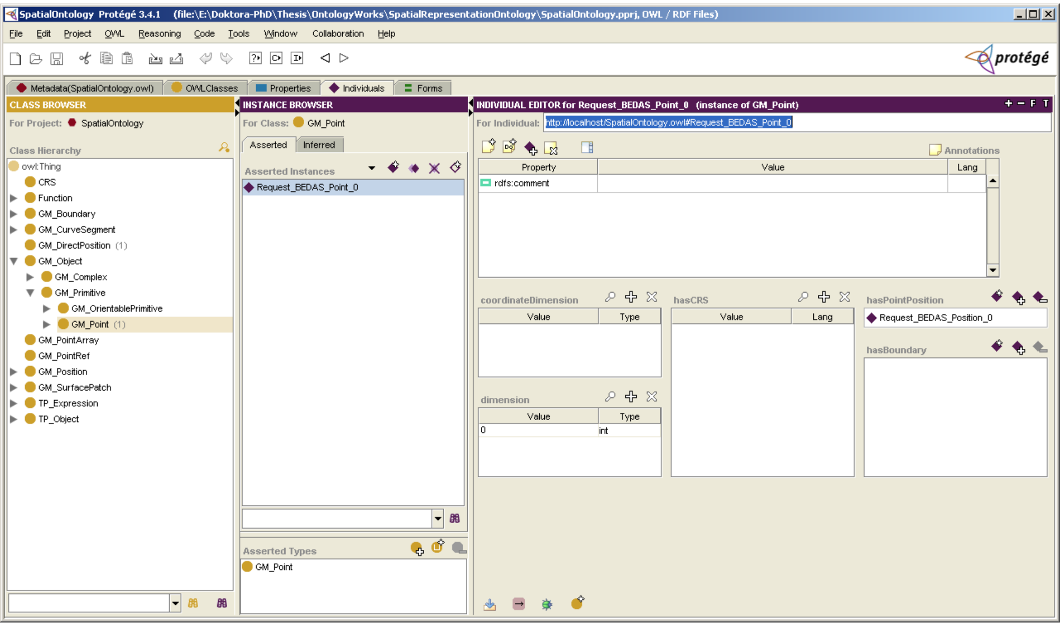

Figure 63 The GM_Point instance created in spatial representation ontology (Protégé screenshot)

After information request has been sent, the TT operator checks for if there is any request. He is checking the request in terms of common vocabulary elements because information request is sent in terms of common vocabulary term and related individuals are created in Common Vocabularies Ontology (See Figure 65). Checking operation is performed by querying created individuals distribution line individual in Common Vocabularies Ontology. The individuals are obtained from the ontology by using getDirectInstance method of Protégé API (See Figure 64).

```
 @WebMethod
public String[] getAllDLIndividual() throws OntologyLoadException, URISyntaxException
{
    String u="file:///E:/Doktora-PhD/Thesis/OntologyWorks/CommonVocabularies/CommonVocabularies.owl";
    JenaOWLModel cvOwlModel=ProtegeOWL.createJenaOWLModelFromURI(u);

    OWLNamedClass distributionLineClass=cvOwlModel.getOWLNamedClass("http://localhost/CommonVocabularies.owl#DistributionLine");

    Collection  dlIndividualArray = distributionLineClass.getDirectInstances();
    Integer collcount=dlIndividualArray.size();
    Integer i=0;
    String[] dlArray=new String[collcount];
    for (Iterator it=dlIndividualArray.iterator();it.hasNext(); )
    {
        OWLIndividual individual = (OWLIndividual) it.next();
        dlArray[i]=individual.getBrowserText();
        i++;
    }
    return dlArray;
 }
```

Figure 64 getAllDLIndividuals method and usage of getDirectInstance method in Protégé API (NetBeans screenshot)

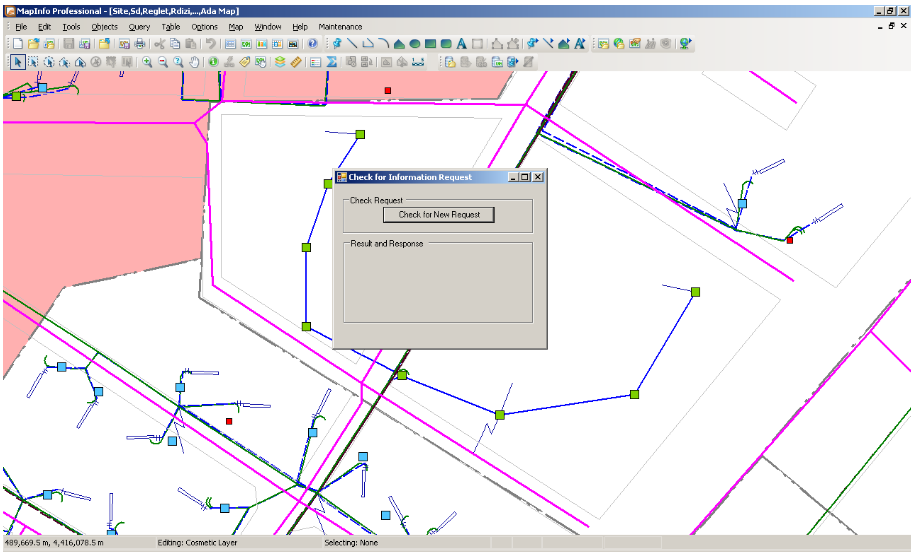

Figure 65 The dialog box for checking new request from TELEKOM GIS (MapInfo screenshot)

The result of the checking operation is displayed on the same dialog box. If there is a request, then it is listed in the drop down list on the dialog box (See Figure 66).

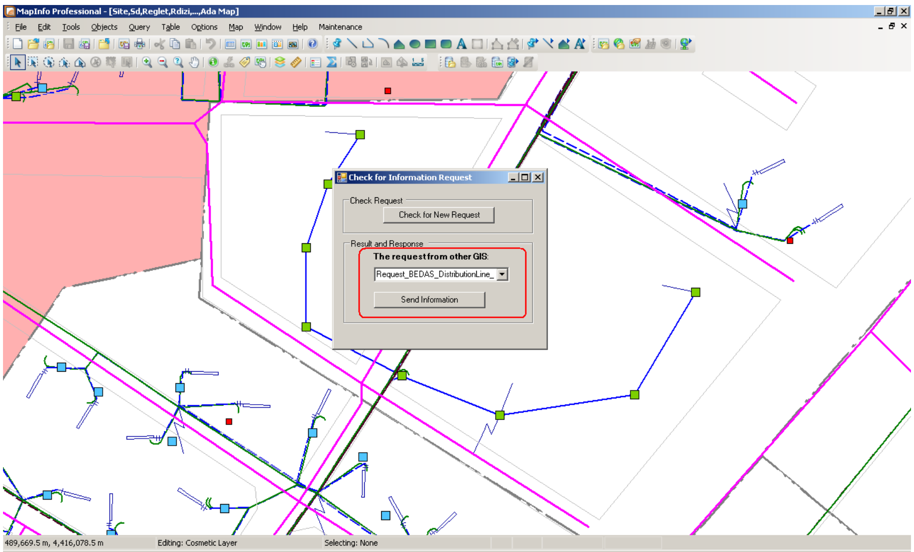

Figure 66 The request sent by BEDAŞ (MapInfo screenshot)

If there is any TT element at the location where BEDAŞ maintenance will take place, TT operator sends it. Before sending the element, the TT GIS communicates with the TELEKOM web service in order to find TT network elements, which are subclasses of corresponding common vocabularies element. Then the network elements are sent to the AYKOME web service as an answer to the BEDAŞ query. The network elements sent as a response are also in terms of common vocabularies. The last step of the scenario is to check for the response of TT system and show the response at the map. These operations are performed by another dialog box developed in Microsoft .NET environment. First, the operator at BEDAŞ checks the AYKOME web service for any response available from TT. If there is any response, then they are listed within the same dialog box (See Figure 67).

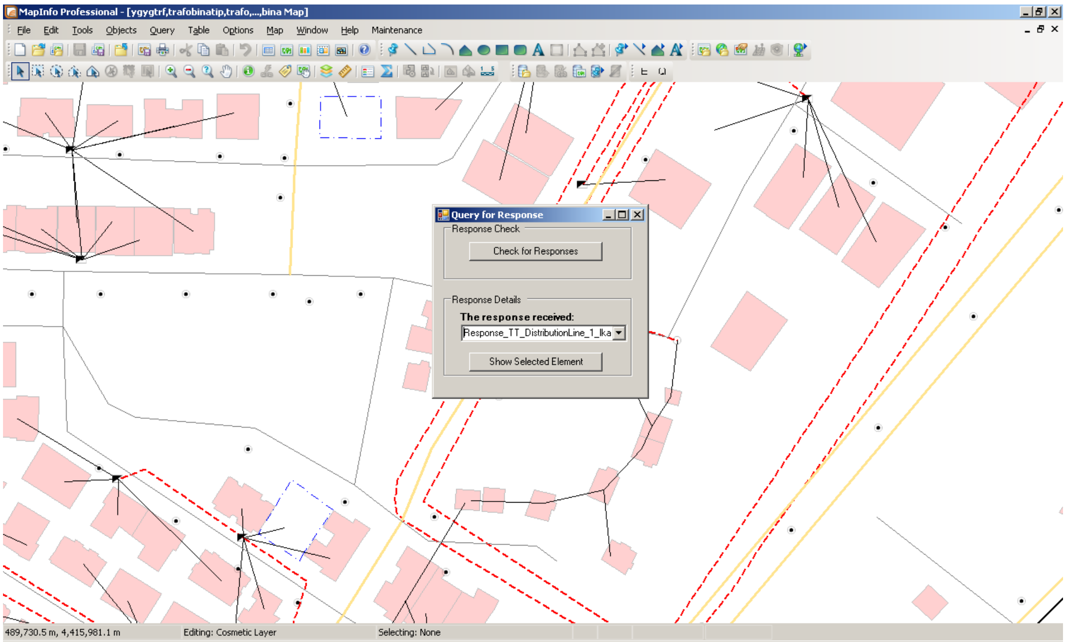

Figure 67 Response returned by the TT GIS (MapInfo screenshot)

There can be more than one element in the response. Therefore, operator selects one of the elements and displays the element on the map (See Figure 68).

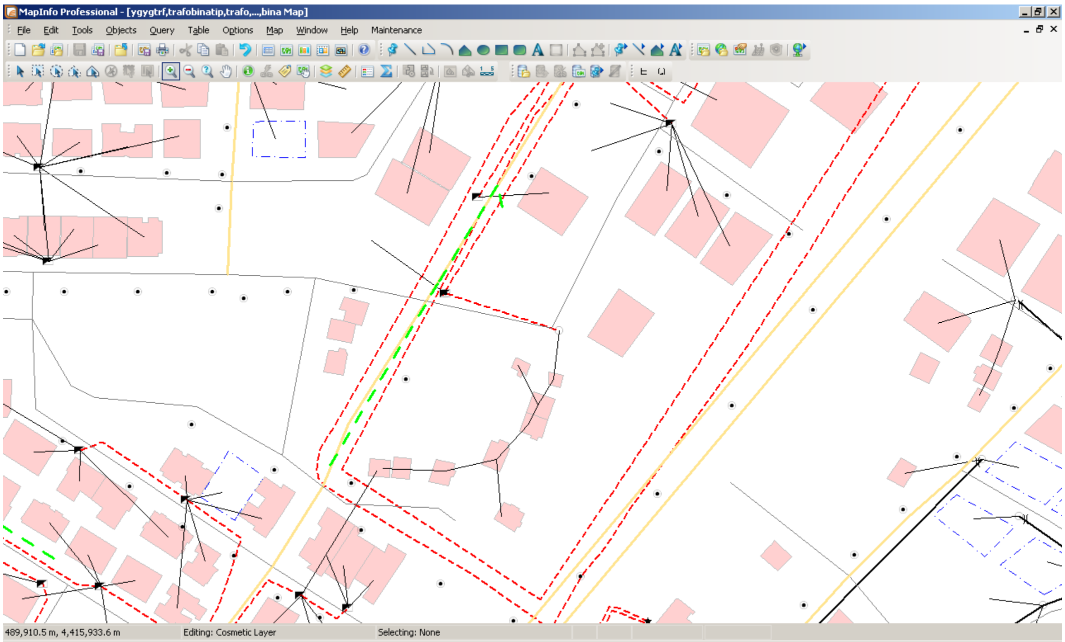

Figure 68 Element of TT network displayed on the map (MapInfo screenshot)

5.2 Second Scenario: Effects of GIS on each other

The second scenario allows interaction between GIS's. When an operator at the infrastructure company plans an event, the possible effects of the event on the company itself and other companies should be examined. The exact process of the second scenario can be summarized as;

1. The operator at BEDAŞ makes a plan to repair or maintain a network element at some point.

2. The system responses what actions to be taken to make the maintenance possible.

3. The maintenance plan is sent to the AYKOME web service to store in the Maintenance Context Ontology.

4. The operator performs the actions on the GIS and affected BEDAŞ elements and clients are displayed on the map.

5. The streets which are affected by the action are sent to the AYKOME web service to store in the Spatial Representation Ontology.

6. The TT operator query AYKOME web service to get whether there is an event and affected streets.

7. TT GIS decide a context in which it exists

8. If there is an event, operator gets the affected streets, find action effect range and find affected elements on the network.

9. The system displays affected element on the map.

In this scenario, the major information flow is through the streets. Because, if there is an electricity service is unavailable at some location, the affected locations can be identified in terms of streets. When streets are marked then all the locations in which the electricity is to be cut off can be easily seen. The business flow of the scenario is given in Figure 69.

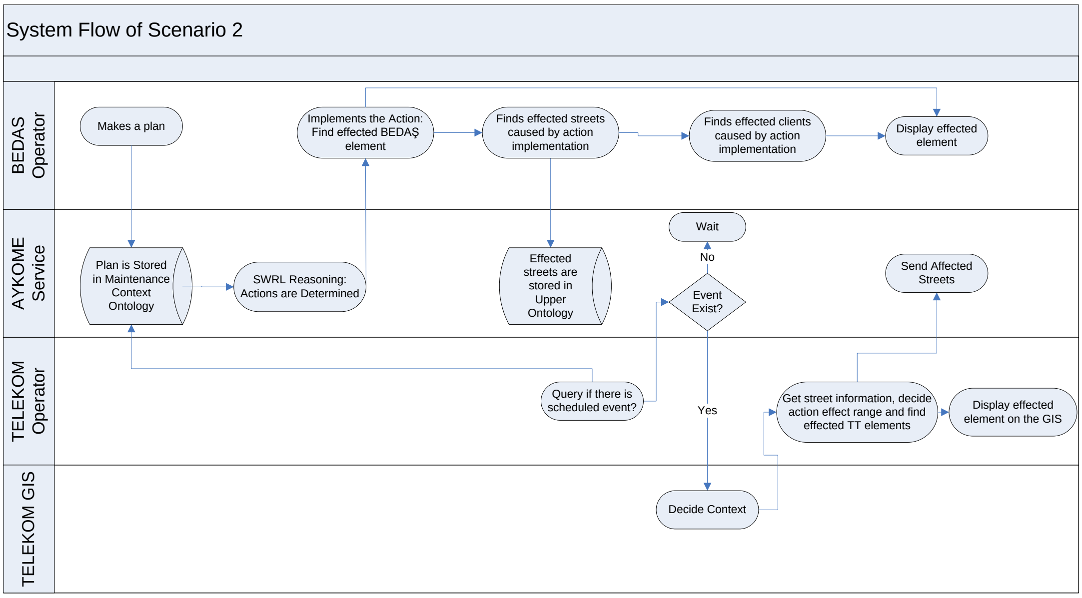

Figure 69 Business flow of Scenario 2

The scenario is implemented by using AYKOME web service and the add-ons developed. The web service is responsible for;

- Find the necessary actions by using SWRL rules defined in the maintenance context ontology.
- Store event and street information in the common vocabulary and spatial representation ontology respectively.

The GIS menu and button pad developed in the first scenario are used in the second scenario. The operator makes the plan by using button added to the GIS (See Figure 70).

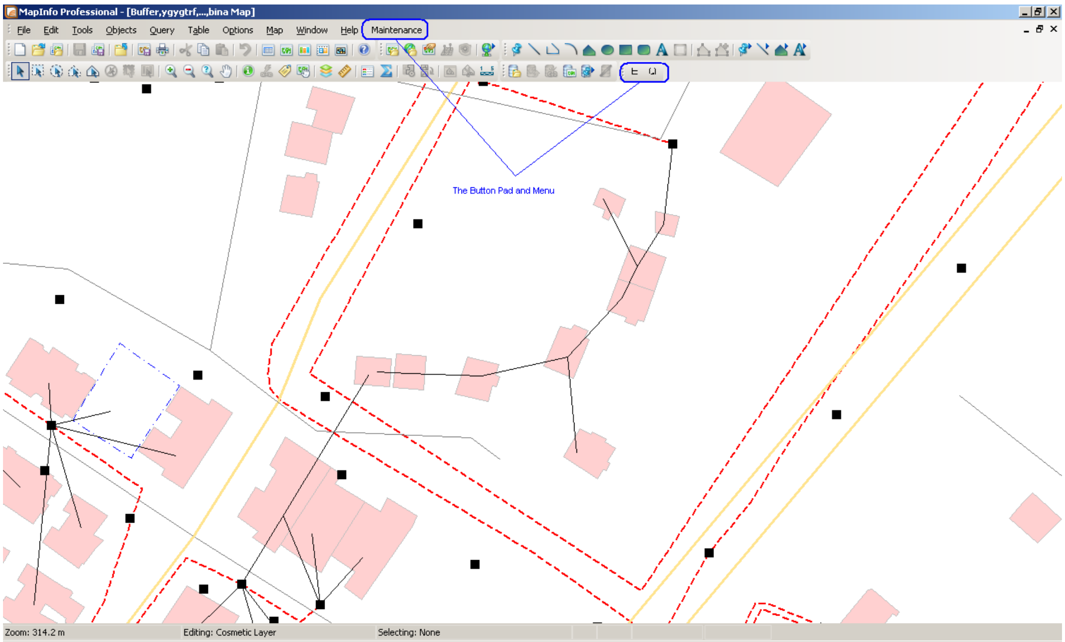

Figure 70 Menu and button pad added to the GIS (MapInfo screenshot)

The dialog box used for event scheduling that is given in Figure 71is appeared after operator clicking a location on the GIS. The requested information are given to the system by using event scheduling dialog box The event information is created in the Maintenance Context ontology as event individual by createOWLIndividual method of Protégé API (See Figure 61). The date, duration, location and object type property, which explains the type of distribution line in BEDAŞ network, are also recorded in the ontology as an instance (See Figure 72). Creating event individuals in Maintenance Context ontology tells interoperating GISs about context information. In other words, BEDAŞ and TELEKOM GISs know that if an event individual is created in Maintenance Context Ontology, they are in Maintenance Context. Therefore context changes can be detected by checking event individuals.

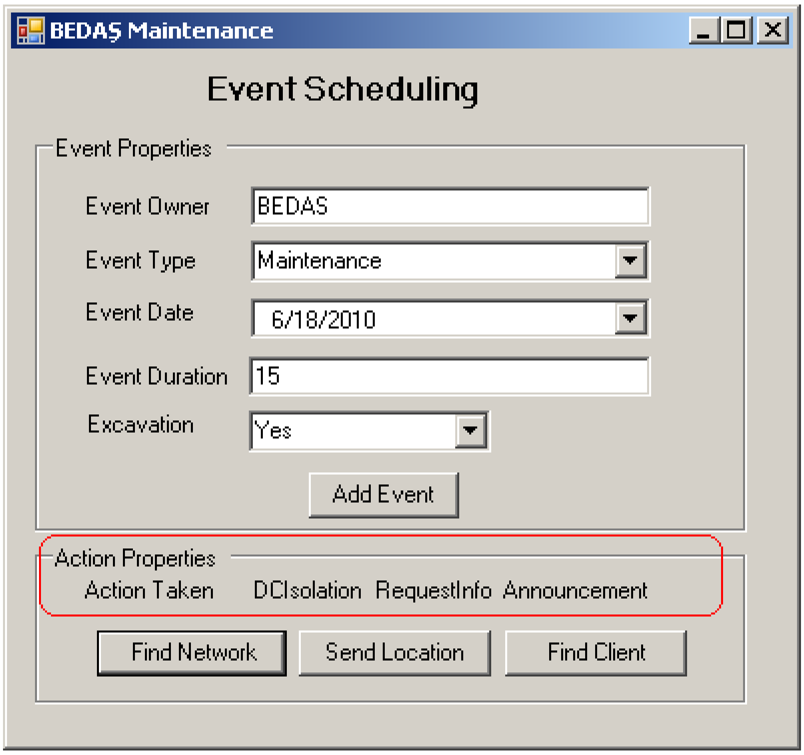

Figure 71 Event Scheduling dialog box

The system returns the actions that should be taken to the operator (See Figure 71). Similar to Scenario 1, GIS knows that, operation performed is related with the maintenance context. Therefore these actions are decided by running SWRL rules in Maintenance Context Ontology.

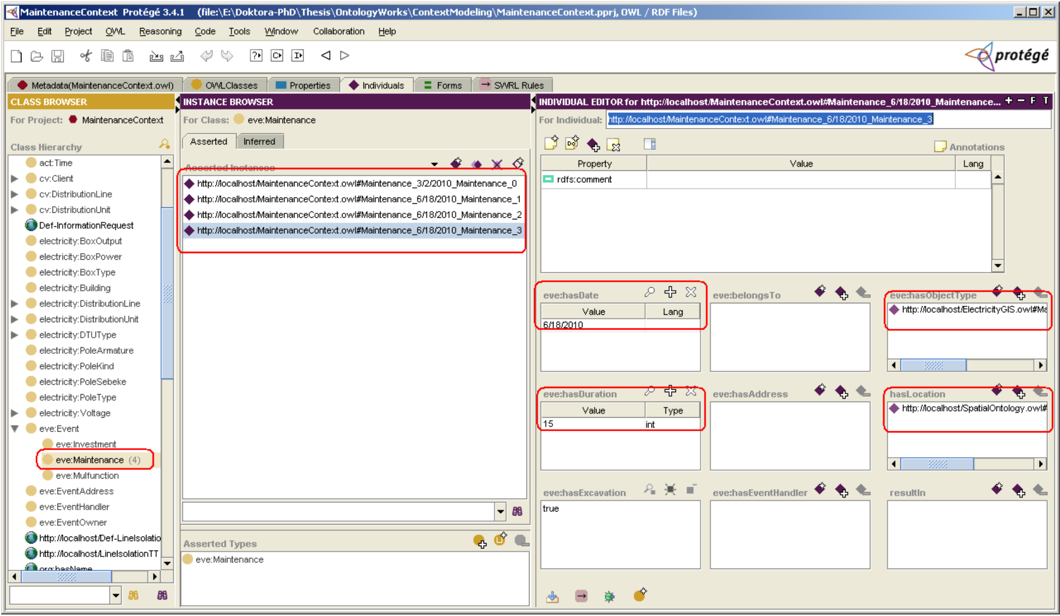

Figure 72 The ontology individuals created as a result of scheduled event (Protégé screenshot)

At the next step, the BEDAŞ GIS calculates the affected network according to the action returned which is triggered by pressing the button Find Network in Figure 71. If the action is DCIsolation as shown in Figure 71, the distribution centre in the BEDAŞ network is the starting point where the electricity cut off will take place. The calculated network affected by an event is marked at the GIS (See Figure 73). On the Figure, red dotted line is the mid-voltage whose voltage value is 34.5 kV. Pink boxes represent clients and black lines connecting clients to the network is Rekortmans. Black squares are for boxes and black line connecting boxes are low-voltage lines.

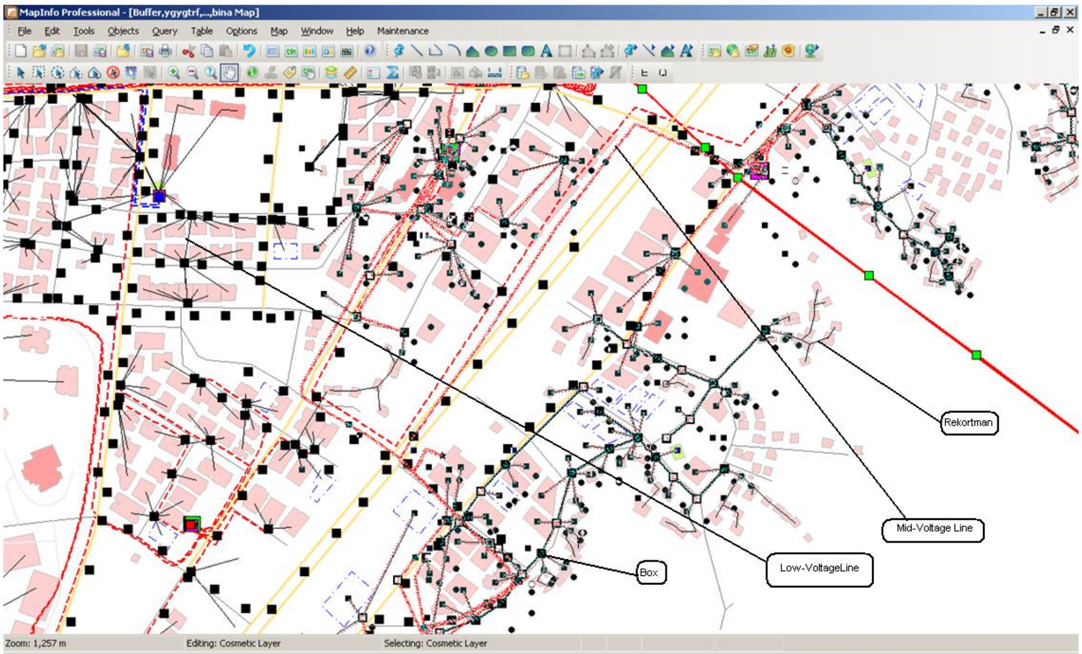

Figure 73 Calculated effect of an event on the network (MapInfo screenshot)

The Send Location button on the Event Scheduling dialog box (see Figure 72) is used to calculate the streets where the electricity is cut off due to an event and send those streets to the other TT GIS. Sending is performed by storing those streets in the Spatial Representation Ontology. After that, the system calculates the affected clients on the BEDAŞ network and displays them on the GIS (See Figure 74). In the figure, shaded pink and green areas represent affected clients of the BEDAŞ network due to an event.

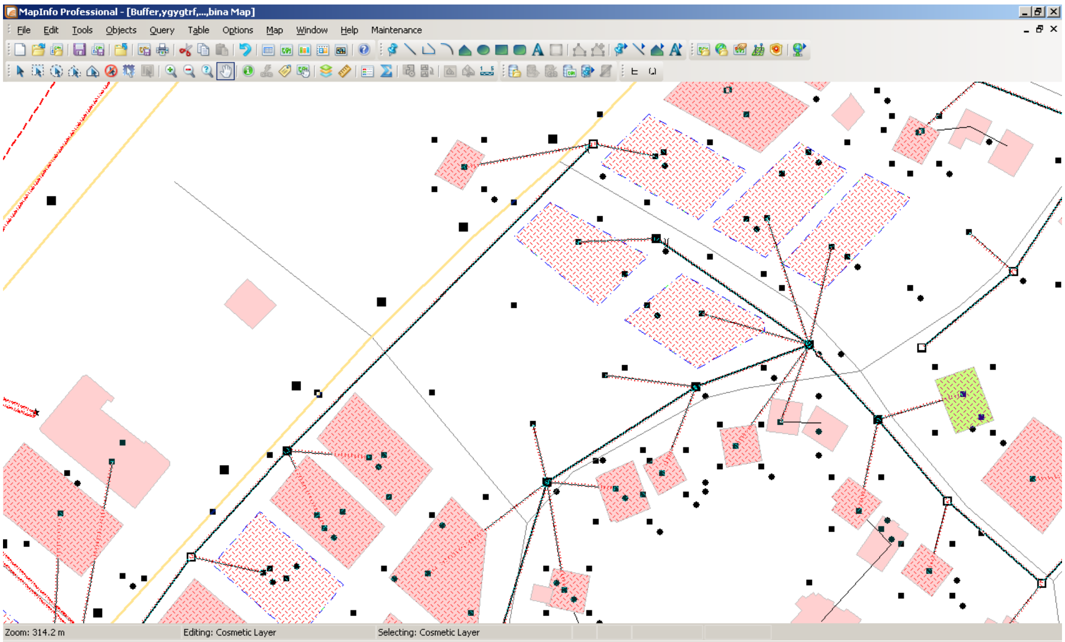

Figure 74 Effected clients on the BEDAŞ network due to an event (MapInfo screenshot)

The maintenance menu has been added to the TT GIS as an add-on to search for information request and check if there is a scheduled event (See Figure 75). The add-on is coded by MapBasic for TELEKOM GIS.

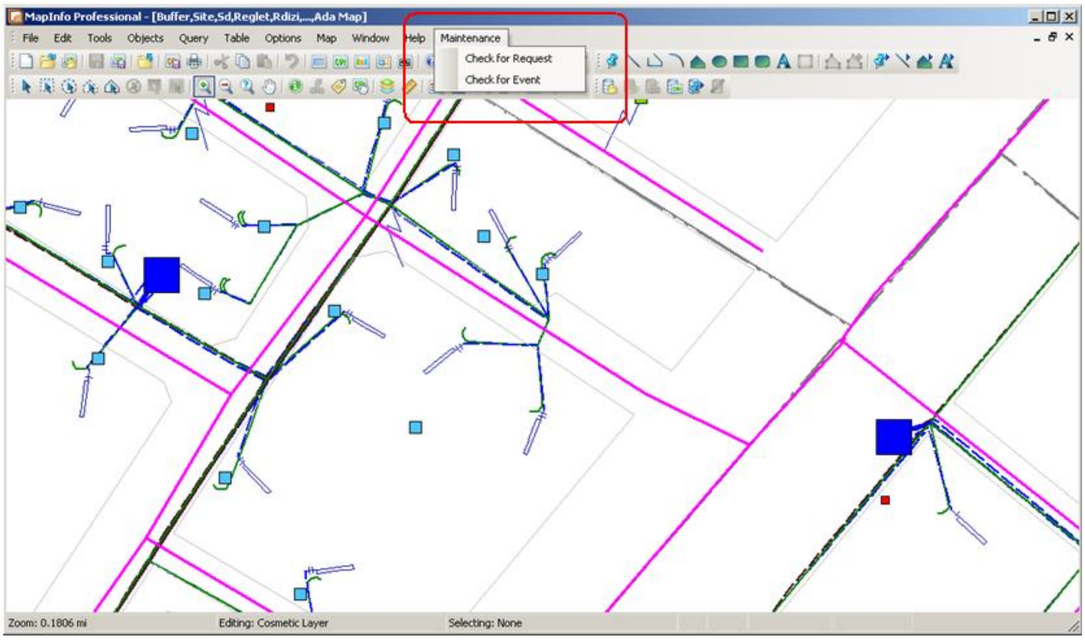

Figure 75 The maintenance menu of the TT GIS (MapInfo screenshot)

Check for Event menu is calling the dialog box coded in the .NET environment which is used to search for scheduled event and the possible effects of the event on the TT network. The Check for Event button has retrieved the event individuals from the Context Ontologies and lists them on the drop down list on the Check Event Information dialog box which is shown in Figure 76. While the individual is retrieving from the Context Ontologies, systems checks if individual belongs to InfrastructureCompanyEvent classes or EmergencyEvent classes. TT GIS understands its context according to owning class of event individual. The current context is also displayed on Figure 76.

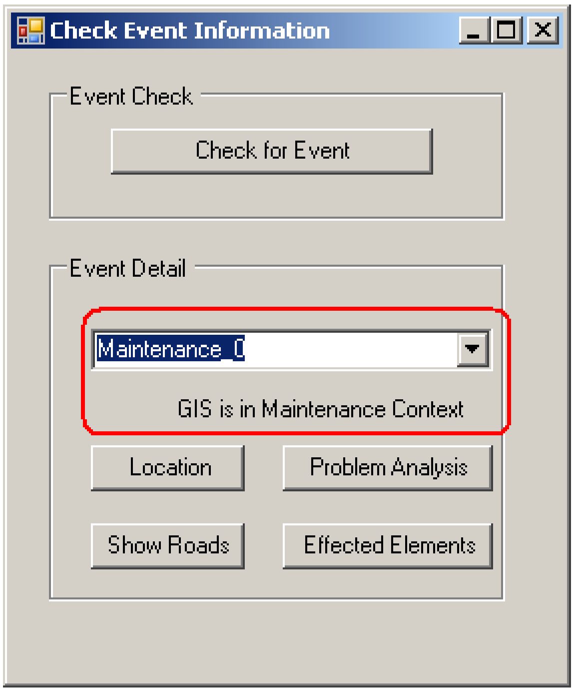

Figure 76 Check event information dialog box

The same dialog box is used to evaluate the possible problems caused by an event in the TT network. After the location of the event is obtained by getting event individuals form Context Ontologies, then the problem analysis is performed. The TT network element is searched within the 2m diameter of the event location. The search range "2m" also depends on the context. In other words 2m diameter is defined in the Maintenance Context as an effect range of an event if there is an excavation by SWRL rule which is given in Figure 77.

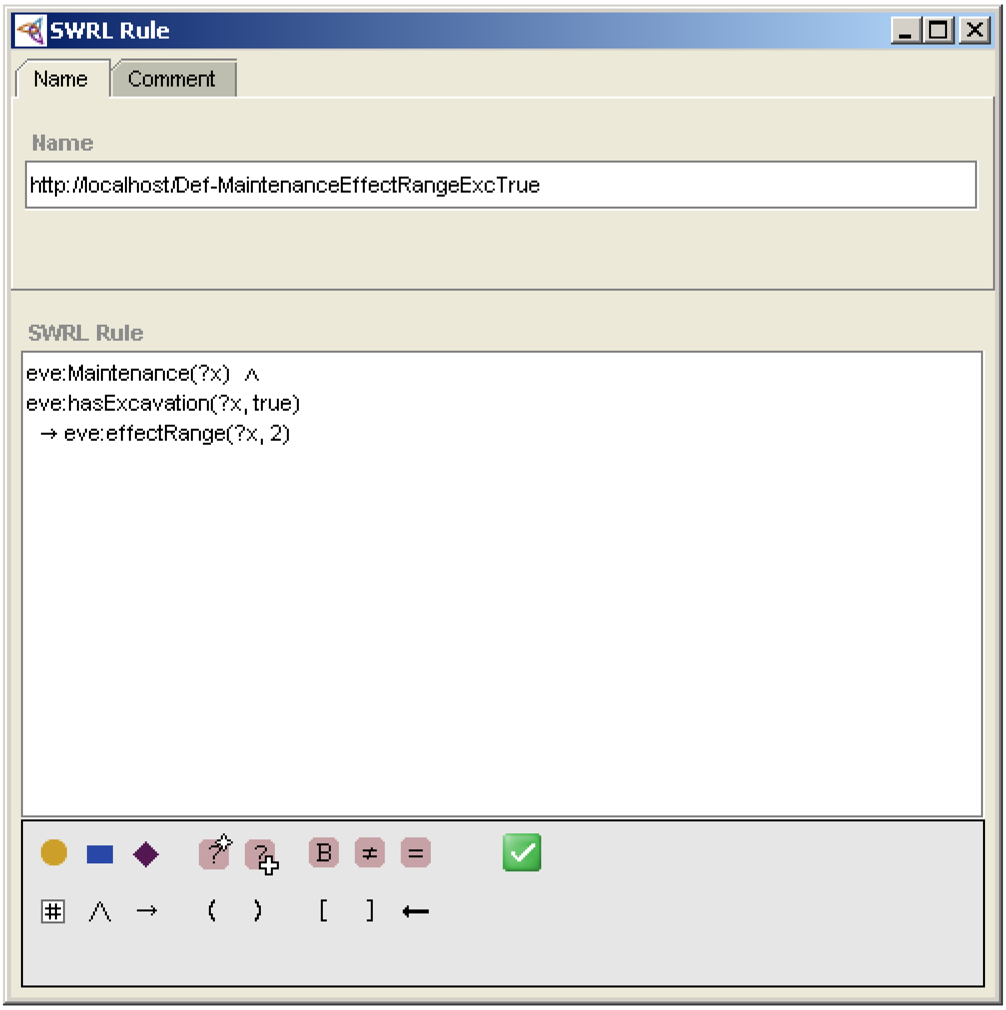

Figure 77 Definition of effect range for an event if there is an excavation (Protégé screenshot)

The assumption of the problem analysis is that; if there is an element, and then there is a possibility of affecting that element from the excavation process. The problem analysis is performed by using Location and Problem Analysis buttons in Figure 76 and event location and possible effects are displayed on the map (See Figure 78).

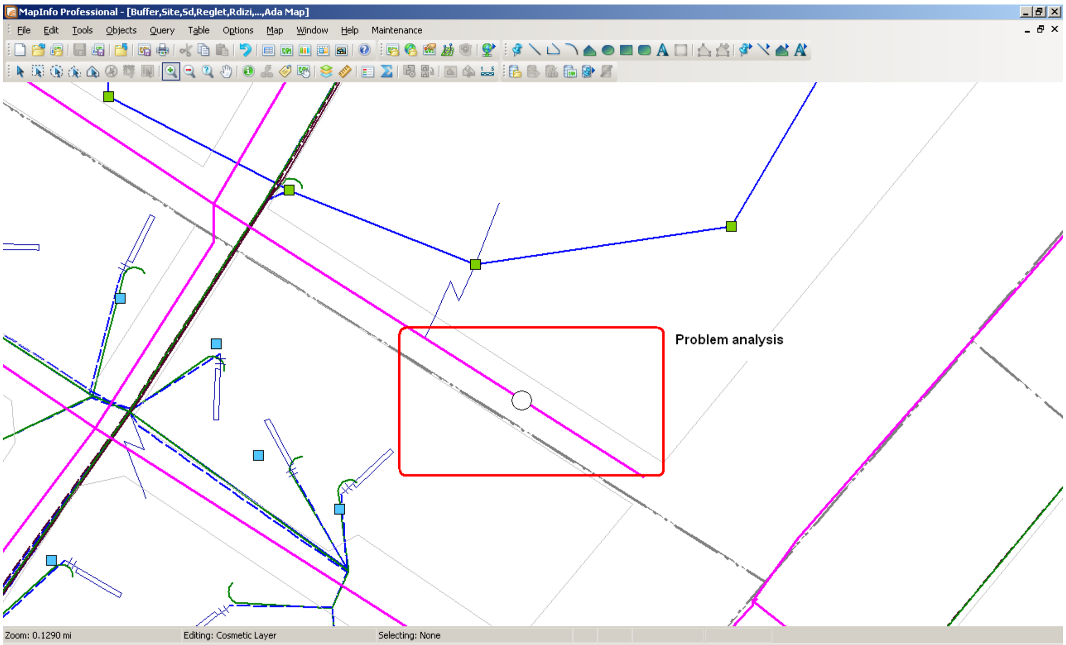

Figure 78 The location of the event and the problem analysis on TT network (MapInfo screenshot)

The streets where the electricity is broken are sent from the BEDAŞ GIS. At the next step, these streets are taken from the spatial representation ontology and displayed on the map as green dotted lines, which are shown in Figure 79.

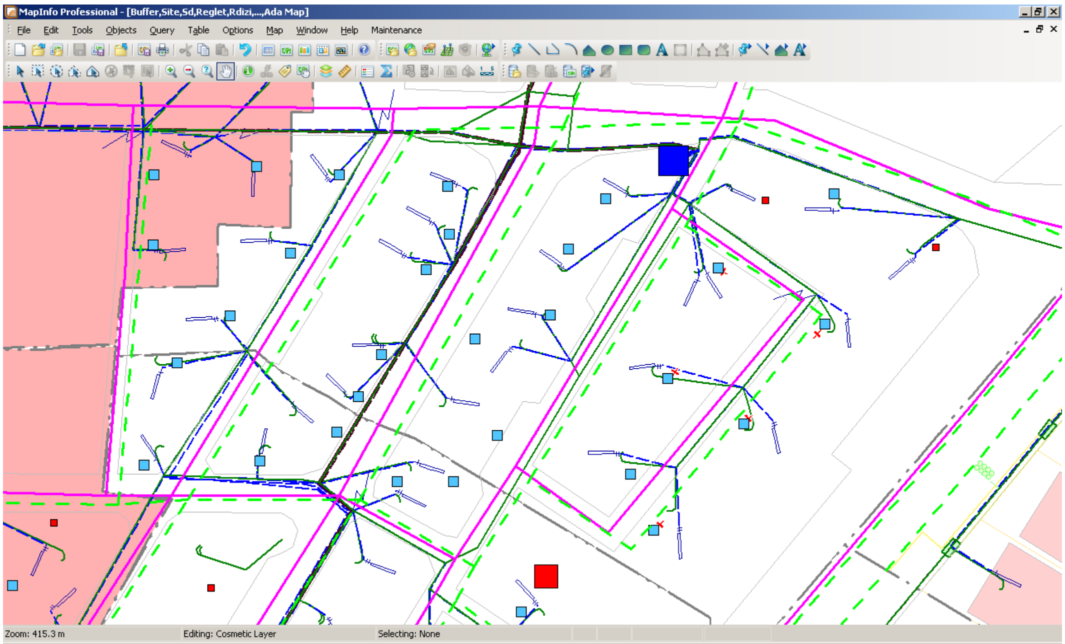

Figure 79 Streets created on the TT GIS (MapInfo screenshot)

As these streets are representing the area where electricity is cut off, the TT field cabinets located near to these streets may be affected by the loss of power. These field cabinets are founded by searching the TT network for these nodes that are located inside the 30m distance from those streets. Similar to effect range for an event, “30m” distance is also context dependent. It is designed as a range as a result of an action which is given in Figure 80.

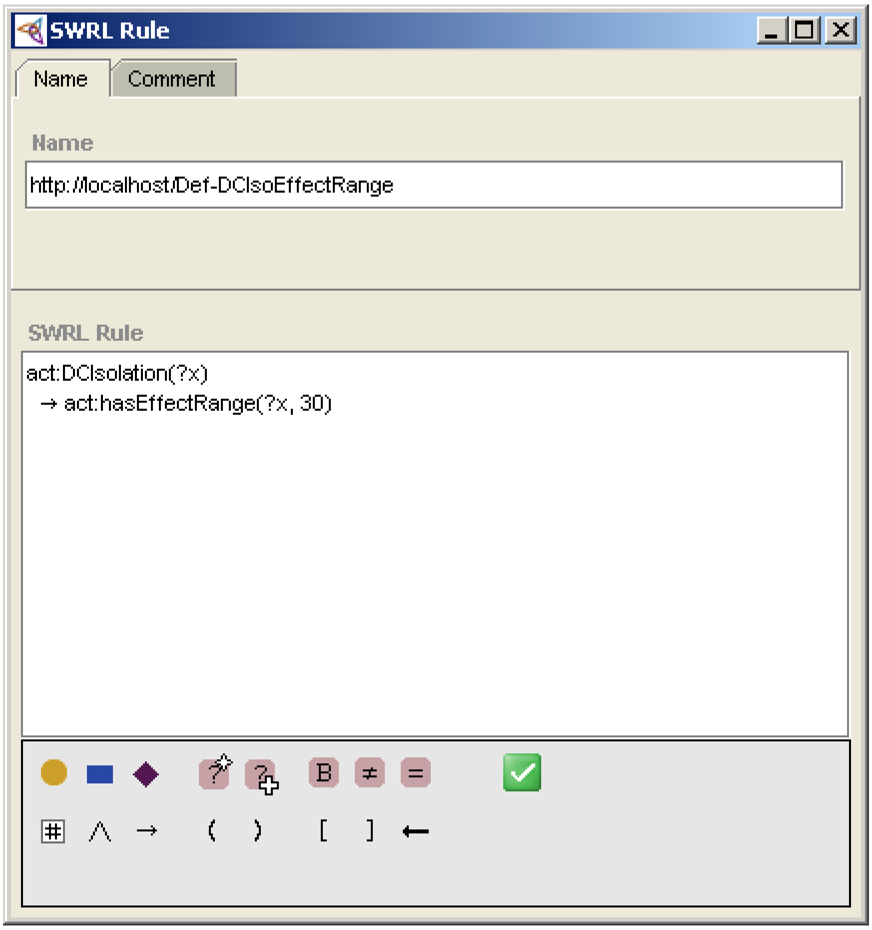

Figure 80 Definition of a range for DCIsolation action (Protégé Screenshot)

Affected field cabinets are marked on the map with red square and they are shown on the map (See Figure 81).

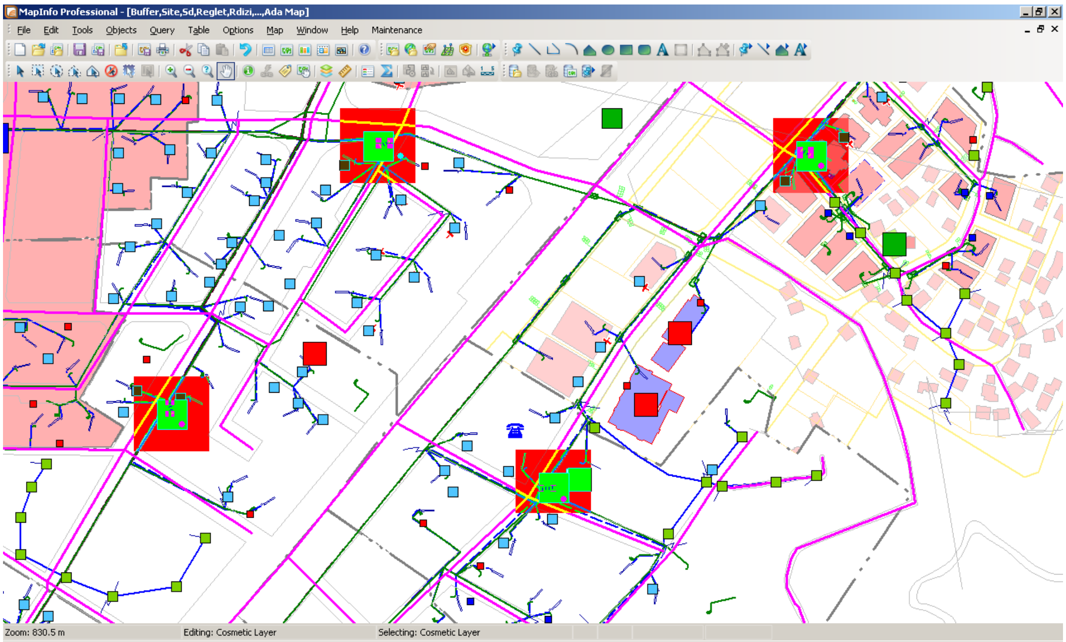

Figure 81 Effected TT elements from scheduled event (MapInfo screenshot)

5.3 Third Scenario: Emergency Context

In order to see how interoperating GIS systems response to context changes, emergency context is added into this study. In this scenario, a flood situation is examined. Sample flood individual is inserted into the Context Ontologies by add-ons designed for this scenario and a flood area is marked on the GISs. However, because a flood creating and flood area marking are out of the scope of this study, the mechanisms of creating flood individual is not discussed in this section.

The objective is to catch the context in which BEDAŞ GIS exists and to model the results of a flood for BEDAŞ GIS and to model the consequences of an action taken by BEDAŞ GIS on TT GIS. The exact processes of scenario are as follows:

1. BEDAŞ Operator checks events for the current day
2. If there is an event, BEDAŞ GIS find out which context it should adopt

3. BEDAŞ Operator sends a query to the AYKOME web service to learn the required action to be taken

4. BEDAŞ Operator performs the action and affected BEDAŞ elements are displayed on the map

5. The streets which are affected by the action are sent to the AYKOME web service to store in the Spatial Representation Ontology

6. The TT operator query AYKOME web service to get whether there is an event and affected streets.

7. TT GIS decide a context in which it exists

8. If there is an event, operator gets the affected streets, find action effect range and find affected elements on the network.

9. The system displays affected element on the map.

Similar to Scenario 2, the major information flow is through the streets. The business flow of the scenario is given in Figure 82.

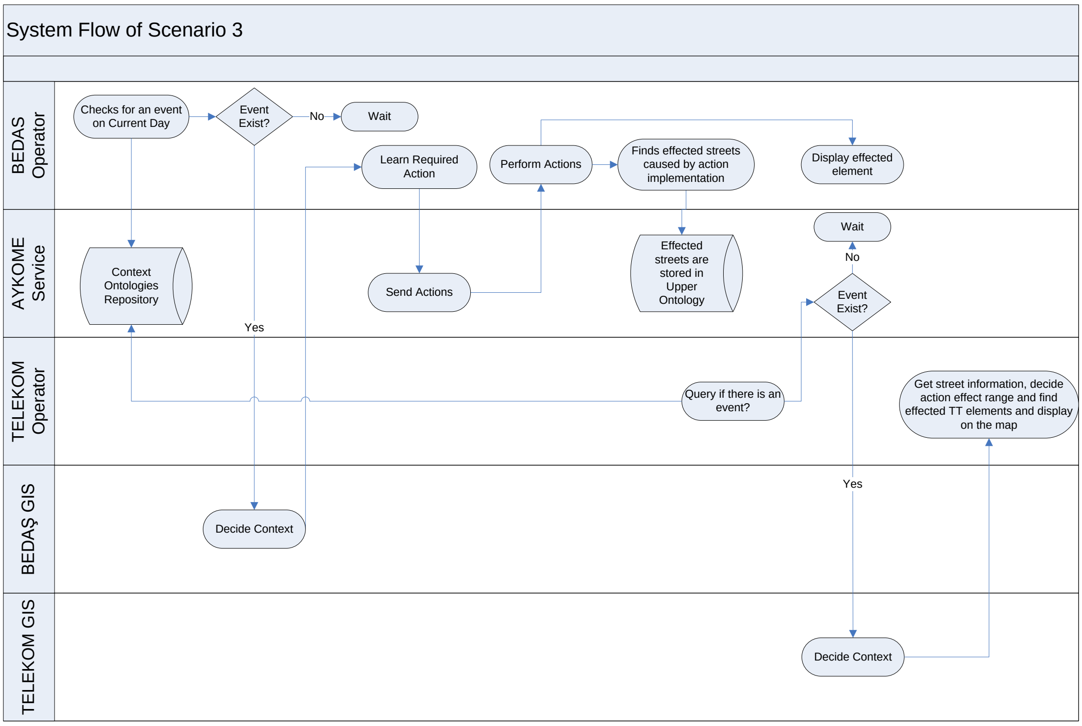

Figure 82 Business flow of Scenario 3

This scenario is starting with acquiring of flood area and flood individual from Context Ontologies. Flood area is marking on the GIS and events are retrieved by the help of the add-on developed for Scenario 3 (See Figure 83 and Figure 84).

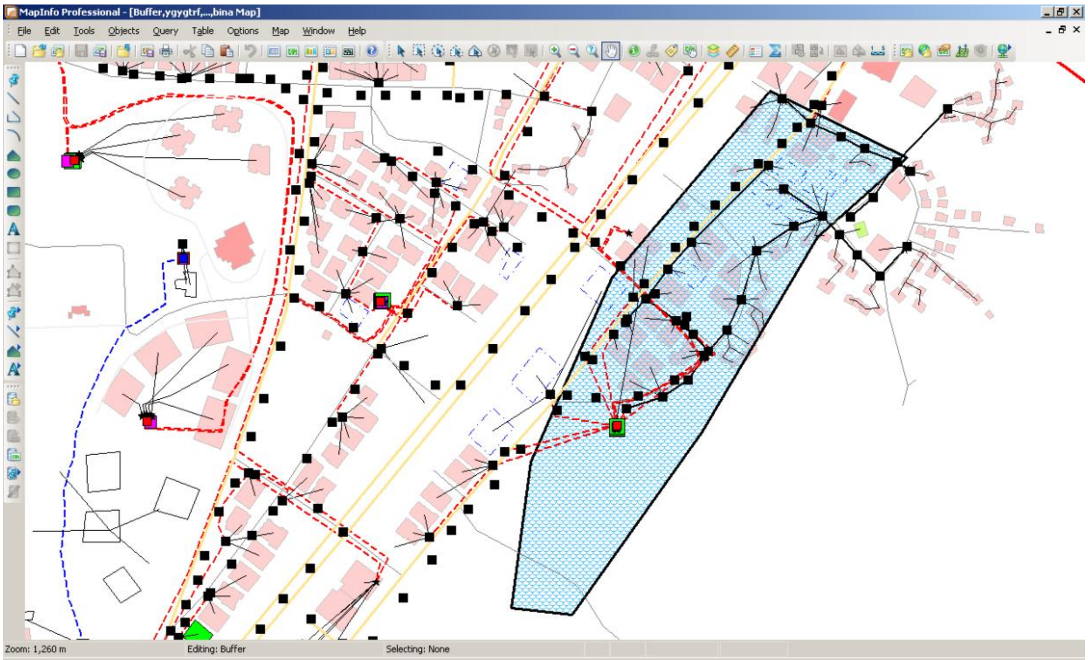

Figure 83 Flood are marked on the BEDAŞ GIS

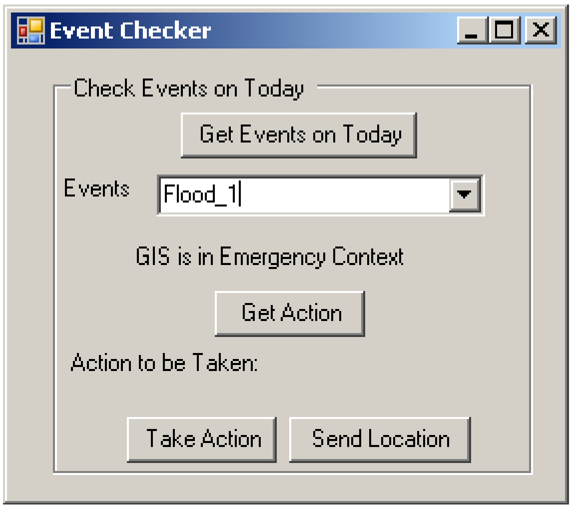

Figure 84 A Listed events and context information

In Figure 84, events on the current day are listed. When an operator selects one of the events, system checks for the owning class of selected event. By this way GIS can understand the context information and rule base, which should be used while deciding actions. The correct context is also displayed on the same dialog box (See Figure 84).

When an operator presses the button "Get Action" in Figure 84, BEDAŞ GIS communicates with AYKOME web service and get required actions. An action is printed in the same dialog box as seen on Figure 85.

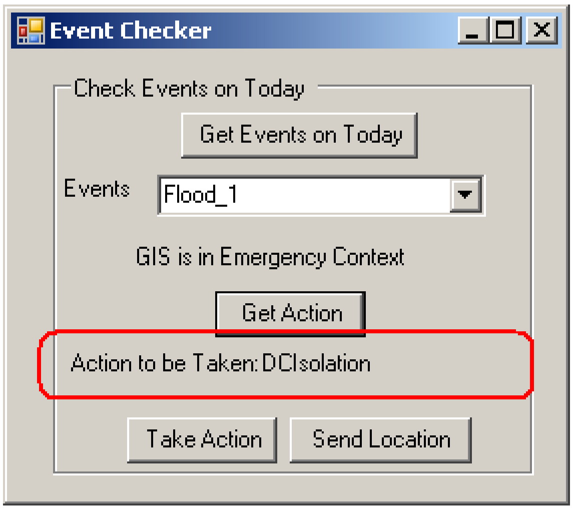

Figure 85 Required action as a result of selected event

After deciding the action to be taken, BEDAŞ operator presses the "Take Action" button and gets the affected elements on the GIS. The next step is sending affected locations to the TT GIS. Similar to Scenario 2, locations are stored in Spatial Representation Ontology as streets individuals.

The maintenance menu, which is used in Scenario 2, is also used in this scenario to search if there is an event (See Figure 86).

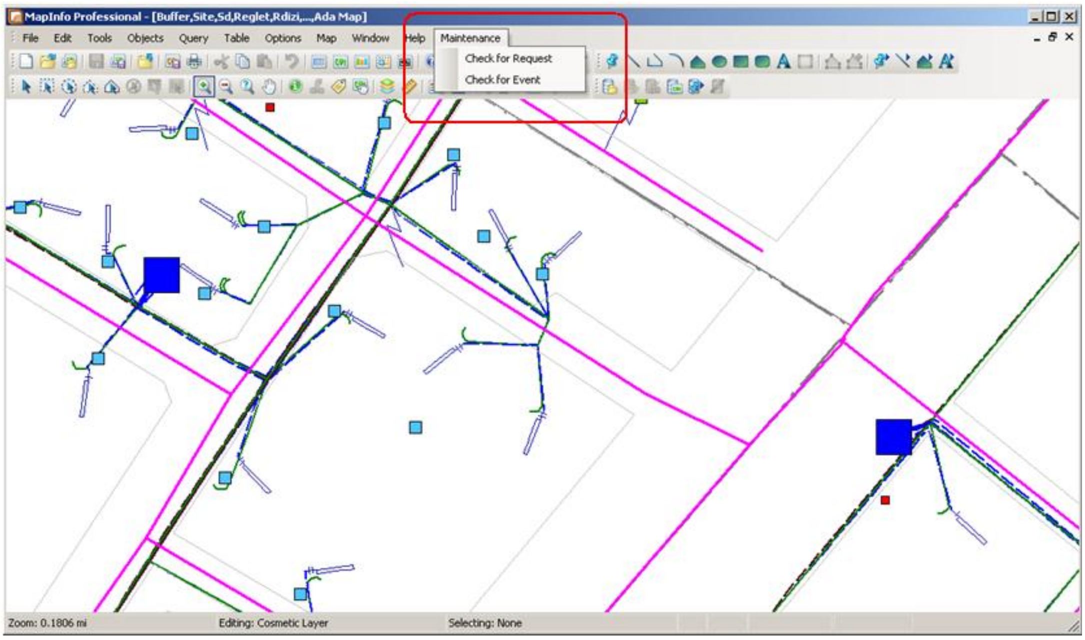

Figure 86 The maintenance menu of the TT GIS (MapInfo screenshot)

Check for Event menu is calling the dialog box coded in the .NET environment which is used to search for an event and the possible effects of the event on the TT network. Check for Event button has retrieved the event individuals from the Context Ontologies and lists them on the drop down list on the Check Event Information dialog box, which is shown in Figure 87. While the individual is retrieving from the Context Ontologies, system checks if individual belongs to InfrastructureCompanyEvent classes or EmergencyEvent classes in the Context Ontologies. TT GIS understands its context according to owning class of event individual. The correct context is also displayed in Figure 87. If context is an Emergency Context, TT GIS does not need to retrieve an event location. Because an event is not a maintenance event and location property is not entered by another GIS. Therefore "Location" button is disabled on Check Event Information dialog box. In this scenario, besides the effect of an event for both GIS systems, consequences of an action taken by BEDAŞ GIS on TT GIS is tried to be modeled.

Therefore “Problem Analysis” button is also disabled on the dialog box for Emergency Context.

Figure 87 Check event information dialog box

Similar to Scenario 2, the streets where the electricity is cut off are sent from the BEDAŞ GIS. At the next step, these streets are taken from the spatial representation ontology and displayed on the map as green dotted lines, which are shown in Figure 88.

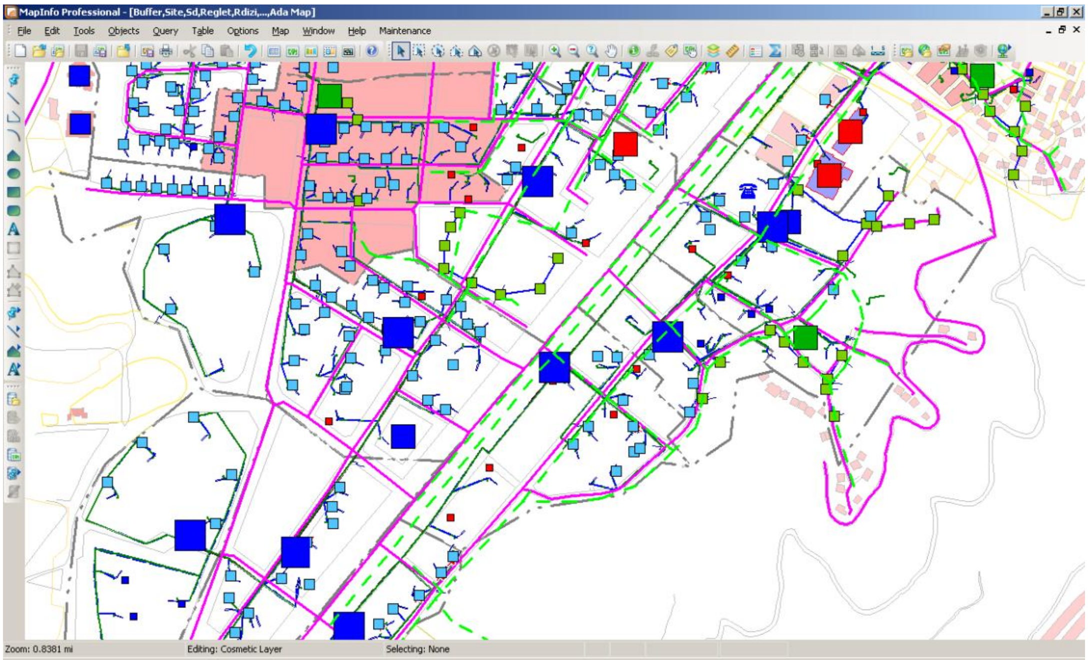

Figure 88 Streets created on the TT GIS (MapInfo screenshot)

These streets are representing the area where electricity is cut off, so TT elements, which require power, may be affected by this power loss. These elements can be found by the same way appointed in Scenario 2. The only difference is the search range depends on the Emergency Context.

Affected network elements are marked on the map with red square and they are shown on the map (See Figure 89).

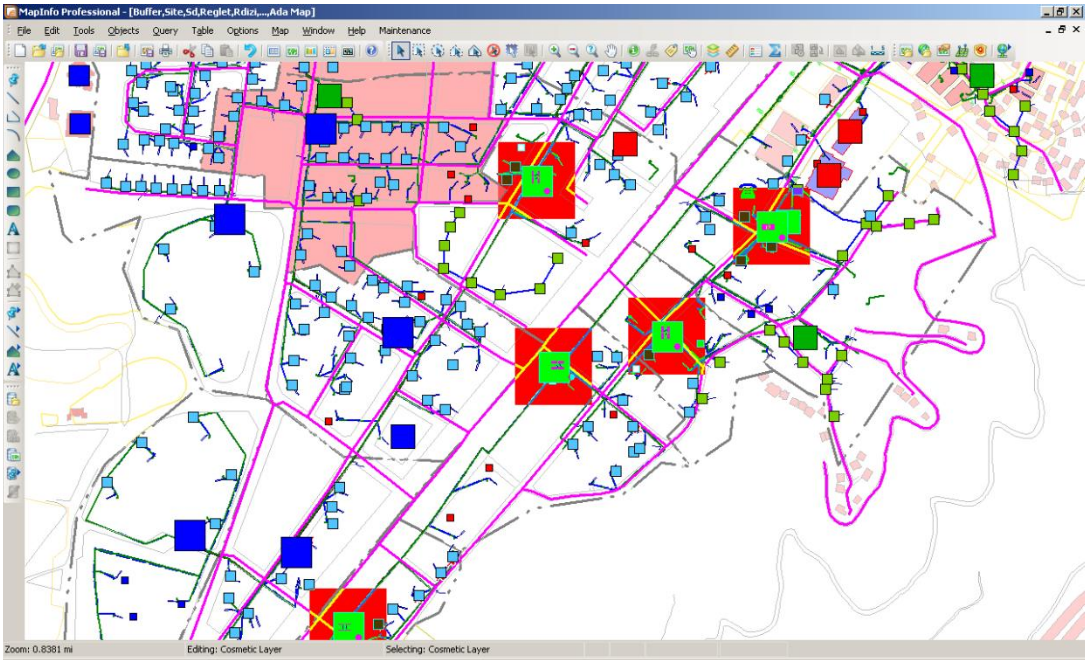

Figure 89 Effected TT elements from scheduled event (MapInfo screenshot)

Appendix E contains a DVD which has all the materials about this study. One can refer the DVD to run the system.

CHAPTER 6

CONCLUSION

Interoperability between Geographic Information System (GIS) of different infrastructure companies is still a problem to be handled. Infrastructure companies deal with many operations as a part of their daily routine such as a regular maintenance, or sometimes they deal with unexpected situations such as a malfunction due to natural event, like a flood or an earthquake. These situations may affect all companies and affected infrastructure companies response to these effects. Responses may result in consequences and in order to model these consequences on GIS, GISs are able to share information, which brings the interoperability problem into the scene.

The present research, aims at finding an answer to interoperability problem between GISs of different companies by considering contextual information. During the study, the geographical features are handled as the major concern and interoperability problem is examined by targeting them. The model constructed in this research is based on the ontology and because the meaning of the terms in the ontology depends on the context, ontology based context modeling is also used.

A system is implemented for two different GISs of two infrastructure companies which are electricity (BEDAŞ) and telecommunication (Türk Telekom), but flexible and open to new GIS systems. In addition a maintenance and emergency are chosen as sample contexts. The ontologies of sample infrastructures are constructed as application ontologies, which are derived from upper ontologies. On the other hand, context ontologies are used to model the maintenance and emergency. Geometric characteristics of entities are defined by another ontology whose base is ISO 19107. Together with the context ontologies and application ontologies, Semantic Web Rule Language (SWRL) is used to complete the knowledge base. “Jess”, the Rule Engine for the Java Platform, is used as a reasoner due to its SWRL and Web Ontology Language (OWL) ontology support. Jess is reasoning on SWRL rules to find out necessary actions to be taken as a result of an event performed by the infrastructure companies.

6.1 Review of Research

The interoperability problem between different GISs is handled by working on the electrical and communication infrastructure system of Ankara Metropolitan Municipality. With this base, if the infrastructure systems are thought as networks then they are composed of edges and nodes. The nodes are distribution units on infrastructure networks such as electrical transformation center and telephone exchange. On the other hand, the edges are distribution lines on the network such as the low voltage lines and local cable. Therefore, there are some common elements on networks and their semantics can be related by ontological definition.

In this study, the interoperability mechanism is constructed over the ontology structure. The common elements of the two systems are described by Common Vocabularies Ontology. In addition, the spatial characteristics of the network elements are formalized by spatial representation ontology. These two ontologies are called as upper ontologies since the specific application ontologies are derived from them. Moreover, for the present research, application ontology has been defined for each GIS. Therefore, the context ontology is defined over the upper ontologies and application ontologies. The context is explained by mainly event, action and organization ontologies.

6.2 Results and Findings

1. Dynamic Level of Interoperability or context based interoperability can be possible by the approach appointed in this study.

2. Performing data exchange at the upper ontology level can eliminate the semantic, schematic and syntactic heterogenity problems

3. Two GISs are aligned at the ontology level not at the process level

4. Semantic Web Rule Language (SWRL) can be used to define the behaviour and state of network elements

5. Use of upper ontology, can make the extension of the system to the third or more GIS of the infrastructure company possible and easy.

6. To interoperate the different GIS, operator of the GIS's does not need to know the other GIS's details such as data structures, wording, processes etc.

7. Major target of the interoperability is geographic data. Non-geographic or attribute data is not included in this study

8. ISO 19107 defines the goegraphical entities in complicated way.

9. SWRL rules and context ontologies can be used to relate different concepts.

10. Context should be handled seperately and event, action and organization can be used to define context

11. World Feature Service(WFS) can solve the GIS software dependency

12. SWRL is easy to learn and implement

13. Jess rule engine has complete application programming interface for Java, so development is easy

14. Protege ontology editory provides handy plug-ins for SWRL definitions and Jess Rule Engine

15. System structure can be matched with the ontological width and depth concepts of Tolk et al. (2008)

16. In order to make the approach clear and understandable, the implementation is kept as simple as possible.

6.3 Discussion of Results

1. Interoperability studies from Tolk et al. (2008) have suggested seven layers interoperability model and the contextual knowledge is also integrated into that model. The study of Tolk et al. (2008) has defined the contextual awareness of the interoperating systems at the pragmatic level which is over the semantic level of interoperability. In addition interoperating systems are aware of context changes at Dynamic Interoperability level. In this study, the context modeling has been applied to solve the interoperability problem, which has no implementation in the GIS domain before. On the other hand, the former implementations examined in this paper such as Lutz et al. (2009), Fallahi et al. (2008), Cruz et al. (2007), Suryana et al. (2009) etc. focus on the semantic interoperability level of the Tolk et al. (2008) architecture. Similar to Tolk et al.’s (2008) study, Manso at al. (2009) mentions seven layers of interoperability. The difference of Manso at al.’s (2009) study from the Tolk et al.’s (2008) work is the non-hierarchical relations between the layers. For the current study, the Tolk et al.’s (2008) approach is adopted rather than Manso at al.’s (2009) study. Because, the author cannot find how context information is handled in Manso at al.’s (2009) study. In addition using hierarchical model is convenient for the development of the interoperability between different GISs. For example handling one context is corresponding to pragmatic level and more than one

context is dynamic level interoperability in Tolk et al.'s (2008) study. Therefore before solving problems in pragmatic level, dynamic level cannot be reached.

2. There are two upper ontologies in the ontology structure. These are Common Vocabularies Ontology and Spatial Representation ontology. Using these ontologies allows us to define commonalities of network elements of different systems whose duty is the same and terminology is different. Therefore semantic conflicts can be solved. In addition, geometric representation of elements can be performed by Spatial Representation Ontology, so the same model is used to define geometry, which allows us to solve heterogeneity at the schematic and syntactic level.

3. In the current study, the processes of the two infrastructure companies are explained by the SWRL rules and the rule base is based on both application ontologies and context ontology. This means that each application ontology does not have its own rules and they are defined at the context level by using terms from both application ontologies and context ontologies. Therefore, in this study, the alignment is done at the ontology level, not at the process level.

4. A state of a network element changes when events take places. In order to perform these events, several conditions should be satisfied. For example, in order to maintain low voltage line, electricity should be cut off. Power interruption is a condition, which should be satisfied before maintenance event occur. In addition, power interruption changes the state of mid-voltage line. These conditions and state changes can be defined by SWRL rules. SWRL rules have conjunctions and built-ins to define these conditions and have implication mechanism to define processes. The processes occur as a result of conditions and cause changes in states of networks elements.

5. The system developed within the current study is quite flexible. The commonalities are defined in Common Vocabularies Ontology and the spatial features are defined in the Spatial Representation Ontology. The application GIS ontologies are defined based on these two ontologies. Maintenance information and semantic rules are defined in the maintenance context ontology and three web services are defined. These are the web services of the infrastructure companies and the AYKOME web service. The last one is responsible for running the SWRL rules and mediation between the TELEKOM and BEDAŞ web services. If the third GIS is desired to be included in the interoperating system, the procedure is simple. First, the infrastructure company should define its ontology which should be derived from the spatial representation ontology and common vocabularies ontology. Then the web services should be developed and these operations are not depending on the knowledge about the other GIS's. At the last step, additional rules should be added to the maintenance and emergency context ontologies.

6. The third or more infrastructure company do not need to know anything about the other GIS to be included into the interoperating system. Because, other GISs derived from upper ontologies and deriving their application ontology from upper ontologies guarantee that third or more infrastructure company can exchange information without having problem.

7. Sample data for the case study implemented in this study composed of data of network elements and other data such as subscription data cannot be acquired. These network elements are physical entities in the world and modeled as geometric features in GIS. Therefore in this research, interoperability problem is studied from exchanging geometric data point of view. In ontology structure, the definition of geometric data is stressed.

8. ISO 19107 defines the goegraphical entities in complicated way. For example, polyline is defined as GM_Curve and GM_Curve is composed of

GM_LineSegment which has GM_PointArray to define the coordinates of the nodes. GM_Point Array consists of GM_Point which has GM_DirectPosition for defining x and y coordinates. The GM_DirectPosition has property coordinate values. Therefore creating geographical feature as ontology instance is time consuming task because the ontology instances are actually created on the XML based text file which has owl extension.

9. One of the important responsibilities of the SWRL rules and context ontologies is to relate different concepts. In other words, the relationship between the events, organization, actions and the network elements of the infrastructure companies and their properties are constructed by SWRL rules and Context Ontologies.

10. Under different context, network elements may have difference states. Context can change as a result of events, which are performed by an organization or performed by nature. Events can be defined by Event Ontology and they produce consequences and these consequences can be defined by actions, which are formalized by Action Ontolology. In addition companies having GIS are modeled by Organization Ontology. These three ontologies can be used to define contextual information and they are capable of explaining the changes in the state.

11. GISs are constructed by using GIS software and each software has its own data model to define geographic data. To overcome heterogeneity due to data model differences, a common data model is necessary. GML is used to define geographic features and because it is constructed by OGC, it is implemented by major GIS softwares, such as MapInfo and ArcGIS. WFSs are using GML in their geographic feature definition, so geographic data served by WFS are readable by GIS software.

12. SWRL has easy syntax and different built-ins. These built-ins make the language easy to implement. In addition, it has satisfactory documentation.

13. Jess Rule Engine is used in AYKOME web service to run SWRL rules. During web service development, a Java API of Jess is used. API has necessary methods to run SWRL rules. Moreover to get the result of executed SWRL rules, API provides required methods. There are mailing lists and wiki pages for Jess, so help is accessible when needed.

14. Protégé Ontology Editor has SWRL and Jess tabs to support SWRL development. All built-ins are included in SWRL definition section of SWRL tab, which makes the SWRL development easier. In addition, Jess Tab executes the SWRL rules and it gives an opportunity to check whether SWRL rules produce desired results or not. Another advantage of Protégé and its tab is a community using it. Protégé has wiki pages and forums from which you can get many information and help.

15. In Tolk et al.'s (2008) definition, the width of the ontology is going from low level to high level as the number of systems included in the ontological definition is increasing. In this study, the application ontologies alone are corresponding the low level width. The mid level width is the society of the systems. Therefore, it is defining the application ontologies working cooperatively in the same context. Therefore in this study, the application ontologies and context ontology constitute the mid level width. On the other hand, the high level width includes all societies and it is the level where the ontology alignment is performed. Having derived all the application ontologies, upper ontology is the high level width in this research. We said that the depth of the ontology is related with the levels of data exchange and there are three depth levels which are system, society and domain depths. The system depth consists of the application ontologies. It is shown in Figure 15 that, at the system depth, the data exchange is not mentioned. The first level, where the data exchange is happening, is the society depth and it

is corresponding to the application ontologies within the specific context which is matching the maintenance context or emergency context individually in this research. However, the domain depth is covering the different contexts. There are two contexts modeled in this study and for both contexts data exchange is performed at the Upper Ontologies. Therefore it can be deduced that, the data exchange at the domain level are actualized at the upper ontology due to being the source of all the application ontologies.

16. In the implementation of the scenarios, all steps are required user intervention. For example, when BEDAŞ operator is planning and submitting an event to the system, TT Operator needs to check whether there is scheduled event. Instead, there may be an observing and alarming mechanism in the system.

6.4 Difficulties

Throughout the study, while gaining experience on the subject, some difficulties were encountered. In this part the difficulties and problems faced during this study will be introduced.

1. Acquiring sample data: The first difficulty was about acquiring the sample data and understanding the network for both BEDAŞ and TT networks. The contact people from both companies were introduced by T. Küçükpehlivan and sample data problem was discussed by contact people. At the time, when the development period of the current study had started, the data production at TT was still in progress. However, the data production of the Çukurca District of the Çankaya Municipality was completed. After getting confirmation about the completeness of the BEDAŞ data at the same location, the sample area was selected compulsorily as the Çukurca District of Çankaya Municipality.

2. Understanding Türk Telekom (TT) and BEDAŞ networks: Understanding how these networks are working is important issue because the way of working affects contextual information.

3. The development of the TT GIS has not been completed at the time when this research was begun.

4. Finding available time to interview with the contact person: After solving the data problem, the interviews with the contact people were performed to gain information about the TT and BEDAŞ domains. The interviews stood as another difficult part of the thesis because of the difficulties faced while managing available time for contact people.

5. Finding aprropriate reasoning methodology and reasoner: Another difficulty encountered during the study was selecting the appropriate reasoning methodology and reasoner among many alternatives. The first thought was using the description logic and the Racer reasoner. Therefore, about 3 months have passed while examining the description logic and the Racer as a reasoner. Nevertheless, after examining SWRL and Jess, the prior decision has changed. Because of the compatibility of SWRL and Jess with Protégé, they were decided as rule language and reasoner for the current study.

6. Doing network analysis on the TT and BEDAŞ network: Network analysis stood as another difficulty for the study. Although, network analysis is not the major part of the research, in order to complete the scenarios and to show the model constructed in this study is working, it needs to be solved. The network analysis problem was arisen from the GIS software used. As the software has no capability to make network analysis, it had to be handled by doing extra coding. The first trial for solving the problem was to analyze the network geometrically which means that; the connection relationship between the geometric entities were tried to be found out. After that, the table structure of the data was noticed. Both BEDAŞ and TT have data

structures such that; the feeding point of each network element is described in a relational database. Therefore, the network analysis was based on the database search which is much easier as the work necessary to solve the network analysis problem concerned.

6.5 Limitations

1. As a limitation to results and findings (3) and (5), we have tested our approach only on two GIS's of the infrastructure company

2. As a limitation to results and findings (3), we have tested our approach for just GIS of the infrastructure company. The other GIS such as the one which is modeled traffic flow are not included in this study.

3. As a limitation of results and findings (3), we do not have the assumptions about the GIS's of BEDAŞ and TT while they have been constructed.

4. As a limitation to results and findings (7), TT did not share the data other than geographic data such as clients or subscription.

5. As a limitation to results and findings (16), constructing the system by impelementing automatic alarm mechanisms can cause miss out of important features of this study for the readers and make the study less understandable.

6.6 Future Works

As a result of the experience gained during this study, some possible research subjects have emerged. In this part, possible future work will be discussed.

1. When the Limitation (3) is overcome, conceptual level of interoperability which is the highest level at the 7 layer interoperability framework of Tolk et al. (2008) can be achieved

2. When the limitation (2) is overcome, effect of infrastructure maintenance for the traffic flow (meaning the investigating the interoperability with the traffic system) can be modeled: The excavation operation for the maintenance may result serious effects not only for other infrastructures but also the traffic flow in the cities. Because, if the infrastructure goes directly beneath the road or cross the road, to excavate the ground, the traffic flow should be redirected to another street. To model the correct action caused by the maintenance event from the traffic flow point of view, an investigation with the municipality should be made. For further studies, the data of the traffic flow can be included in the interoperability problem.

3. When the limitation (1) is overcome and, other infrastructure GIS such as Water and Natural Gas can be added to the existing system: Another possible future work can be related with the other infrastructure companies and GIS software. Other than electricity and telecommunication, the water and natural gas companies may be added to the interoperability problem handled in this study. Moreover, the addition of third and fourth companies may be employed by using different GIS software such as ArcGIS.

4. When the limitation (4) is overcome, non geographic data such as subscription data can be added to the interoperability study: In this study, the interoperability problem for infrastructure companies is examined from geometric data and network point of view. However, the GIS may include other data based on the geographic data such as the client and subscription data. This kind of information may belong to management information system but it may also be processed in the GIS. Another scenario where the subscription data is involved in the systems can also be a research study as the future work.

5. Author believes that, study is understandable enough for the current implementation. Therefore for future work, the limitation (5) can be

underestimated. Therefore the way of implementation can be changed to make the system more fluent.

6.7 Conclusions

In this study, the context modeling and contextual knowledge are used to solve interoperability problem. The heterogeneities caused by different GIS softwares are tried to be achieved by using world feature service and the behavior of the system is modeled as SWRL rules. To communicate with the web service farm and realize the interoperability scenario, add-ons to GIS are developed. In other words, all the web services developed for this research have complementary systems because their main purpose is to communicate with the ontologies to respond the queries coming from GIS through the add-ons. As a result, the context based interoperability is successfully implemented.

Context based interoperability studies are for systems interoperability in general rather than for GIS domain specifically. In GIS domain, studies are concentrated on the semantic level interoperability. Therefore, in GIS domain, there has been no example how context based interoperability is implemented so far. Therefore, this study fills the gap in GIS domain about how context based interoperability can be achieved in GIS domain. The system architecture proposed and application implemented in this study are the solid outcomes of this research. These outcomes make dynamic level or context-based interoperability possible. Consequently, present research contributes to the literature on how context can be handled and how context-based interoperability can be achieved in GIS domain. In addition a way of context handling is shown by a case study and implementation about the case study is successfully performed.

Another important aspect of this research is for industry. This research shows that interoperability is possible for different infrastructure companies while taking care of enabling the system’s privacy and hiding it from all other systems.

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Wikipedia 2010. Meta [online] Available from http://en.wikipedia.org/wiki/Meta [Accessed 31 May 2010]

APPENDIX A

THE COMMON VOCABULARIES ONTOLOGY CLASS DEFINITIONS

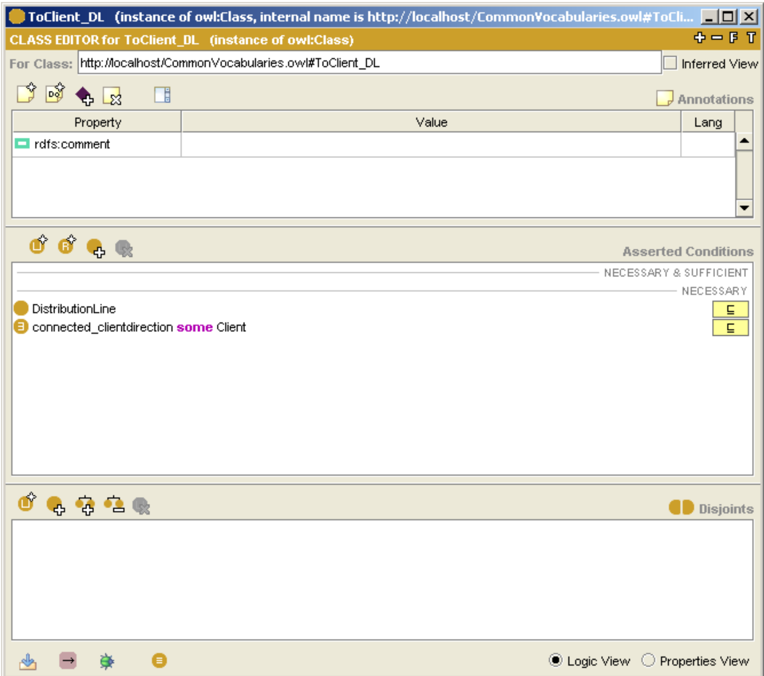

Figure 90 ToClient_DL class definition in common vocabularies ontology

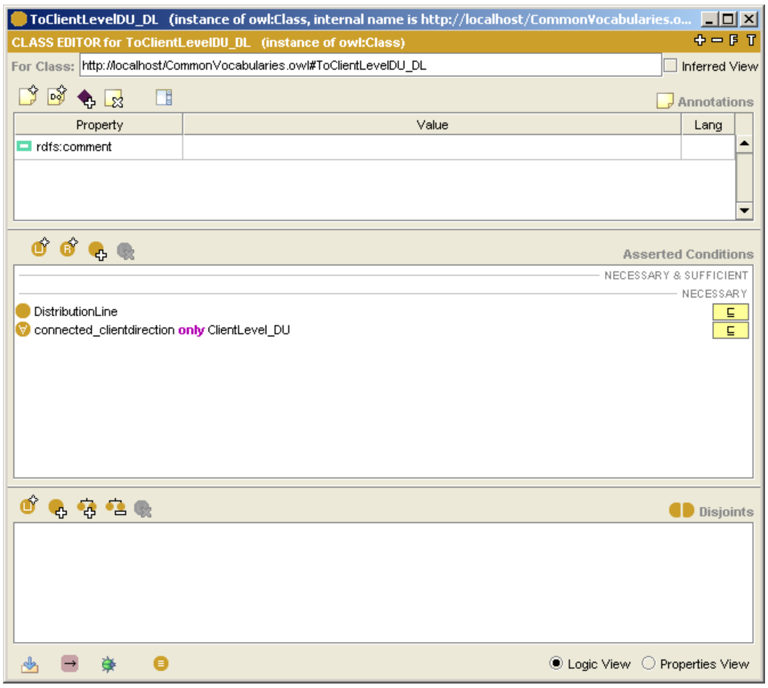

Figure 91 ToClientLevelDU_DL class definition in common vocabularies ontology

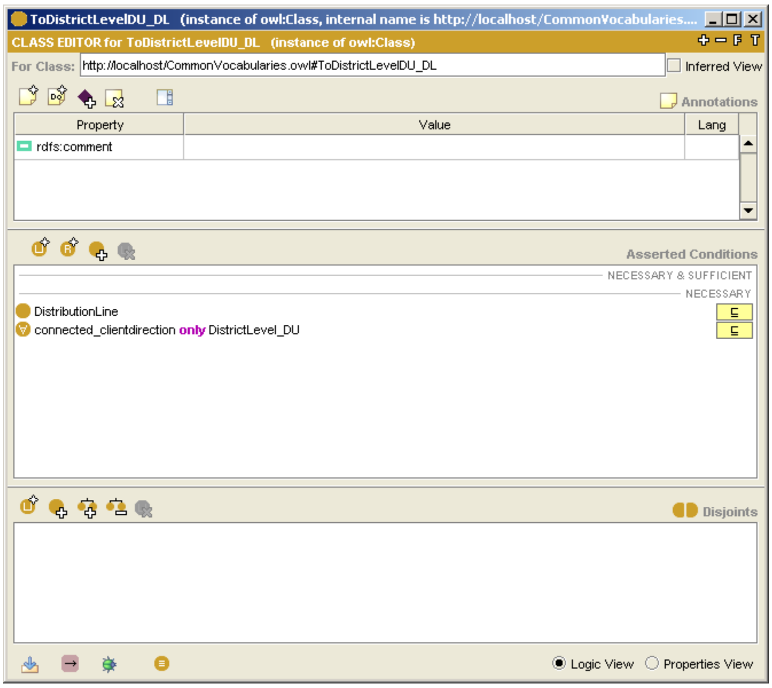

Figure 92 ToDistrictLevelDU_DL class definition in common vocabularies ontology

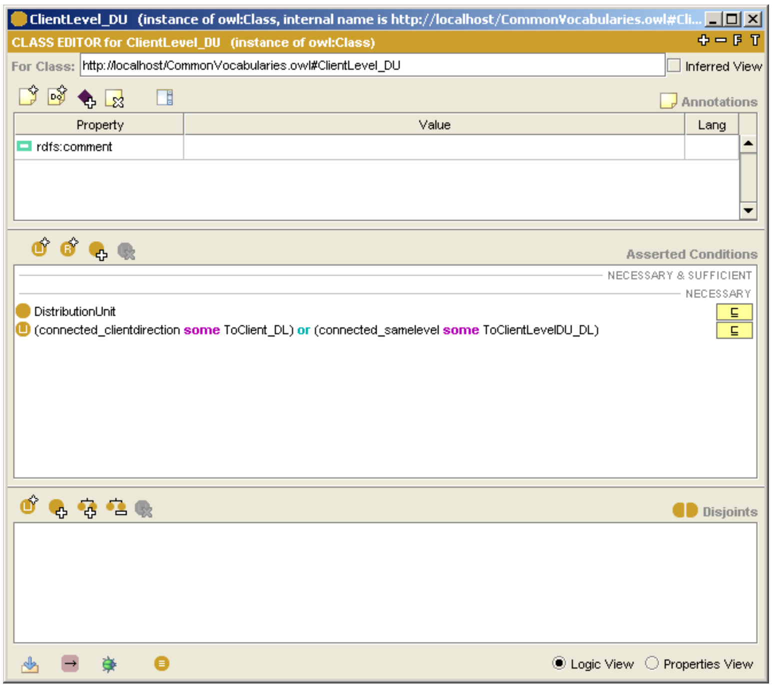

Figure 93 ClientLevel_DU class definition in common vocabularies ontology

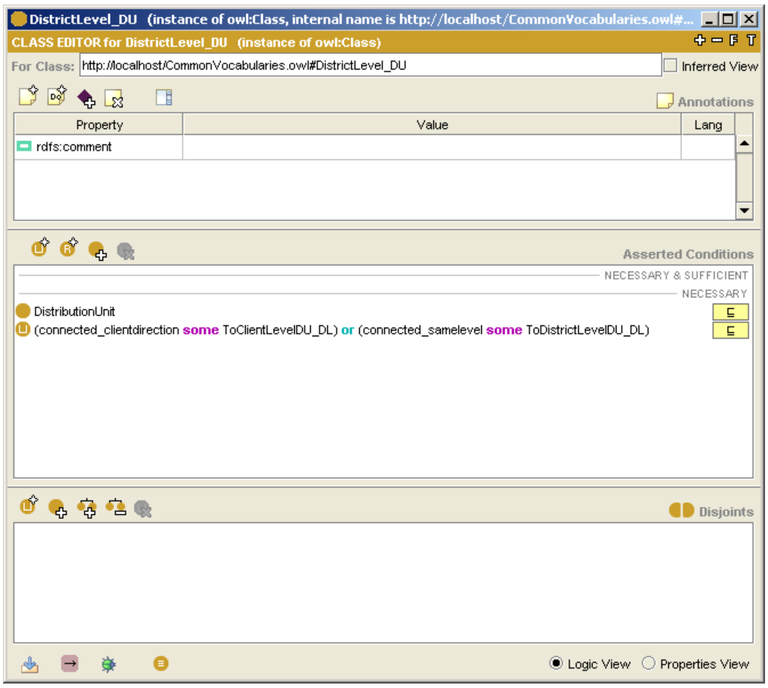

Figure 94 DistrictLevel_DU class definition in common vocabularies ontology

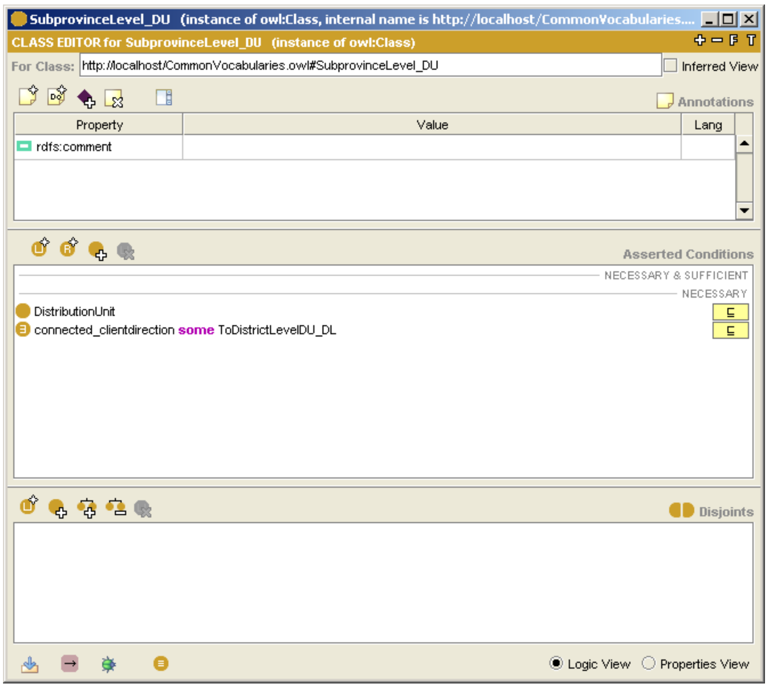

Figure 95 SubprovinceLevel_DU class definition in common vocabularies ontology

APPENDIX B

BEDAŞ ONTOLOGY CLASS DEFINITIONS

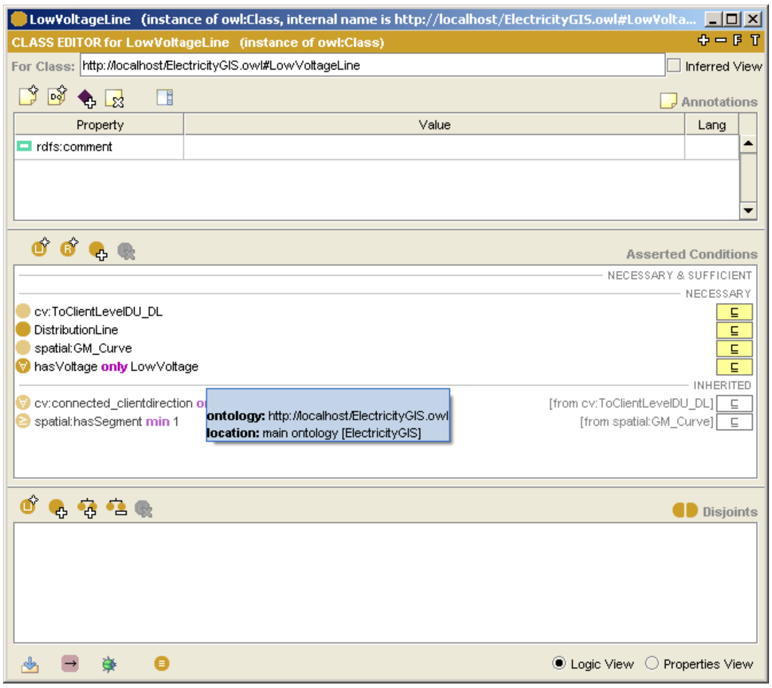

Figure 96 LowVoltageLine class definition in BEDAŞ ontology

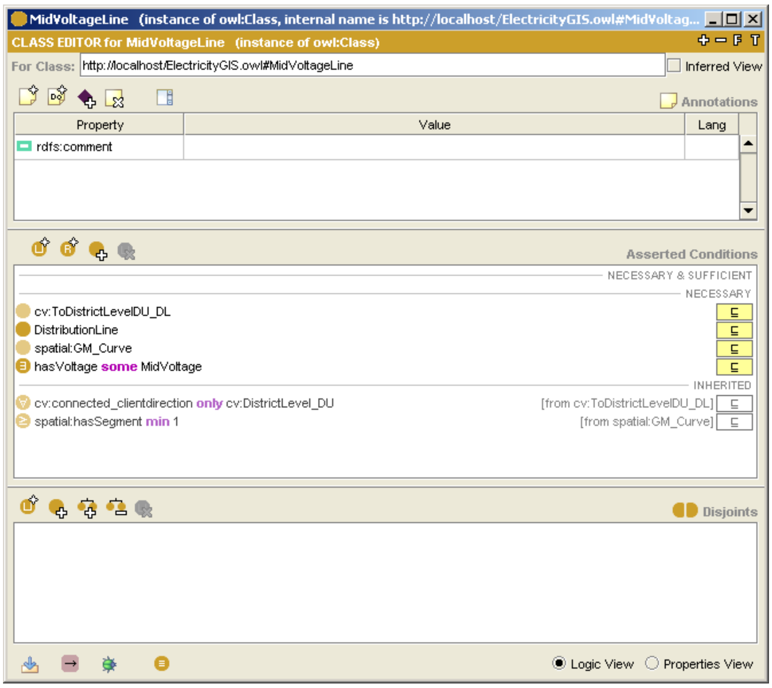

Figure 97 MidVoltageLine class definition in BEDAŞ ontology

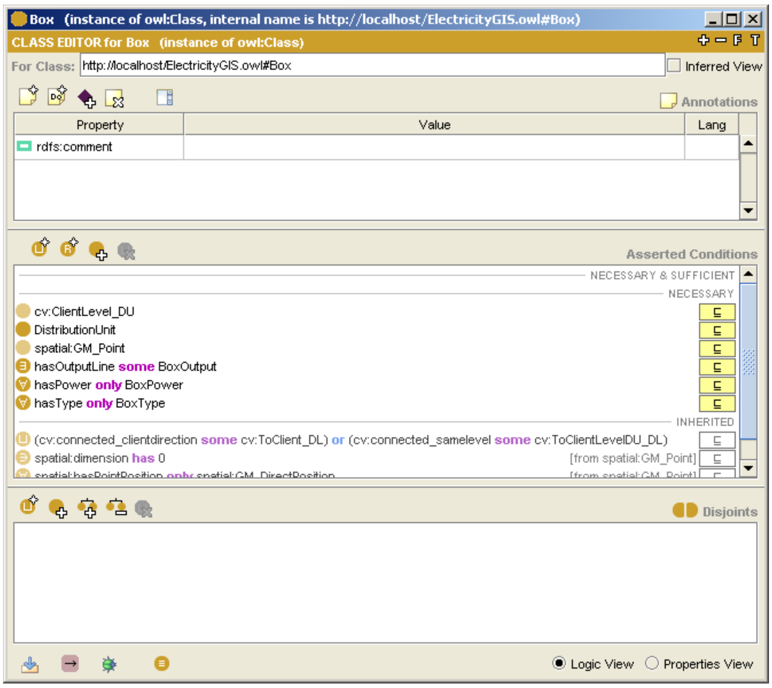

Figure 98 Box class definition in BEDAŞ ontology

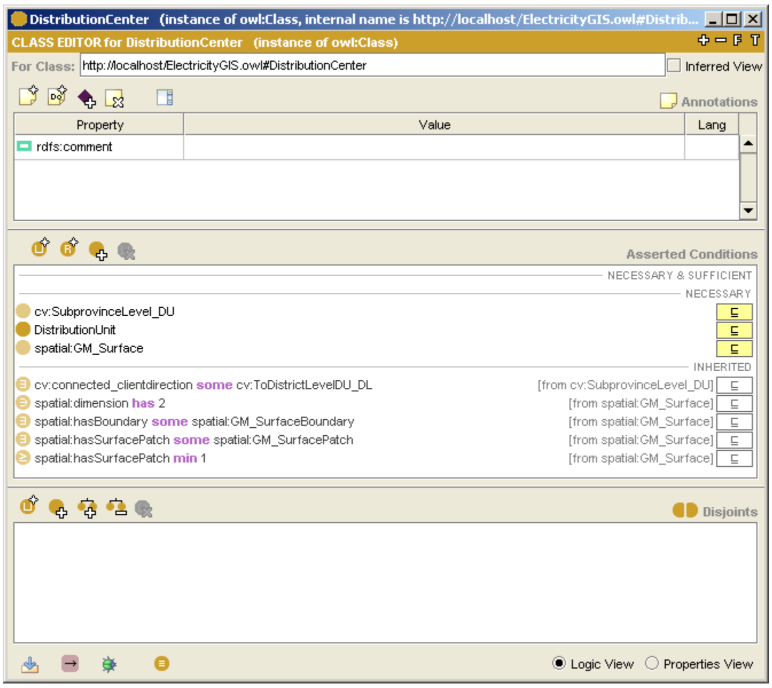

Figure 99 DistributionCenter class definition in BEDAŞ ontology

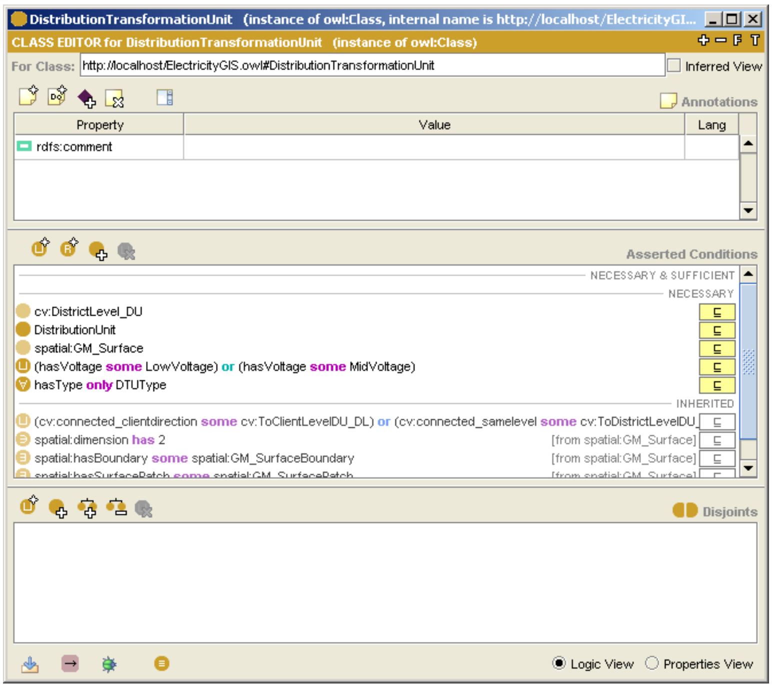

Figure 100 DistributionTransformationUnit class definition in BEDAŞ ontology

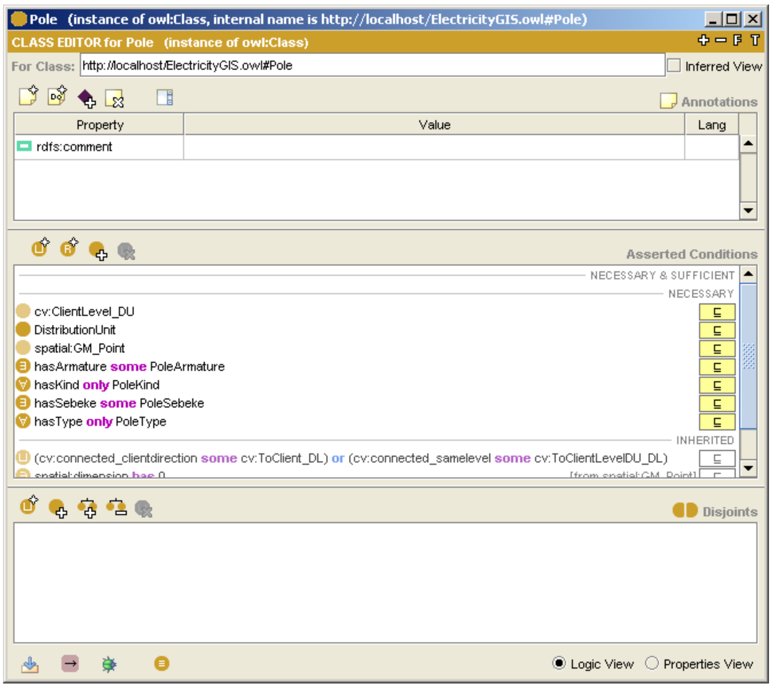

Figure 101 Pole class definition in BEDAŞ ontology

APPENDIX C

TT ONTOLOGY CLASS DEFINITIONS

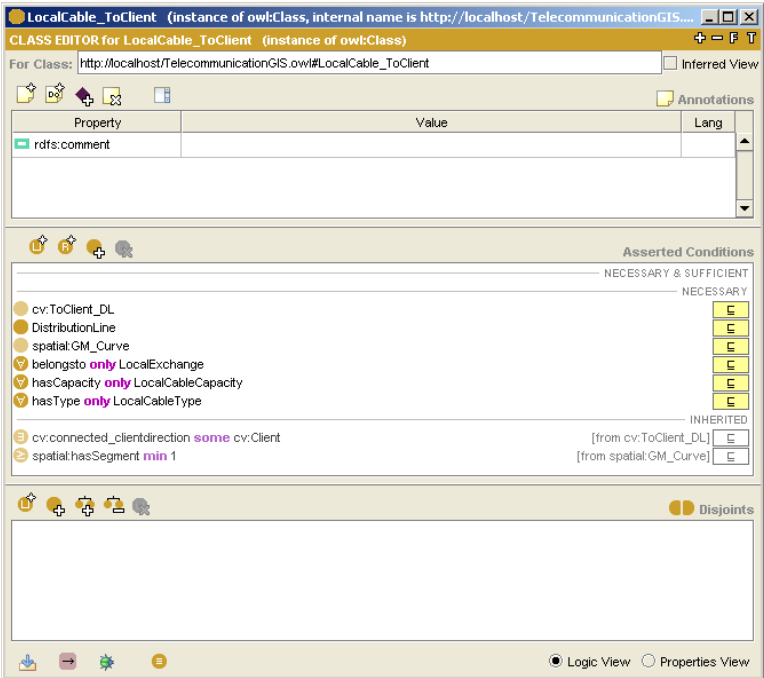

Figure 102 LocalCable_ToClient class definition in TT ontology

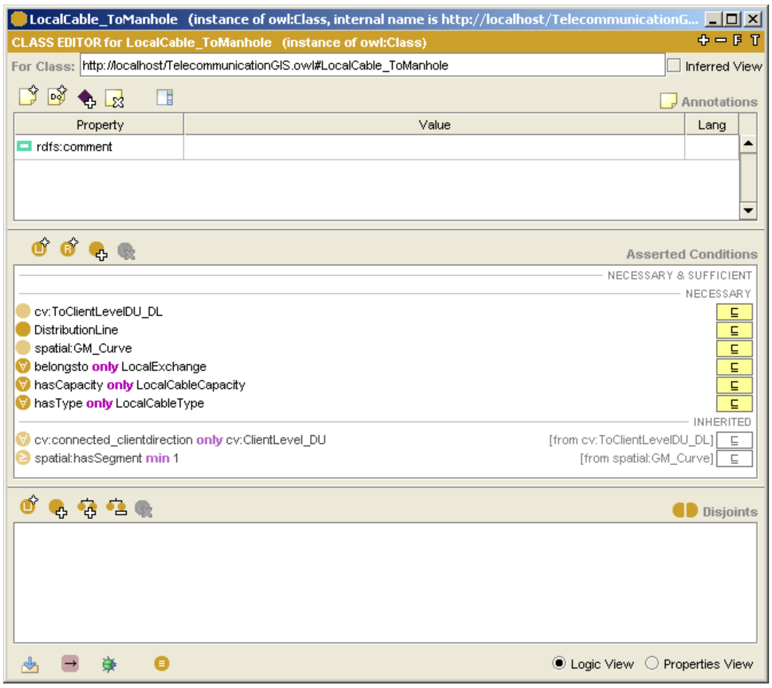

Figure 103 LocalCable_ToManhole class definition in TT ontology

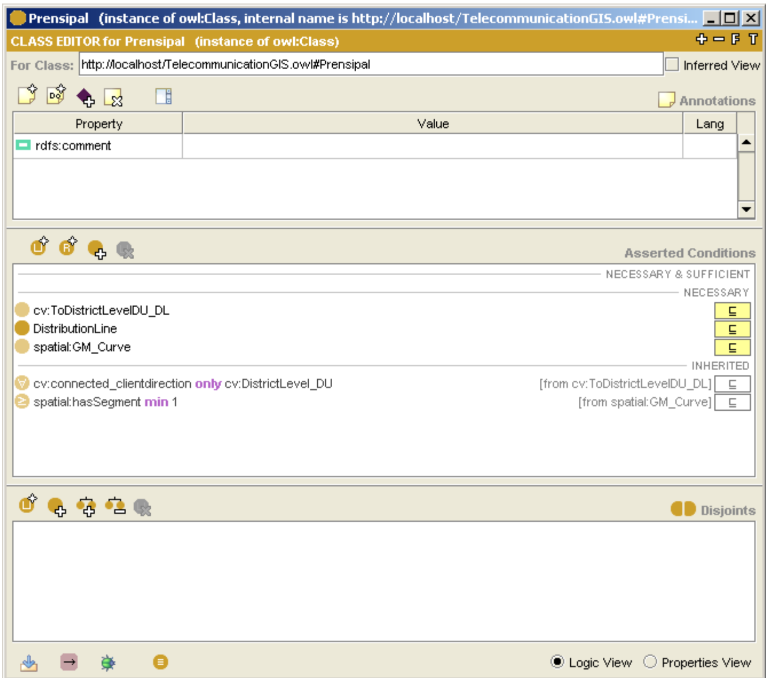

Figure 104 Prensipal class definition in TT ontology

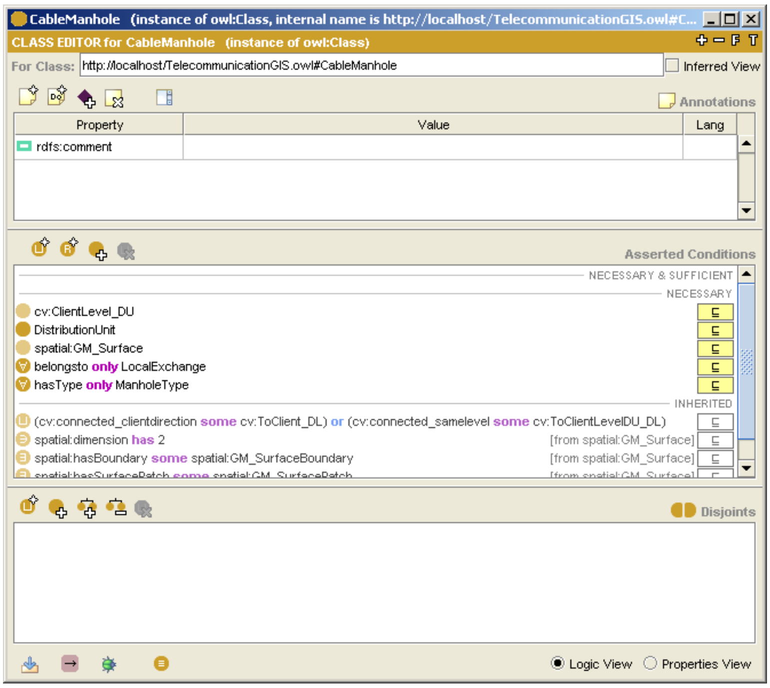

Figure 105 CableManhole class definition in TT ontology

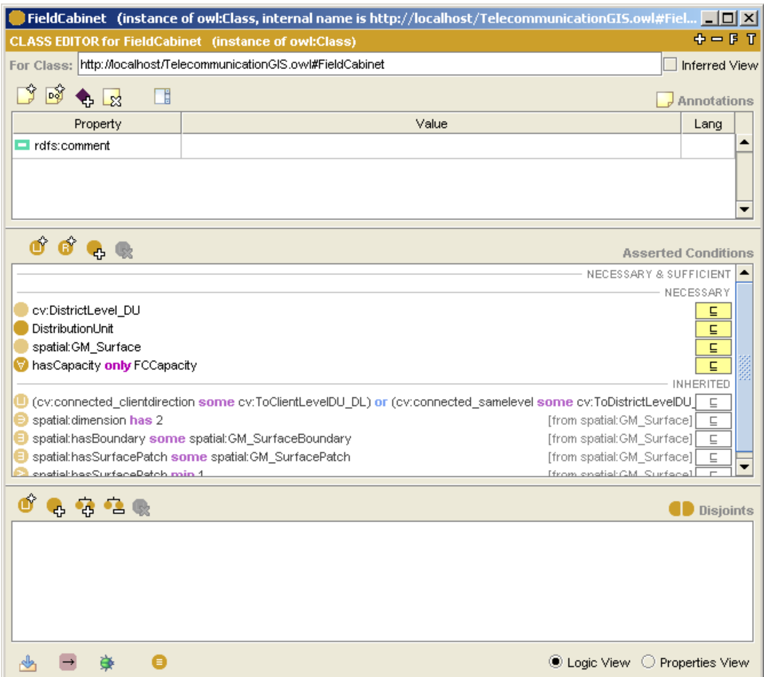

Figure 106 FieldCabinet class definition in TT ontology

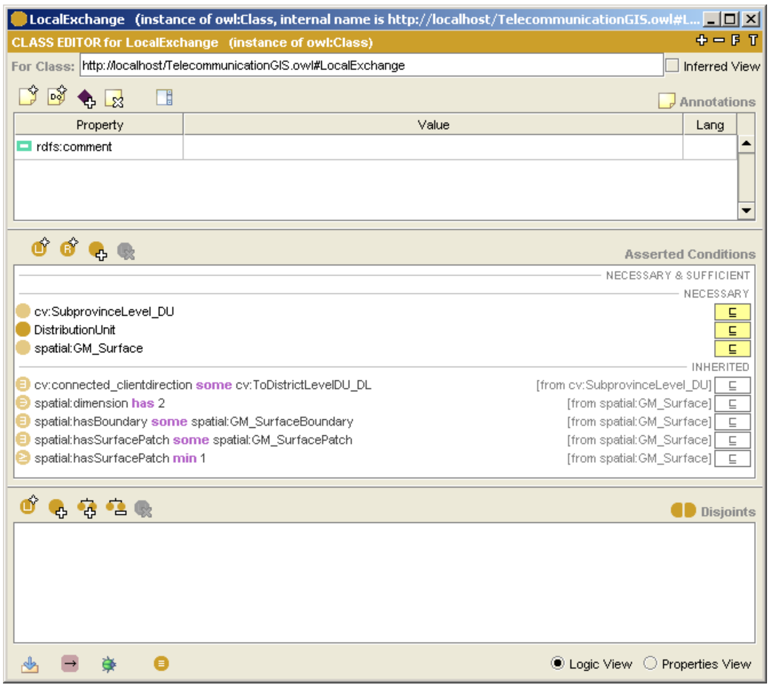

Figure 107 LocalExchange class definition in TT ontology

APPENDIX D

SEMANTIC RULES USED IN THE STUDY

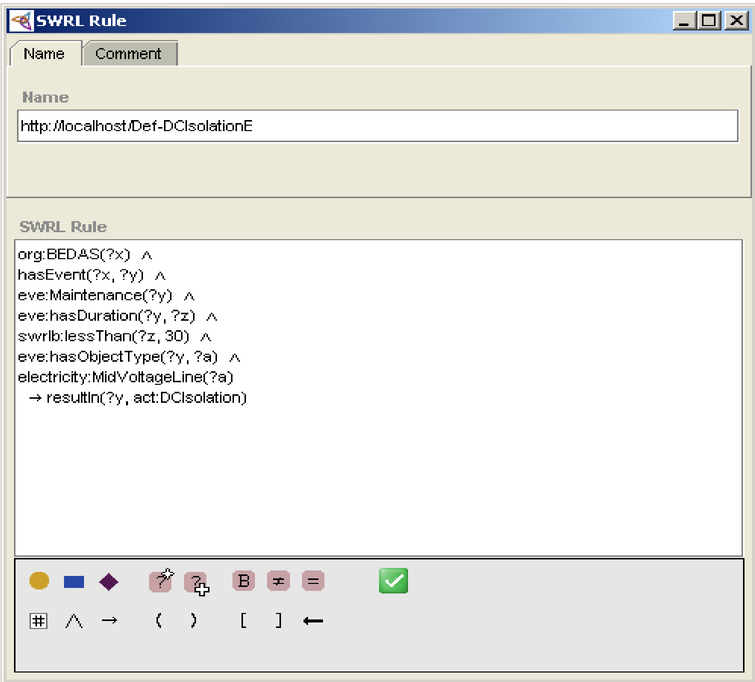

Figure 108 Definition for Distribution Center Isolation from Maintenance Context Ontology

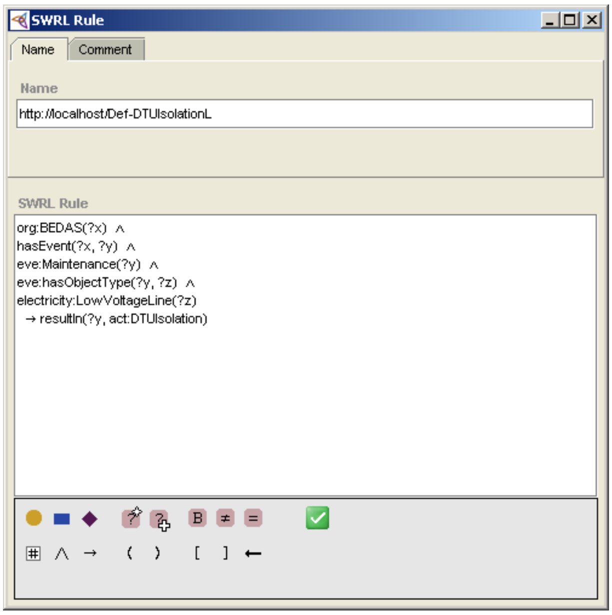

Figure 109 Definition for Distribution Transformation Unit isolation caused by Low Voltage Line from Maintenance Context Ontology

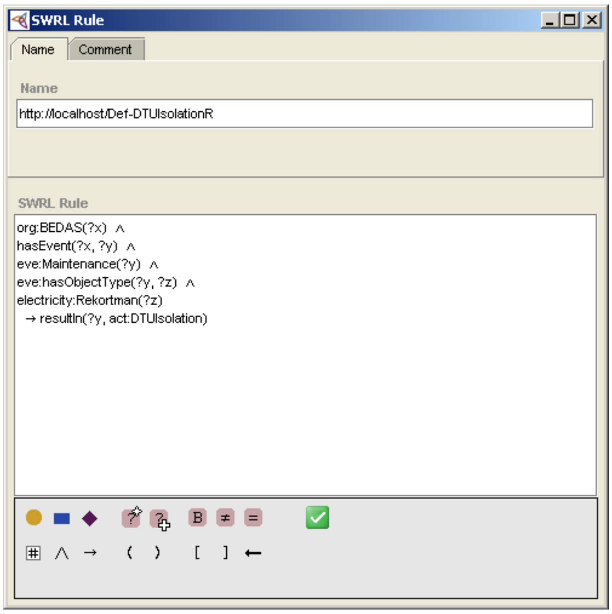

Figure 110 Definition of Distribution Transformation Unit isolation caused by Rekortman from Maintenance Context Ontology

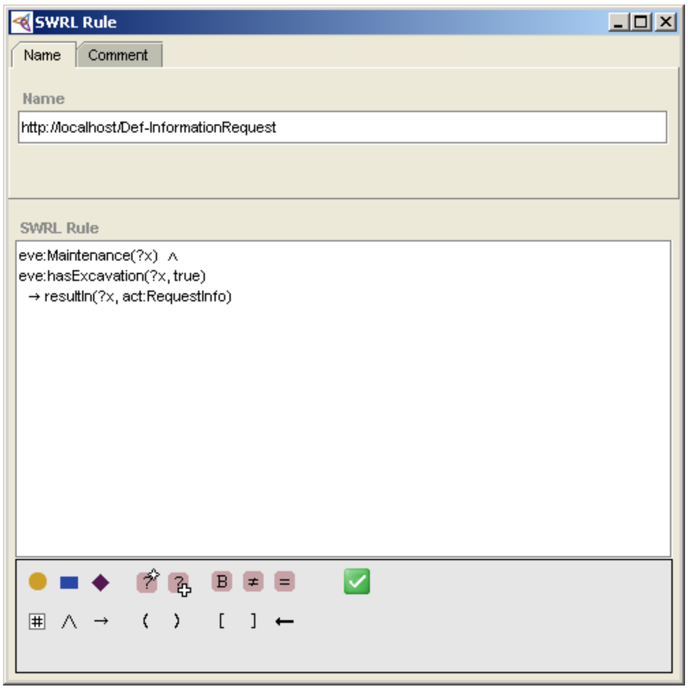

Figure 111 Definition for information request from Maintenance Context Ontology

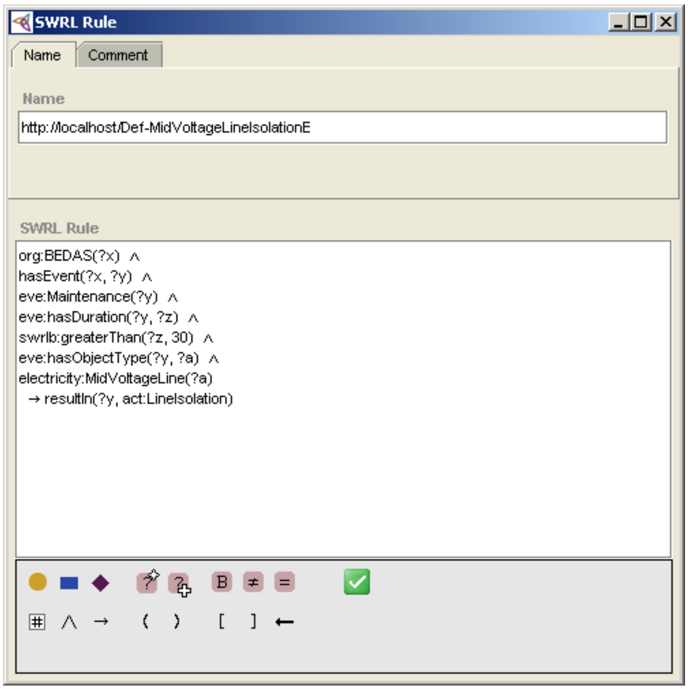

Figure 112 Definition for Mid Voltage Line isolation caused by BEDAŞ events from Maintenance Context Ontology

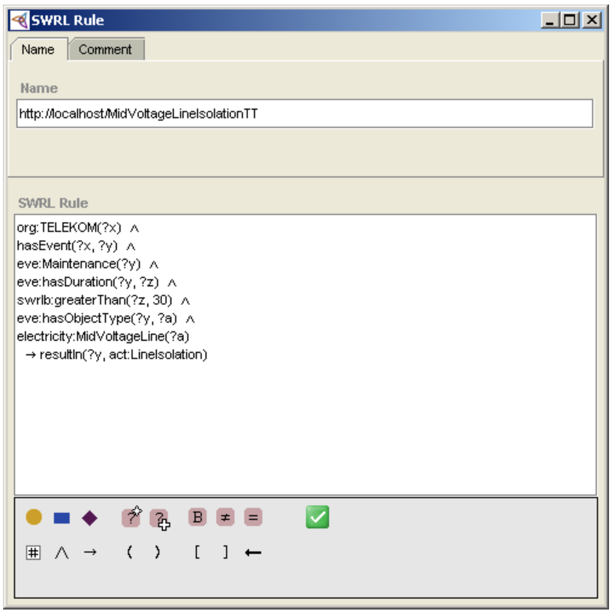

Figure 113 Definition for Mid Voltage Line isolation caused by TT events from Maintenance Context Ontology

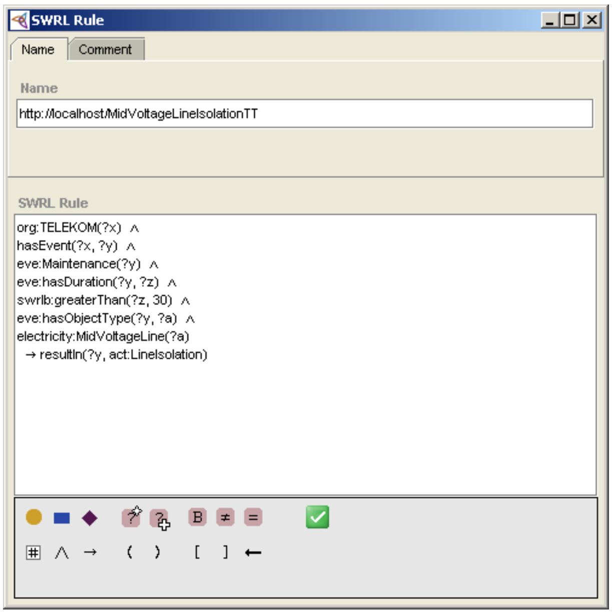

Figure 114 Definition for Mid Voltage Line isolation caused by TT events from Maintenance Context Ontology

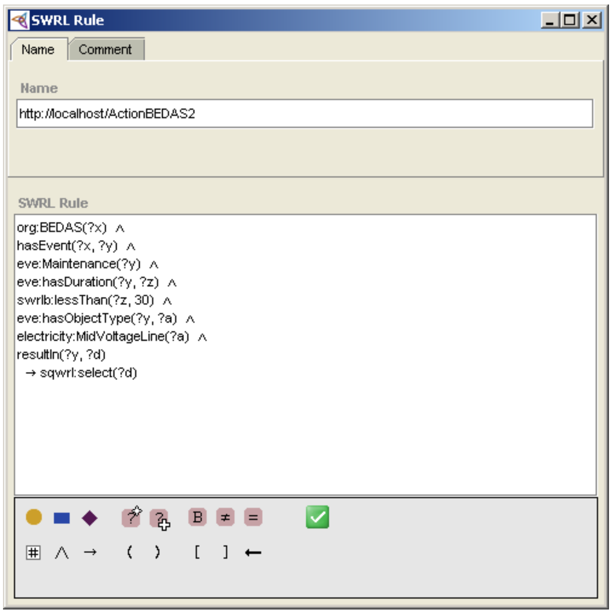

Figure 115 Second selection rule for BEDAŞ network from Maintenance Context Ontology

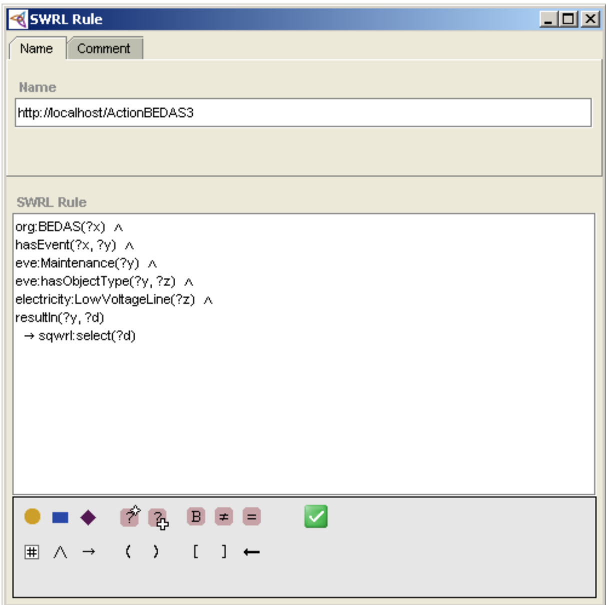

Figure 116 Third selection rule for the BEDAŞ network from Maintenance Context Ontology

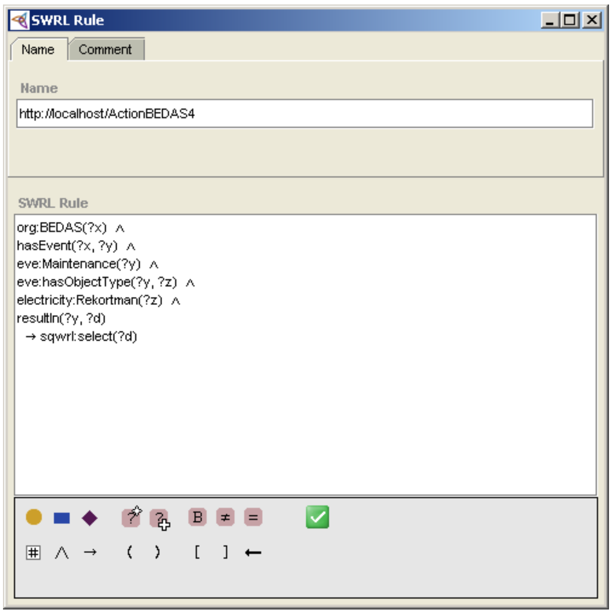

Figure 117 Fourth selection rule for the BEDAŞ network from Maintenance Context Ontology

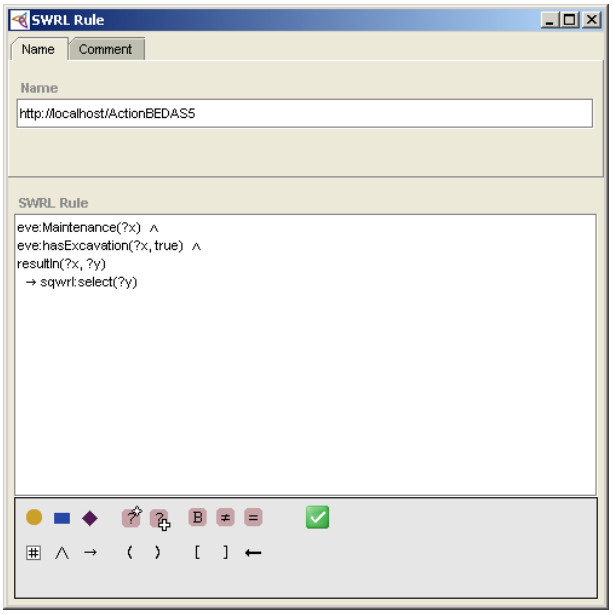

Figure 118 Fifth selection rule for the BEDAŞ network from Maintenance Context Ontology

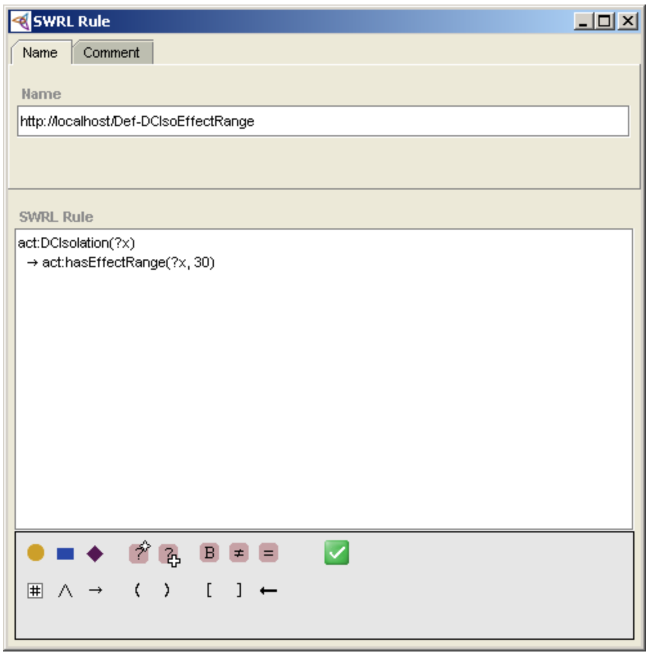

Figure 119 Definition of an effect range as a result of a DCIsolation action in Maintenance Context Ontology

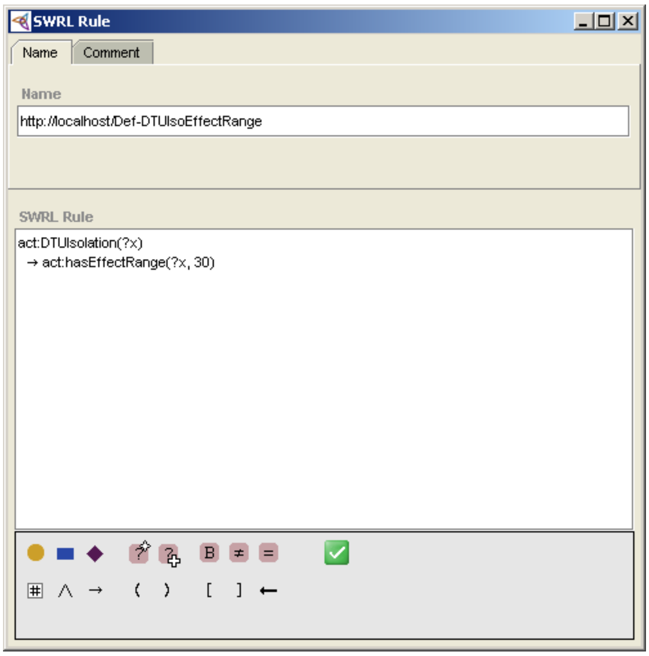

Figure 120 Definition of an effect range as a result of a DTUIsolation action in Maintenance Context Ontology

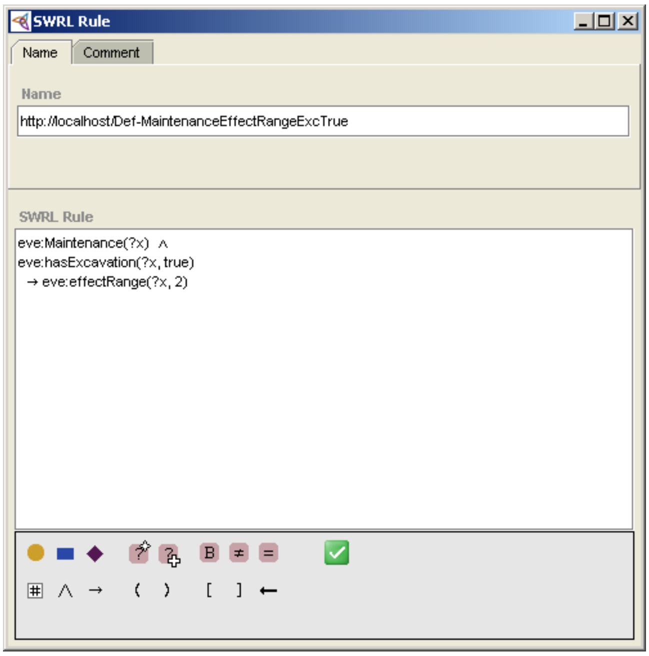

Figure 121 Definition of an effect range as a result of a Maintenance event when there is an excavation in Maintenance Context Ontology

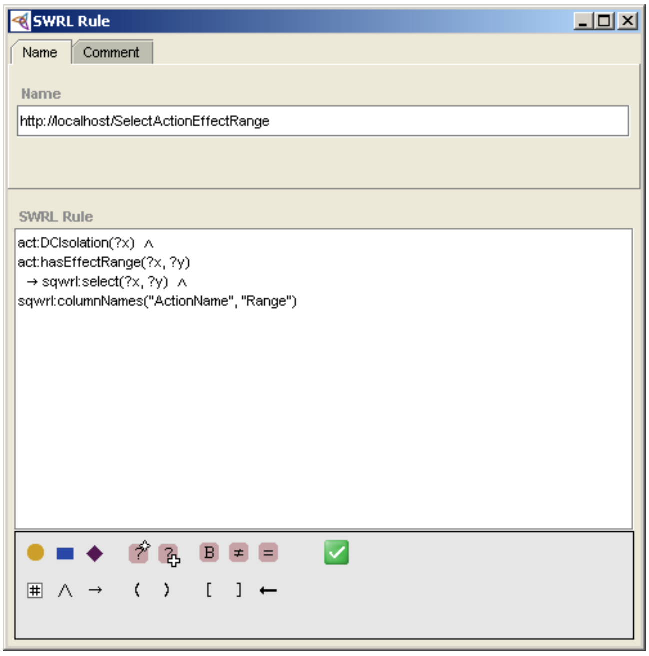

Figure 122 Selection rule of an effect range as a result of a DCIsolation action in Maintenance Context Ontology

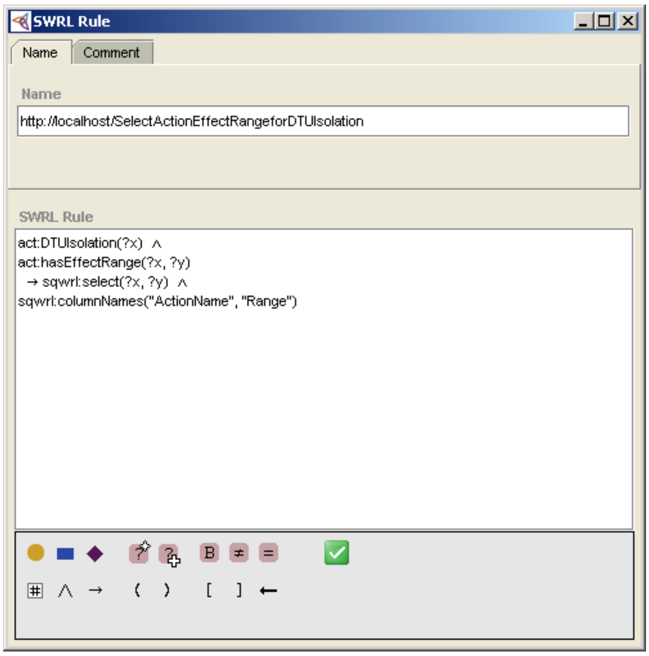

Figure 123 Selection rule of an effect range as a result of a DTUIsolation action in Maintenance Context Ontology

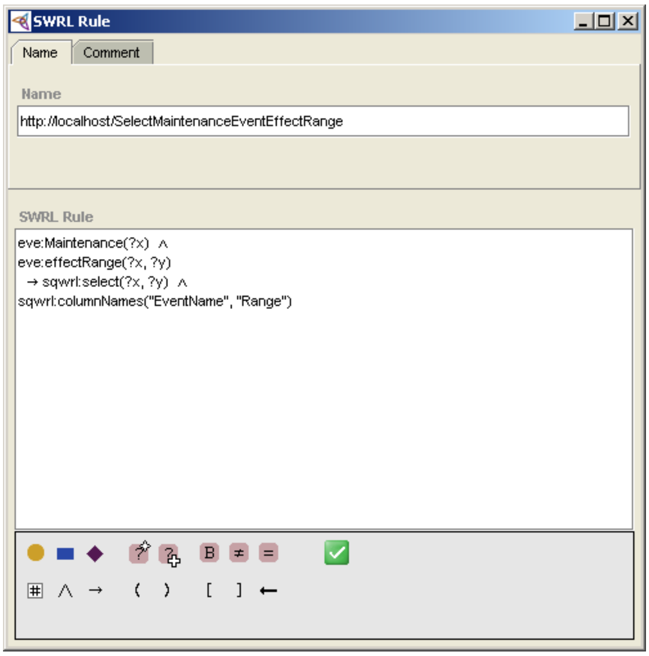

Figure 124 Selection rule of an effect range as a result of a Maintenance event in Maintenance Context Ontology

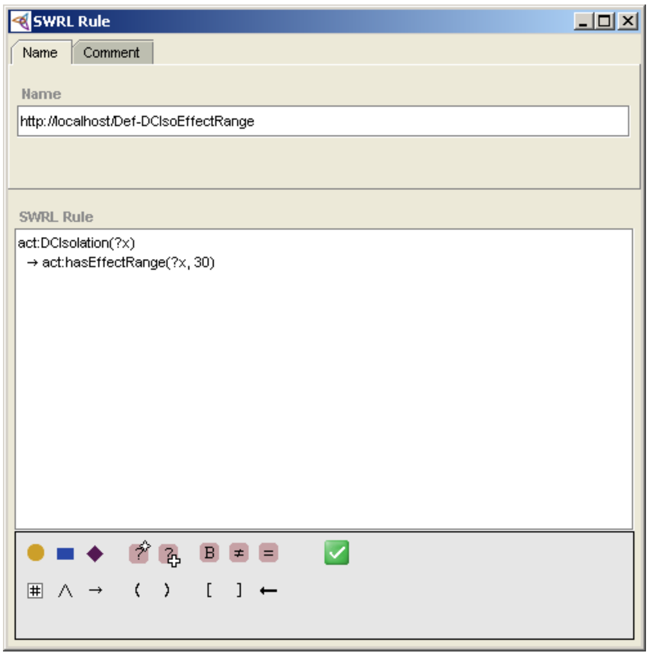

Figure 125 Definition of an effect range as a result of a DCIsolation action in Emergency Context Ontology

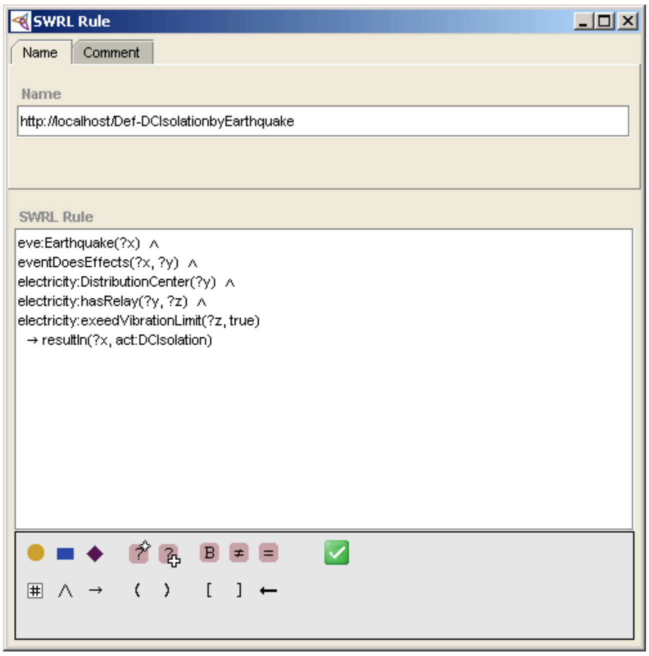

Figure 126 Definition of a DCIsolation action in Emergency Context Ontology due to an Earthquake event

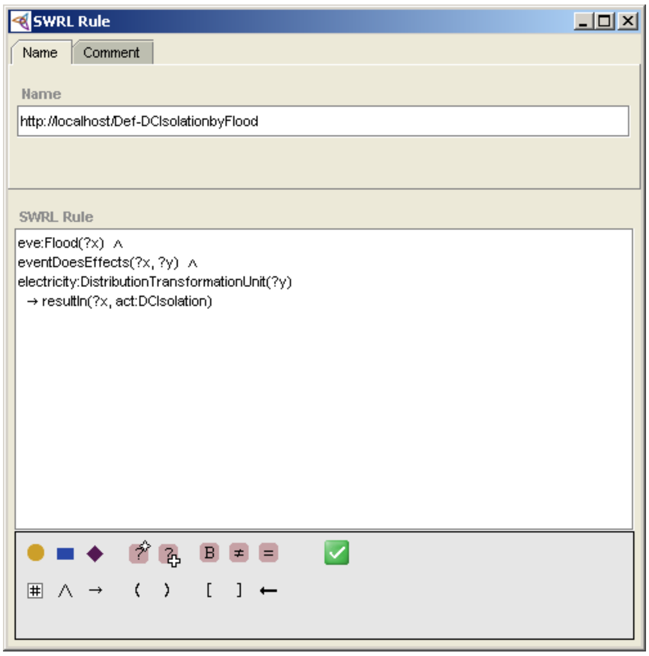

Figure 127 Definition of a DCIsolation action in Emergency Context Ontology due to a Flood event

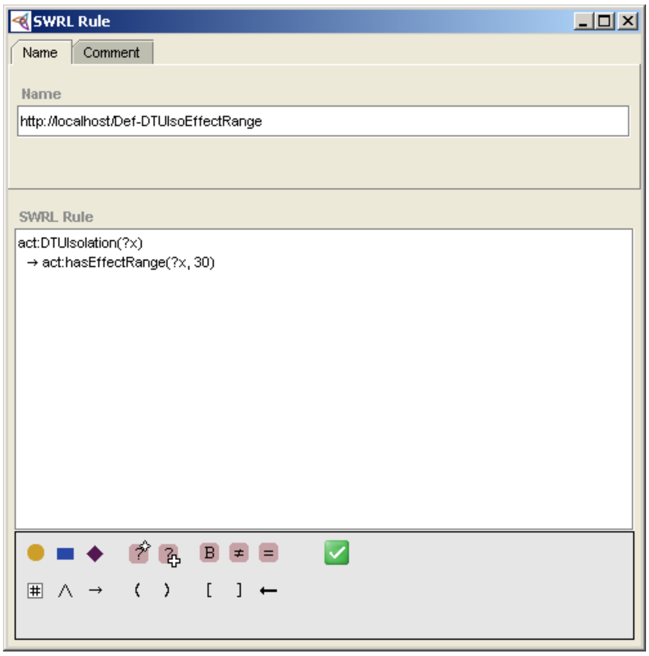

Figure 128 Definition of an effect range due to DTUIsolation action in Emergency Context Ontology

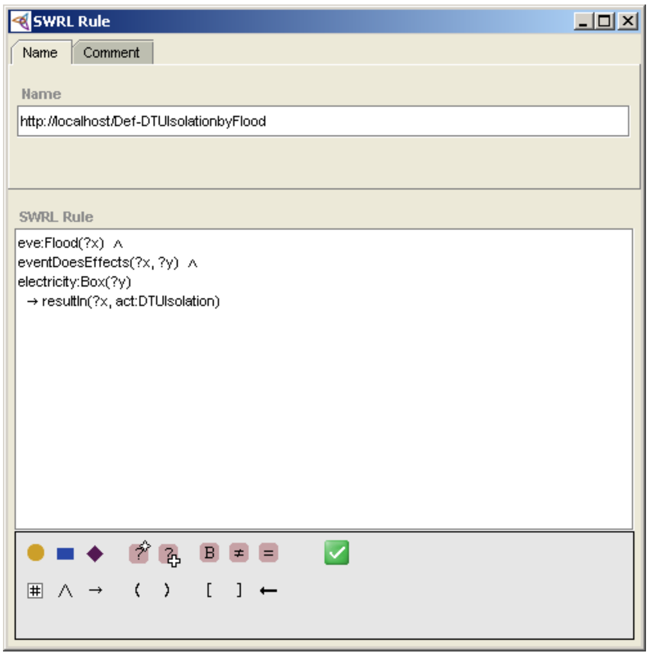

Figure 129 Definition of a DTUIsolation action in Emergency Context Ontology due to a Flood event

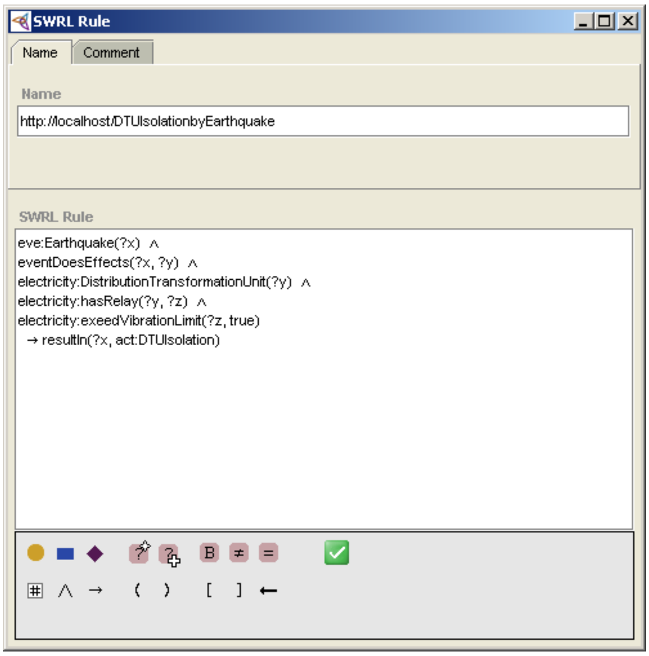

Figure 130 Definition of a DTUIsolation action in Emergency Context Ontology due to an Earthquake event

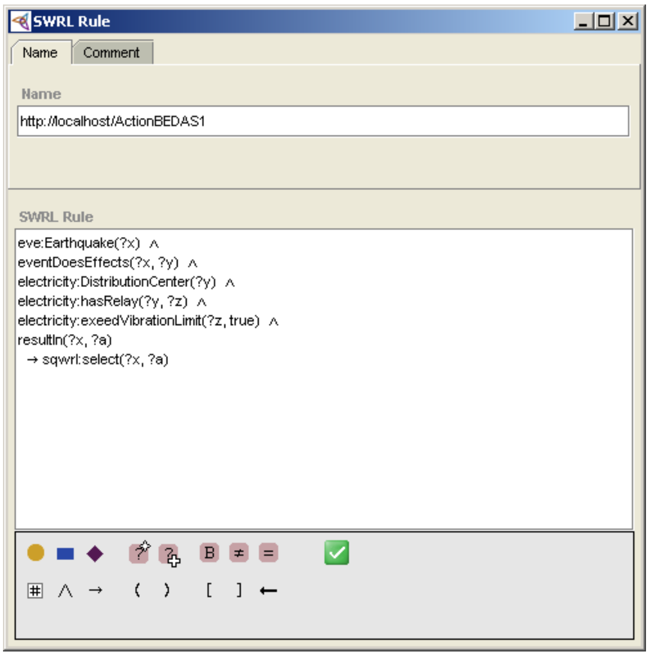

Figure 131 First selection rule for the BEDAŞ network from Emergency Context Ontology

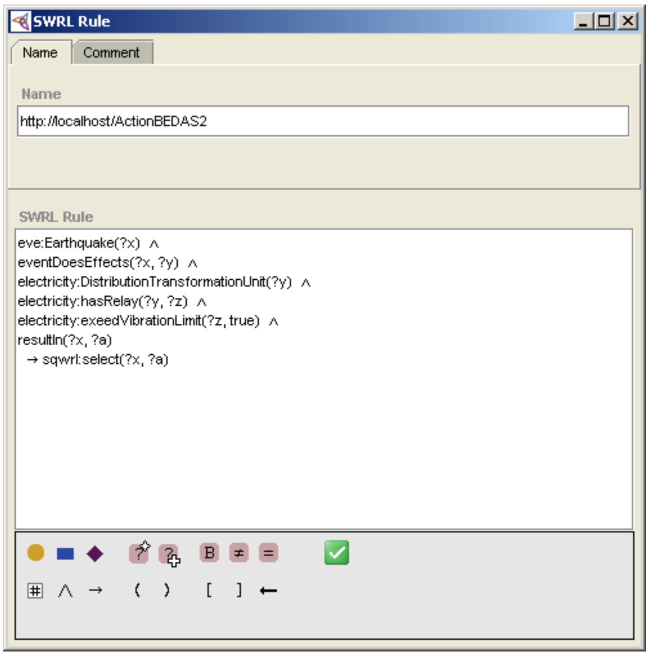

Figure 132 Second selection rule for the BEDAŞ network from Emergency Context Ontology

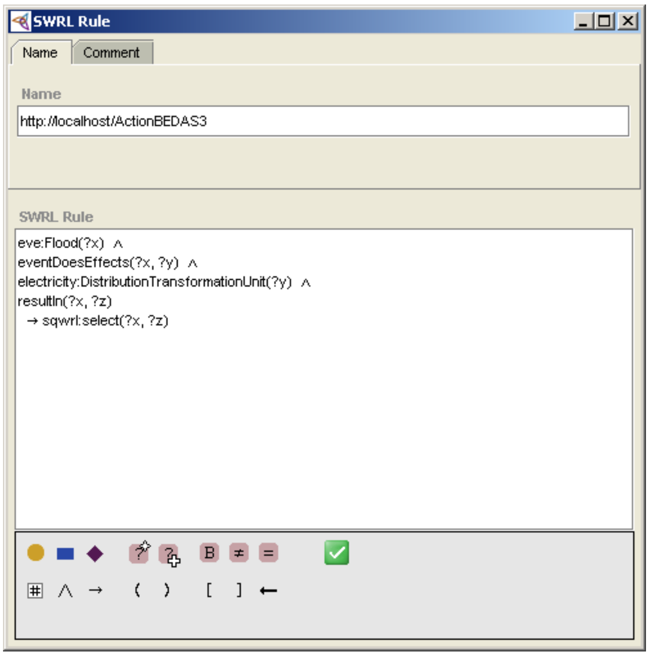

Figure 133 Third selection rule for the BEDAŞ network from Emergency Context Ontology

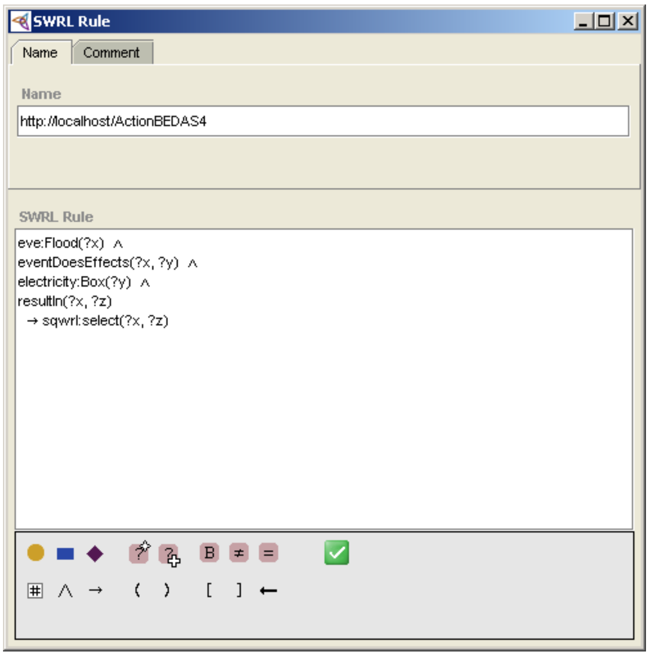

Figure 134 Fourth selection rule for the BEDAŞ network from Emergency Context Ontology

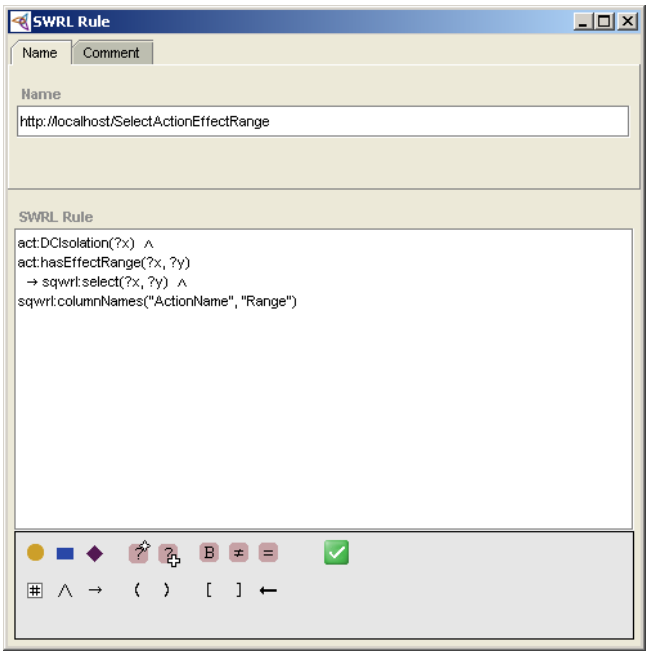

Figure 135 Selection rule for an effect range as a result for a DCIsolation action from Emergency Context Ontology

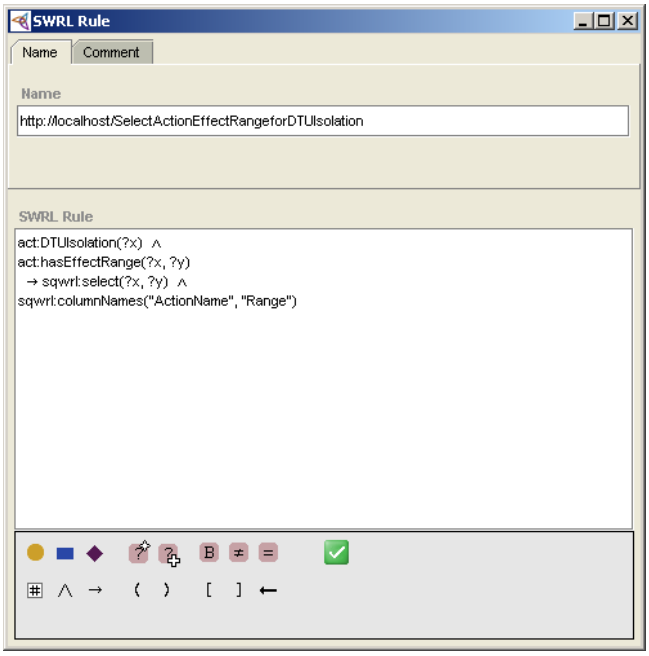

Figure 136 Selection rule for an effect range as a result for a DTUIsolation action from Emergency Context Ontology

APPENDIX E

THE COMPLETE INTEROPERABILITY STUDY

APPENDIX E is appended to this dissertation in DVD environment. Content of the DVD is as follows:

1. Common Vocabularies Ontology: It is the owl files of the common vocabularies ontology which is constitute the upper ontology together with the spatial representation ontology

2. Spatial Representation Ontology: It is the owl files of the spatial representation ontology which is constitute the upper ontology together with the common vocabularies ontology

3. Electricity Network Ontology: It is the owl file of the BEDAŞ ontology which is one of the application ontology

4. Telecommunication Network Ontology: It is the owl file of the Türk Telekom ontology which is other application ontology

5. Maintenance Context Ontology, Emergency Context Ontology and SWRL Rules: It is the owl file of the Event, Action and Organization ontologies. In addition, in this folder, there is an owl file of the maintenance context ontology which hosts the SWRL rules.

6. The GIS Add-Ons: The related folder contains add-ons which are developed in the MapBasic and Microsoft .NET environment. For both types, the executables and source codes are given.

7. AYKOME, BEDAŞ, TELEKOM Web Services: It is the source code of the web services developed on the Java environment.

8. Sample Data: It is the sample data of both BEDAŞ and Türk Telekom.

9. World Feature Services Configuration File: It is the configuration file of the world feature service served by Map Extreme software and Internet Information Service which is a trademark of Microsoft Corporation.

10. Trial Version of Map Extreme: It is the setup files of trial version of the Map Extreme software. In addition to setup files, the configuration manual of the software is given.

11. MapBasic: It is the setup files of the scripting platform of MapInfo software

12. NetBeans IDE: It is the setup files of the integrated development environment (IDE) which is used while the AYKOME, BEDAŞ and TELEKOM services were developing. The IDE also contains Tomcat which is a web server on which the services are hosting.

13. Trial Version of Jess Reasoner: It is the jar file of the Jess which is used as a reasoned in this study

14. Trial Version of MapInfo: It is the setup files of the trial version of the MapInfo software.

15. Protégé Ontology Editor: It is the setup files of Protégé ontology editor

CURRICULUM VITAE

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Profession: Civil Engineer

EDUCATION:

School	***Years***	***Diploma, Grade and Subject***
Primary School		
Kazımpaşa Primary School Torbalı, İzmir, TÜRKİYE	1983 – 1988	Primary School Diploma
Secondary & High School		
Torbalı Lisesi Torbalı, İzmir, TÜRKİYE	1988 - 1991	Secondary School Diploma
Eskişehir Fatih Science High School Eskişehir, TÜRKİYE	1991 - 1994	High School Diploma
University		
METU Department of Civil Engineering İnönü Blv., Ankara, TÜRKİYE	1995 – 2000	B.Sc.
METU Department of Geodetic and Geographic Information Technologies İnönü Blv., Ankara, TÜRKİYE	2000 - 2003	M.Sc. , "Developing A Parcel-Based Information System by Object-Oriented Approach"
METU Department of Geodetic and Geographic Information Technologies İnönü Blv., Ankara, TÜRKİYE	2004 - 2010	Ph.D. , "Context Based Interoperability to Support Infrastructure Management in Municipalities"

LANGUAGE SKILLS:

Native Language : Turkish

Other Languages : English

WORK EXPERIENCE:

Organization	Years	***Job***
BAŞAR SOFTWARE COMPANY Ankara, TÜRKİYE	2001 – 2002	GIS Specialist

Organization	Years	Job
TÜBİTAK-SAGE Ankara, TÜRKİYE	2002-2005 2005-2010 2010-	Research Engineer Senior Research Engineer Head Research Engineer