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ARAŞTIRMA MAKALESİ / **RESEARCH ARTICLE**

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DESCRIPTION LOGIC BASED EARTHQUAKE DAMAGE ESTIMATION FOR DISASTER MANAGEMENT

ABSTRACT

Earthquake damage estimation within the first few hours of devastating earthquake is critical from the point of decision-making and post-disaster planning. With recent developments in earthquake engineering, earthquake damage estimation can be effectively determined using strong ground motion network. However, a number of densely populated cities in earthquake risk zones do not have access to such costly and advanced systems. In this paper, we propose a system for estimating earthquake damage in the early post-disaster period, using a limited number of data sources, such as up-to-date earthquake source parameter, population, building quality, roads and bridge locations. This information, however, is distributed, and therefore poses semantic heterogeneity problems in data sharing. For this reason, it is very challenging to derive accurate damage and loss estimation solely based on the source parameter of the earthquake. To solve this problem, in the proposed system, ontologies are used to ensure semantic interoperability, and description logic (DL) rules are defined for damage estimation. Other features of this study include the use of parliament triple store to store and query disaster ontology, and the provision of damage assessment maps to enable disaster managers to reduce their response time.

Keywords: Earthquake damage estimation, Ontology, Description logic, Disaster management, Semantic interoperability.

AFET YÖNETİMİ İÇİN BETİMLEME MANTIĞI TABANLI DEPREM HASAR TAHMİNİ

ÖZ

Yıkıcı bir depremin ilk birkaç saatinde deprem hasar tahmini yapılabilmesi afet sonrası planlama ve karar verme açısından çok kritik öneme sahiptir. Deprem mühendisliğindeki gelişme ile deprem hasar tahmini kuvvetli yer hareketi ağı kullanılarak etkin bir şekilde yapılabilmektedir. Buna rağmen birçok deprem riski taşıyan bölgelerdeki yoğun nüfusa sahip olan şehirlerde bunun gibi gelişmiş ve maliyetli sistemler bulunmamaktadır. Bu çalışmada deprem sonrası süreçte güncel köprü, yol, bina kalitesi, nüfus ve deprem parametreleri gibi kısıtlı veri kaynakları kullanılarak deprem hasarını tahminlemeyi amaçlayan bir sistem önerilmektedir. Bununla birlikte bu bilgiler dağıtık ve veri paylaşımı açısından anlamsal heterojenliğe sahiptir. Bu sebeple sadece deprem parametrelerine dayanarak hasarın ve kayıpların tahmininin doğru yapılması zorlu bir görevdir. Bu problemi çözebilmek için hasar tahmini için betimleme dili kuralları tanımlandı ve ontolojiler kullanılarak anlamsal heterojenliği sağlaması amaçlanmıştır. Bu çalışmanın diğer özellikleri ise afet ontolojisinin sorgulanması ve saklanması için parliament triple store kullanılmıştır ve afet yöneticilerinin afete müdahale süresinin kısaltmak için hasar değerlendirme haritaları üretilmiştir.

Anahtar Kelimeler: Deprem hasar tahmini, Ontoloji, Betimleme Mantığı, Afet Yönetimi, Anlamsal heterojenlik.

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1. INTRODUCTION

Earthquakes are prevailing natural events which threatening more than 50% of cities of at least 2 million populations located within 200 km of plate border zone (Bilham, 2009). By their very nature, earthquakes cannot be prevented, and for this reason, earthquake damage assessment and rapid intervention in the disaster is required in order to minimize loss of life and property. In recent years, earthquake damage estimation studies have made great progress due to the development of earthquake engineering. These studies have been conducted at different levels and with different scenarios, in which rapid response systems are activated immediately after the earthquake, and provide assessment of the distribution of ground shaker intensity. Earthquake rapid response systems provide ground motion measurement, using strong ground motion network and data processing system for assessment (Erdik et al., 2010). Although strong ground motion networks already exist in several cities of the world, including Tokyo, Yokohama, and İstanbul, this network is not available in other high risk cities due to cost. In these cities, damage estimation has to be carried out using information retrieval from different data sources. While strong ground motion network estimates damages geologically, this in itself is insufficient for complex damage estimation such as broken bridges and closed road location identification. Integrated damage estimation which takes into account earthquake source parameter, building inventory, population, and land use maps information enables more effective decision-making. However, deriving damage solely based on the source parameter of earthquake, without other sources of information is a very challenging task.

Lang (2008) performed damage estimation using a decision-tree method on earthquake source parameters. They carried out near-real time application using a damage estimation tool named SELENA. However, using static and heterogeneous data source in damage estimation does not allow for the immediate use of ad hoc information with semantic relations. There are several difficulties in the damage estimation process; however, these can be overcome by machines regarding data sources schemas information. For this reason, the content of each information source must be fully understood by, and described for machines, so that the sources can be discovered and combined automatically (Xu and Zlatanova, 2009). Disaster conditions require fast and accurate decision-making, and in fact it is impossible for humans to examine all distributed information, understand the content, and then access and combine this information in disaster management. In contrast, if machines are able to access, inference and manage data automatically, disasters can be managed much more effectively.

Ontologies are used for ensuring semantic interoperability, and DL rules are used for damage estimation. DL allows for the inferencing new information using existing relations between concepts in ontology. For example, DL allows inferencing with rules, such as "*if an earthquake has a greater magnitude than 6, it is determined as disaster*". Thus, while humans can inference from distributed and heterogeneous data sources without the help of technology, the process can be greatly accelerated and performed with greater accuracy by computers using DL rules and ontologies.

1.1. Literature Review

There exist several ontology-based disaster management studies; some studies address only ontology-based disaster modeling (Tanasescu et al., 2006; Kructhen et al., 2007), and various studies were conducted to provide semantic interoperability between data sources (Xu and Zlatanova, 2007; Fan and Zlatanova, 2011). These studies can be considered the foundation studies on ontological disaster management literature. More specific other work includes Klien et al. (2006), who used ontology-based discovery of geographic information services for estimating potential storm damage in forests. This approach uses terminological reasoning alone to ensure semantic interoperability during information retrieval, and employs reasoning mechanism to match concepts during service discovery. Zhang et al. (2014) defined inference rules to enable further investigation from the OWL knowledge base in the domain of transportation. They used DL and inference rules based spatial relations, and the proposed framework facilitates knowledge-sharing and reuse via automatic machine processing. Xu et al. (2008) focused solely on the conceptualization of disaster management processes, and concepts were modeled with UML and OWL-DL languages on any type of reasoning mechanism. They proposed ontology building for the disaster domain and demonstrated the reasoning power of ontology (OWL-DL). However, we have found no DL-based disaster ontology specifically designed to estimate earthquake damage. In this paper, therefore, we propose earthquake preliminary damage assessment using description logic (DL) rules via disaster ontology. Within this study, we provide a solution that enables a rapid and efficient disaster response using an ontological reasoning mechanism that does not depend on preliminary damage assessments from the territory.

1.2 Background

Compared to developed countries, developing countries are significantly more exposed to natural disaster risks. The economic cost of natural disaster is considerably greater for developing countries due to lower standards of building construction (Perry, 2009). Turkey is located in a seismically active region, and approximately half of the country is declared as first order earthquake zone. In spite of this, the majority of the population lives in cities. Many of these metropolitan areas are threatened by natural disasters. Although there is an increasing awareness of this danger, there is limited strong ground motion network in Turkey. In addition, those responsible for disaster management seem not to have learnt the lessons from previous experience. Disaster management (DM) is described as the management of the risks and consequences of a disaster (Othman, 2013), and can be divided into the following four phases; preparedness, mitigation, response and recovery (Figure 1).

Figure 1. Disaster management cycle (Source: the Federal Emergency Management Agency)

We propose a system that will allow damage estimation without the need for any field work in early post-disaster period, at the response stage. This system is applied district of Buca İzmir in Turkey for assessing the disaster, treating remaining hazard effects, providing water and food, shelter, and sanitation are the critical actions at this stage. When past earthquakes are examined in different cities, several coordination problems emerge, such as transporting the injured to hospital, which is of key importance, as well as the efficient allocation of resources, deciding on the initial gathering points to be used after the disaster, and the determination roads which are unusable owing to wreckage, which also requires immediate attention at the response stage. In all of the above, disaster managers face the challenge of taking action without sufficient field information after the disaster. However, an efficient response can be procured if it can be decided which areas are the safest and most suitable bases for the aid efforts in district of Buca in İzmir.

2. METHODOLOGY

2.1 The Framework for Earthquake Damage Estimation

The aim of the framework proposed here is to provide damage assessment for the earthquake domain using an ontology reasoning mechanism. The proposed framework for damage assessment is illustrated in (Figure 2). Heterogeneous spatial data sources comprise data file in different formats. Spatial data sources are converted into GML and mapped onto the earthquake ontology which was previously developed for the disaster management domain (Aydın and Tecim, 2013). Thus this proposed framework can resolve the interoperability problem between distributed institutions. Through the creation of earthquake ontology, it is aimed to create a model for disaster management in the earthquake domain. Methontology methodology was chosen because it is capable of providing ontology reuse in other domains, is widely used by developers, is easy to use, and the ontology development cycle is used during disaster ontology design. DL based rules and restrictions are used to infer results for efficient decision-making. Triple store is used to store ontology, and query with GeoSPARQL language. GeoSPARQL language provides spatial query capabilities for earthquake ontology. According to DL rule, several spatial queries are examined for calculating damage on neighborhoods, and so ground acceleration is calculated using a reasoning mechanism. At the same time, the system is able to make a more cost effective damage assessment compared to advanced technological systems, such as strong ground motion, and it can infer results using DL from heterogeneous data sources.

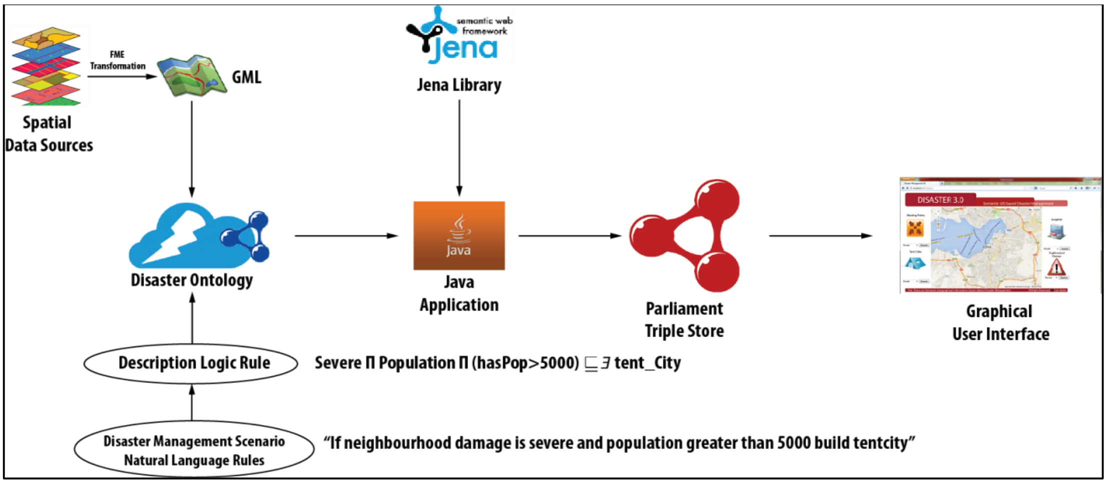


Figure 2. Ontology Based Damage Estimation Methodology

2.2 Ontology Mapping from Spatial Data Sources

Heterogeneous spatial data sources are converted into OGC standard GML data format to provide interoperability. The literature review mentioned several studies which involved mapping spatial data into ontologies. However, as seen in these studies, data sources were mostly published with spatial web services, which have a limited amount of metadata. For this reason, ontology mapping process can be improved by mapping metadata onto ontologies. Several methods are investigated for ontology mapping in cases in which it is not possible to publish spatial data via web services such as geo-portals, owing to problems at the institutional level. For example, in our case, institutions in İzmir store their own data in proprietary formats rather than serving from WMS or WFS standard formats. Thus all institutions have a static and heterogeneous structure. In order to solve this problem, a Feature Manipulation Engine template was prepared to convert all data sources into standard GML format. GML schema contains a variety of objects, such as coordinate system, geometry, feature attributes (name, population, type). Instances of OWL classes are mapped onto individual features attributes, and geometry is inserted into triple store as RDF triple using the same method. These processes are realized by mapping GML onto an ontology algorithm, which checks all elements from GML until an element is found. Once an element is found, it is mapped onto ontology. The process continues in this sequence until every object is mapped onto OWL ontologies.

2.3 Using DL Rules and Restrictions on Earthquake Damage Assessment

In this study, DL rules are used to create restrictions and carry out damage assessment. The key concept is that a particular class of individuals is described by the relationships that these individuals have with each other, and at the same time we can define such classes by using restrictions (Horridge, 2009) which are based on DL in ontologies. DL has developed into important knowledge representation formalism. With the formal semantics introduced it was rather immediately clear that DLs can be seen as a fragment of first-order predicate logic (FOL). In contrast to the well-known correspondence to FOL, there are several different DL types, such as $\mathcal{ALC}$, $\mathcal{SHOIN}^{(\mathcal{D})}$, $\mathcal{SROIQ}^{(\mathcal{D})}$. $\mathcal{ALC}$ is just a syntactic variant of the multimodal logic of knowledge and $\mathcal{SHOIN}^{(\mathcal{D})}$ is more expressive than $\mathcal{ALC}$ and letters indicate various extensions such as 'S' used for $\mathcal{ALC}$ extended with transitivity axioms and 'H' hierarchy role, 'O' nominal, 'I' inverse roles and finally 'N' for number restrictions. In our study, DL expressiveness is based on $\mathcal{SROIQ}^{(\mathcal{D})}$ which differentiate $\mathcal{SHOIN}^{(\mathcal{D})}$ with 'R' role box and 'Q' for qualified number restrictions property and $\mathcal{SROIQ}^{(\mathcal{D})}$ is the most suitable for the OWL 2 language and most expressive yet decidable version of OWL called OWL 2 DL (Rudolph, 2011), which is used in the design of disaster ontology. Description logic rules are created according to the disaster management scenario. First, we define rules in natural language rule format, and then these rules are converted into description logic rules. Finally, we integrate these rules into disaster ontology using Protégé.

Some inferences should be made within DL rules in disaster ontology in order to carry out damage assessment. First, natural language rules are defined within the boundaries of the disaster management scenario. For instance, "*Earthquake Π (>6.5 hasMagnitude Π>1 hasTime) ⊑ Disaster"* rule states that, to be classified as a disaster, an earthquake magnitude must be greater than 6.5 and the duration longer than 1 minute for prerequisite of disaster. After specifying an earthquake as disaster, the next rule determines neighborhood damage failure such as "If earthquake acceleration greater than 12 and soil type "Soft" than neighbourhood damage is severe with using *"Neighbourhood Π (hasSoilType "Rock") Π (<12 hasAcceleration)"*. Accordingly, a neighborhood is defined as being severely, moderately or lightly damaged, based on the earthquake acceleration value and basement type. The acceleration value should be calculated for each neighborhood. Several models exist for damage assessment after an earthquake. In this study, we use the Hu, Liu and Dong model, which depend on acceleration value, based on distance from epicenter, magnitude of earthquake, and basement type parameters. The regions which are most severely damaged are pre-defined by determining the magnitude of damage; therefore, this model allows the direction of resources to these regions. In the above model, the horizontal acceleration value is calculated depending on basement type (Rock Soil, Hard Soil etc.), taking into account distance between epicenter and the district, earthquake magnitude variables, and some constants (Hu Liu Dong, 1997) (Table 1).The neighborhood acceleration value decreases with the increasing distance from fault. The nature of basement conditions has a great influence on the value of the acceleration. The estimated damage is calculated by establishing damage ratio on buildings, classified as light, medium and severe damage, and also as wreckage and severe wreckage, based on building materials (loam, brick or concrete), and acceleration value (Karagöz, 2012).

Table 1. Horizontal Acceleration Equations (Hu, Liu, Dong 1997).

Soil Type	**Equation**
Rock Soil	$a=46x10^{0.208M} (D+10)^{-0.686}$
Hard Soil	$a=24.5x10^{0.333M} (D+10)^{-0.924}$
Medium Hard Soil	$a=59x10^{0.261M} (D+10)^{-0.886}$
Soft Soil	$a=12.8x10^{0.432M} (D+10)^{-1.112}$

After determining neighborhood damage conditions, it is critical to establish the condition of roads and bridges on the route to the disaster location. To forecast the condition of bridges, if neighborhood damage is severe, all bridges within the boundaries of the neighborhood can be considered to be destroyed, and *"Severe ⊑ ∃ hasDestroy Bridge; Moderate ⊑ ∃ hasDestroy Bridge; Light ⊑ ∃ hasDestroy Bridge"* rules can be defined in ontology. In addition, to forecast the conditions of roads, if neighborhood damage is severe and building height is more than 15 meters on the road, *"Severe Π Building Π (hasFloor>5) ⊑∃ hasClosed Road; Severe Π Building Π (hasFloor>5) ⊑ ∃¬ hasClosed Road "* rules can be applied. Destroyed bridges and unusable roads can be determined via both rules. Thus, the disaster manager is able to make predictions about routes and the types of vehicles required to reach the disaster location. The inferences that can be made are not confined to the early post-earthquake response. After the earthquake, distant logistics of resources is another important challenge. For example, tent cities are required for those made homeless. There are unlikely to be enough tents in the affected city, so more have to be brought in immediately from nearby cities. For this reason, the estimated number of tents needed and the locations of the tent city can be defined according to neighborhood population, and neighborhood damage assessment. *"If neighbourhood damage is severe and population greater than 5000 than build tentcity?"* Rule can be identified with *"Severe* Π *Population* Π *(hasPop>5000)* ⊑ ∃ *tentCity"* DL rules in order to allow these preparations to begin after the early post-earthquake period. This ensures that the homeless can be settled without delay. DL rules are converted into OWL language in the above and attached into disaster ontology using Protégé. For example; "*Neighbourhood Π (hasSoilType "Rock") Π (>12 hasAcceleration)" rule defined as* Neighbourhood and (hasAcceleration some integer [>="15"^^integer]) and (hasSoilType only Alluvion), as seen in Figure 3.

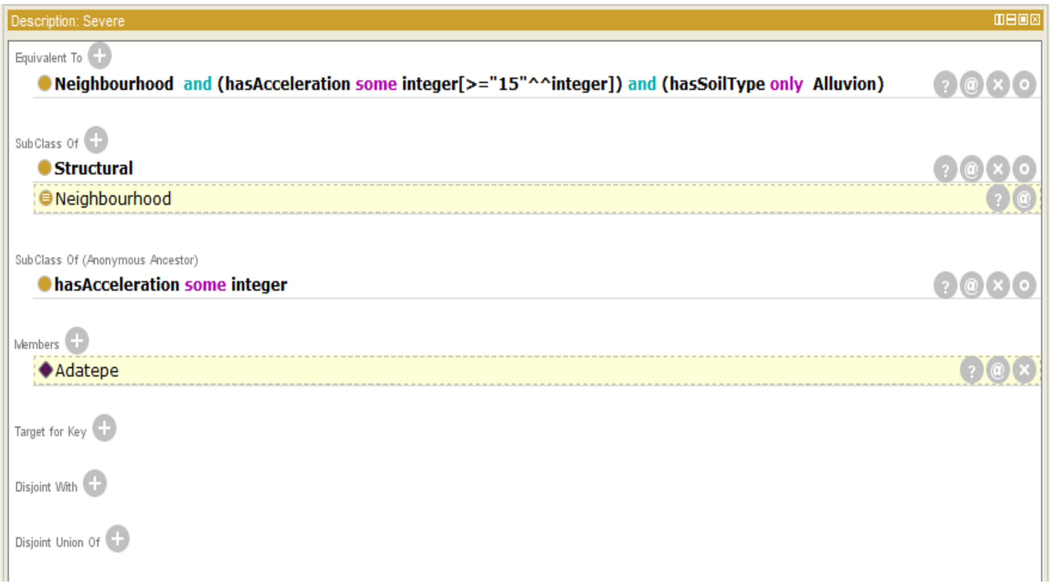


Figure 3. Attaching DL rules into disaster ontology with Protégé

One benefit that disaster ontology has in defining rules is its use of the concepts of class and property. Class-subclass and disjoint relations are described between classes and properties before the rules are defined. At the same time, ontology determines the class and range that a type of data belongs to, as described in previous studies. One of the characteristics of these rules is that they enable the system built on them to infer implicit knowledge which can be used to increase the effectiveness of disaster management. This inferred knowledge is important because information about the damaged neighborhood itself is more relevant to disaster management than information about the epicenter of earthquake.

2.4 Triple Store

Based on the proposed methodology, we enable the storage and querying of disaster ontology using triple store. The semantic web employs a different data model compared to a relational database. A relational database stores data in tables, while RDF represents data as directed graph of ordered triples of the form. Accordingly, a semantic web data store is often called a graph store, knowledge base, or triple store (Emmons, 2012). A directed graph can be stored in relational databases, but the only practical method of storing the graph is to use a single table to store all the triples. As a result, the query performance of such implementation is usually poor. In the current study, Parliament Triple Store was chosen to store and query ontology because this is a query processor and includes a rule engine which applies a set of inference rules to the directed graph of data in order to derive new facts. Another advantage is that Parliament supports spatial and temporal index due to spatial query chance. This is possible due to its compatibility with Jena library for selecting Parliament Triple Store. Spatial data are converted into RDF statements into triple store, and a number of queries can be carried out which allow the use of the acceleration formula in the calculation of damage estimation. These queries, which include neighborhood distance from epicenter and neighborhood basement type and the results of these queries, were used to calculate the neighborhood acceleration, which is exist as a variable in formulas.

2.5 GeoSPARQL Query Operations

Query solutions are developed for damage assessment over the network. Query arrays consists of a several operations (distance, contains and numerical operations) which are used to determine damage assessment, and facilitate decision-making under the conditions of a disaster trauma. Almost queries achieve results without the need for human assistance from distributed data sources. Neighborhood distance from the main epicenter, basement type queries are expressed using GeoSPARQL language, which supports spatial queries. We used these query results in ground acceleration calculation.

2.5.1 Neighborhood Distances from the Main Epicenter Query

The critical distances to the epicenter from the neighborhood were determined with distance () function of GeoSPARQL query languages. Distance function algorithm is very similar to standard spatial distance operations in GIS programs. As it seen in Figure 9, queries are performed on same data set using both GeoSPARQL and MapInfo spatial query library (Table 2). The results were found to be very close in comparison.

Table 2. Comparisons between GeoSPARQL and MapInfo neighborhood distances from epicenter

GeoSPARQL neighborhood distances	
Neighborhood Name	**Distance From Epicenter**
http://www.izmirdeafet.com /Disaster.owl#HURRİYET	"3373.970773739"^^<http: //www.w3.org/2001/XML Schema#double
http://www.izmirdeafet.com /Disaster.owl#INONU	"5975.125387461"^^<http: //www.w3.org/2001/XML Schema#double
http://www.izmirdeafet.com /Disaster.owl#EFELER	"3090.607821837"^^<http: //www.w3.org/2001/XML Schema#double
http://www.izmirdeafet.com /Disaster.owl#ADATEPE	"1299.062137617"^^<http: //www.w3.org/2001/XML Schema#double
http://www.izmirdeafet.com /Disaster.owl#GOKSU	"5298.857904089"^^<http: //www.w3.org/2001/XML Schema#double
http://www.izmirdeafet.com /Disaster.owl#GUVEN	"3299.288710264"^^<http: //www.w3.org/2001/XML Schema#double

MapInfo neighborhood distances from epicenter	
Neighborhood Name	**Distance From Epicenter**
HURRİYET	3367.381440
INONU	5979.398766
EFELER	3090211030
ADATEPE	1299733589
GOKSU	5299368685
GUVEN	3294.096032

2.5.2 Basement Type Query

Another query is neighborhood basement type in district for use in the earthquake acceleration calculation. For this query, we used GeoSPARQL intersect function to establish neighborhood basement type. Basement type information for the province was derived from the 1:25,000 scaled digital geologic formation maps of the province, provided by MTA (General Directorate of Minerals and Exploration). Each formation was assigned one of the four basement types ("Rock", "Hard", "Medium", "Soft"). Rock formations represent massive volcanic rock, which is the most suitable for settlement. "Hard" represents slightly deformed volcanic rocks, also settlement suitable. "Medium" represents altered volcanic and metamorphic rocks which have limited suitability for settlement, and the "Soft" represents thick alluvial deposits, the least suitable basement type for settlement. These formations are shown in (Table 1) (Alparslan, 2008). We used 'contains' spatial operations for determining basement type on same data set with GeoSPARQL and MapInfo query operations. The results were found to be same in comparison (Table 3).

Table 3. Comparisons of neighborhood basement type

GeoSPARQL query results of neighborhood basement type	
Neighborhood Name	**Basement Type**
http://www.izmirdeafet.com/ Disaster.owl#HURRİYET	http://www.izmirdeafet.com/ Disaster.owl#Hard
http://www.izmirdeafet.com/ Disaster.owl#INONU	http://www.izmirdeafet.com/ Disaster.owl#Hard
http://www.izmirdeafet.com/ Disaster.owl#EFELER	http://www.izmirdeafet.com/ Disaster.owl#Hard
http://www.izmirdeafet.com/ Disaster.owl#ADATEPE	http://www.izmirdeafet.com/ Disaster.owl#Hard
http://www.izmirdeafet.com/ Disaster.owl#GOKSU	http://www.izmirdeafet.com/ Disaster.owl#Hard

MapInfo query results of neighborhood basement type	
Neighborhood Name	**Basement Type**
HURRİYET	Hard
INONU	Hard
EFELER	Hard
ADATEPE	Hard
GOKSU	Hard

2.5.3 Ground Acceleration Calculation

Ground acceleration is the measure of how much and how fast the basement is shaken during an earthquake. The most and least affected regions can be determined by the ground acceleration value (Campbell 1997). Distance from the epicenter and basement type variables abovementioned are acquired for using spatial queries with calculating ground acceleration. According to this scenario, we defined all neighborhood ground acceleration values for the assessment of damage (Figure 4). For example, Adatepe neighborhood in Buca district, '1299' meters from the epicenter with 'Hard' basement type, bwas queried with GeoSPARQL.

Neighborhood damage estimation was determined as 'Moderate' after calculating acceleration formula as in the above.

Algorithm 1 Acceleration Calculation

Input: *B* basement types, *M* magnitude of earthquake, *N* neighborhood, D neighborhood distance from epicenter, *cons1, cons2, cons3* from formula, *A* result

for i=0 to *N* size
  if *B* equals 'rock' **do**
    M=*M***cons2*
    D=*D*+10
A=*cons1**Math.pow(10,*M*)*Math.pow(*D*,*cons3*)
end
AssignNeighbourhoodResult(*N*,*A*)
return

3. EXPERIMENTAL RESULTS

All neighborhoods in Buca district ground acceleration value were calculated using acceleration formula in accordance with rules for damage assessment in the above section. In the implemented prototype, JSP (Java Server Pages) was used to publish the disaster management web site. Apache Tomcat Server used a container for web application. Jena, a semantic web framework for Java, was used to access, and infer knowledge from ontology. Parliament Triple Store works on a Joseki Server to retrieve query results. Graphical User Interface (GUI) components are comprised of items such as unusable roads, destroyed bridges and neighborhood, according to damage ratio queries. The results of the queries were published using Google Map API. Figure 4 illustrates query example using GeoSPARQL for the geometry of severe damage neighborhoods. This result can be described as the first stage of the query chain. After defining the severely damaged neighborhoods, a number of query results are provided to disaster managers according to damage status. These queries include meeting places, hospitals, security control points, logistic support control centers, head distribution centers, and police stations.

Severe Damage Neighbourhood in Buca District

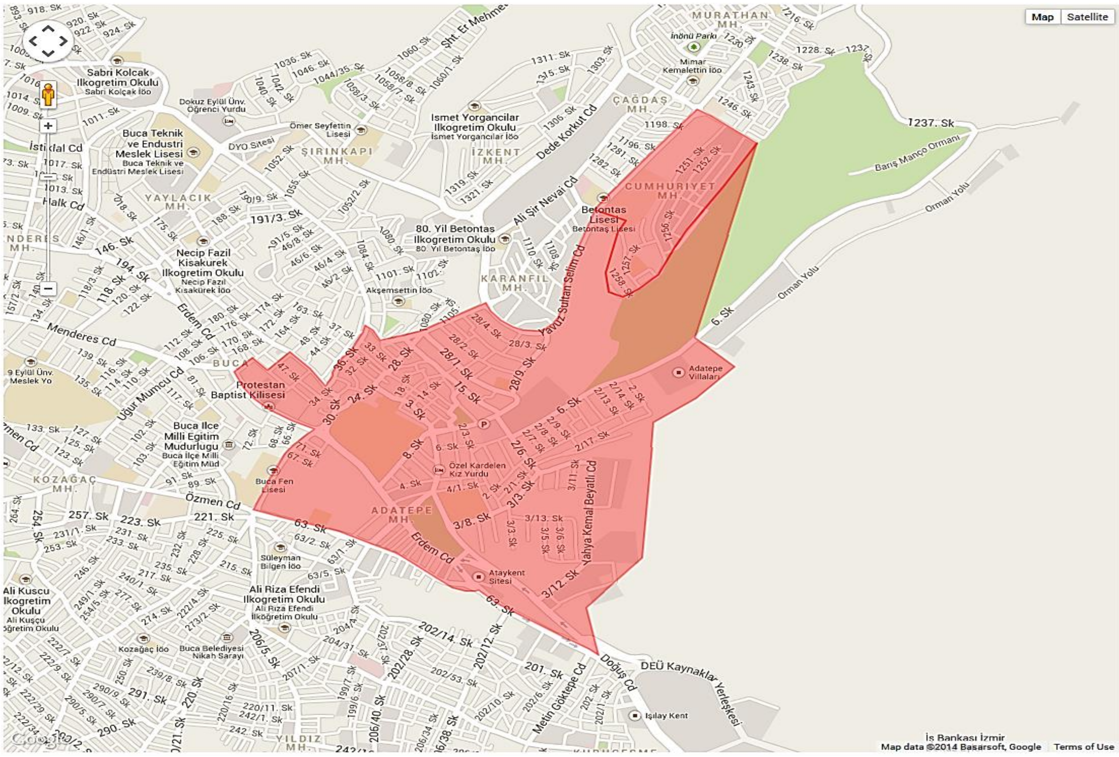
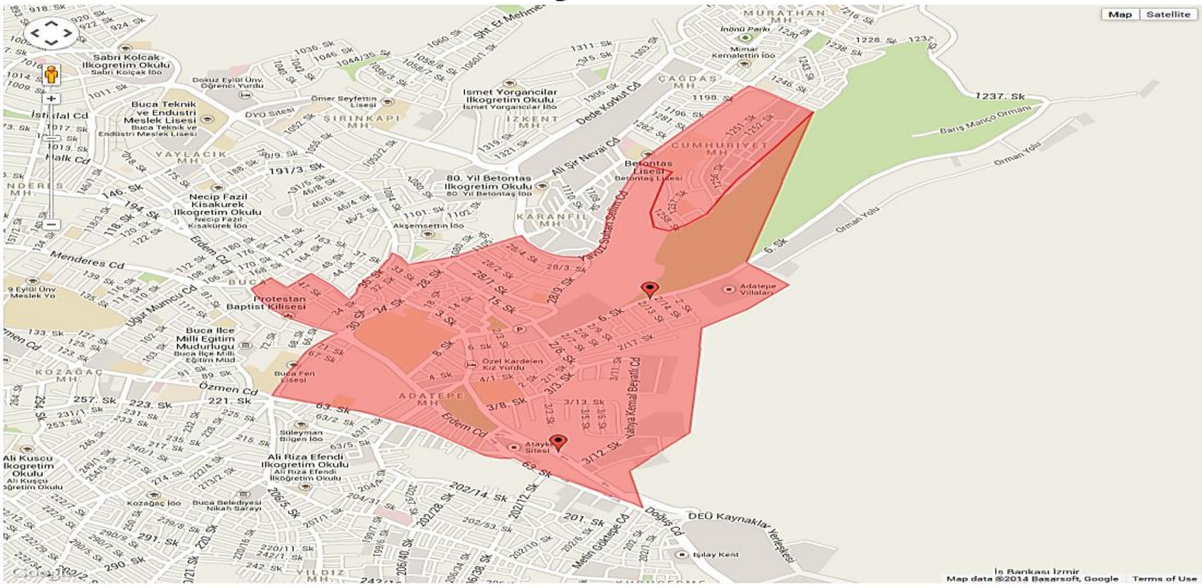


Figure 4. Severe damage neighborhood query

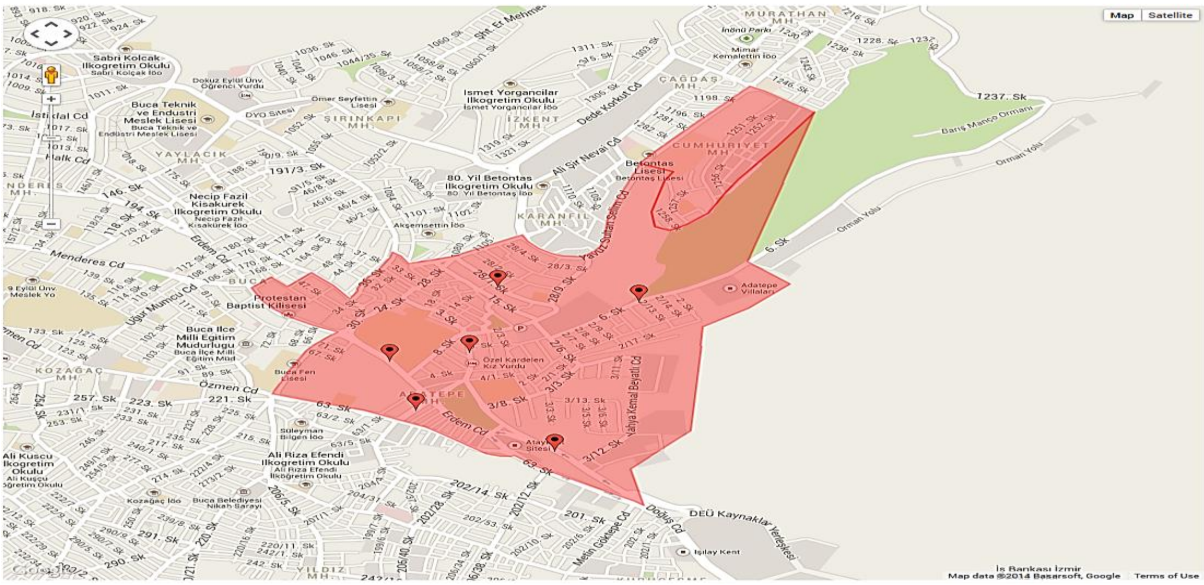
Another query result is to show unusable roads and destroyed bridges, according to damage status. This information is important for determining the most suitable route into the disaster area for distributed rescue and the other teams (Figure 5 a-b).

Broken Bridges in Buca District



a)

Closed Roads in Buca District



b)

Figure 5. Unusable roads and destroyed bridge according to Neighborhood Damage

The main procedure in the examples is as follows: the user send request from GUI. This request is sent to the Parliament Triple Store for querying with GeoSPARQL via java class. Parliament returns query results with DL reasoning ability as inference result into java class. The built-in reasoning algorithm of Parliament is used to infer features. When user sends the request 'closed road' to the server, parliament triple store sends back to the client an inferred result.

4. CONCLUSION

Earthquake damage estimation is very important for decision-making and planning after a disaster. Damage estimation can be determined using strong ground motion network. However, a number of cities at risk of have no such network available. Although damage assessment can be carried out with static and heterogeneous data sources using the decision tree method, semantic disparity can make it very difficult to automate the discovery of these geospatial features and undertake reasoning. Using human integration alone, it is not possible to automatically retrieve the desired information from semantically heterogeneous and distributed data sources. Therefore, to expedite automatic damage assessment, in this paper we propose a DL-based damage assessment which is capable of both reasoning and querying. We focus on intelligent damage assessment with DL rules and map interface to enhance the decision-making process. The proposed methodology combines the power of ontology with damage assessment methods. The results of the implementation show that it is possible to make damage assessment with DL rule based ontologies in cities which lack strong ground motion networks. Within the DL rule, distributed data sources become machine understandable and gain inference capabilities, and ontologies facilitate the querying of these data sources for damage assessment. The results show that is possible to make spatial queries from distributed data sources using GeoSPARQL and Parliament Triple Store in combination. By providing an interface for accessing damage assessment information, the proposed framework can facilitate all levels of disaster management without the need for prevailing semantic web technologies. In other words, there is no requirement for disaster managers themselves to understand either DL language or ontology.

REFERENCES

Alparslan, E. Ince, F., Erken, B., Aydöner, C., Özen, H. and Dönertaş, A. (2008). A GIS Model for Settlement Suitability Regarding Disaster Mitigation, A Case Study in Bolu Turkey, *Engineering Geology 96*, 126-140.

Aydın, C. and Tecim, V. (2013). Research on Geo-ontologies at Earthquake Domain for Disaster Management on Urban Areas, *Urban and Regional Data management*, Taylor & Francis Group London, 239-251.

Bilham, R. (2009). The Seismic Future of Cities, *Bull Earthquake Eng*, 7-4, 839-887.

Campbell, K.-W. (1997). Empirical Near-source Attenuation Relationships for Horizontal and Vertical Components of Peak Ground Acceleration, Peak Ground Velocity, and Pseudo-absolute Acceleration Response Spectra, *Seismological Research Letters*, *68*-1, 154 -179.

Erdik, M., Şeşetyan, K., Demircioğlu, M.-B., Hancılar, U. and Zülfikar, C. (2010). Rapid Earthquake Loss Assessment After Damaging Earthquakes, *Earthquake Engineering in Europe, Geotechnical, Geological, and Earthquake Engineering* 17.

Emmons, I. (2012). Parliament User Guide.

Fan, Z. and Zlatanova, S. (2011). Exploring Ontologies for Semantic Interoperability of Data in Emergency Response. *SIFET 2011. Appl Geomat* 3:109-122.

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

Hu, Y.-X., Liu, S.-C., and Dong, W.-M. (1996). Earthquake Engineering. *E& Spon, Champan & Hall*, 2-6 Boundary Row, London SEI 8HK, UK, 26-36.

Kruchten, P., Woo, C., Monu, K. and Sootodeh, M. (2007). A Human-centered Conceptual Model of Disasters Affecting Critical Infrastructures, *Proceedings of The 4th International Conference on Information Systems for Crisis Response and Management (ISCRAM2007),* Delft, The Netherlands:327–344.

Klien, E., Lutz, M. and Kuhn, W., (2006). Ontology-based Discovery of Geographic Information Services, *An Application in Disaster Management, Computers, Environment and Urban Systems*, 30:102-123.

Karagöz, Ö., Özel, O. and Tan, O., (2012). Analyzing Acceleration Waveforms and Determining Source Parameters of 23 October 2011 Van Earthquake (Mw = 7.2), *International Earth Science Colloquium on The Aegean Region-2012*, 01-05 October, Dokuz Eylül University-İzmir, Abstracts, 322 (Oral Presentation).

Lang, H., Moline-Palacios, S. and Lindholm, C.-D. (2008). Towards Near-Real-Time Damage Estimation using a CSM-Based Tool for Seismic Risk Assessment, *Journal of Earthquake Engineering*, 12(S2):199-210.

Othman, S. and Beydoun, G. (2013). Model-Driven Disaster Management, *Information and Management*, 50 (5), 218-228.

Perry, G. (2009). Beyond Lending: How Multilateral Banks Can Help Developing Countries Manage Volatility, *Center for Global Enviroment*.

Rudolph S. (2011). Foundation of Description Logics. *Reasoning Web. Semantic Technologies for The Web of Data Lecture Notes in Computer Science*, 6848, 76-136.

Tanasescu, V. (2006). A Semantic Web Services GIS Based Emergency Management Application. *The Semantic Web – ISWC The Lecture Notes in Computer Science*, 4273, 959-966.

Xu, W. & Zlatanova, S. (2007). Ontologies for Disaster Management Response. *Geomatics Solutions for Disaster Management Lecture Notes in Geoinformation and Cartography*, 185-200.

Xu, Li., Yang, K., Wang, J., Peng S. and Yi, J. (2008). A Study on Ontology-driven Geospatial- Information Retrieval Systems in The Semantic Web, *The International Archives of the Photogrammetry*. Vol. 352/B2.

Zhang, C., Zhao, T., Li, W. and Osleeb, J. (2014). Towards Logic-based Geospatial Feature Discovery and Integration using Web Feature and Geospatial Semantic Web, *International Journal of Geographical Information Science*, 24:6, 903-923.