HAZUS-based Drill Scripts Generation Using Unity and Ontology with Semantic Rules

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Abstract

As there is an increasing number of disasters hitting countries around the world, numerous mitigation strategies have been proposed and implemented to alleviate such impacts. Indeed, every year many public and private organizations work together to prepare various disaster exercises for training their first responders. Design of an appropriate drill script, hence, plays an important role of enhancing the capability of first responders or emergency response units in response to a real disaster. However, developing a reasonable disaster scenario is a time-consuming and error-prone task, not to mention the prerequisites pertaining to extensive experience and knowledge in disasters handling that drill script designers must have. Therefore, in this research an ontology model with SWRL (Semantic Web Rule Language) constructs was proposed to help the drill scripts generation process. Drill script designers can use the Taiwan Earthquake Loss Estimation System (TELES), which is a customized and simplified version of the HAZUS-MH program from FEMA (Federal Emergency Management Agency), to create data sets describing the impact of a simulated earthquake in a certain region. Then, the proposed model and tools, called EDSS (Earthquake Drill Scripts generation and rendering System), can incorporate the input data sets and generate a set of corresponding drill scripts, which follow the pre-defined rules represented in the ontology model. Each drill script will contain a unique and possible scenario describing the earthquake damage on different buildings or facilities in the region. Unity, a serious game platform, was utilized in the proposed system for displaying all the events associated with the earthquake in accordance with the drill script designed. Finally, disaster mitigation experts were asked to evaluate the drill scripts generated and to assess the effectiveness of the proposed model. The assessment results showed that the proposed model and tools can help first responders possess better situation awareness regarding how an earthquake will progress. Mitigation of earthquake damage can be achieved if first responders can use the proposed system to review the scene before commencing any search and rescue work.

Keywords –

MAZUS-MH; serious game; ontology; Semantic Web Rule Language (SWRL)

1 Introduction

Nowadays, in disaster-prone regions such as Taiwan, public and private organizations often work together to prepare various exercises for their first responders or emergency response units, in hope of mitigating disaster impacts. According to the United States Homeland Security Exercise Evaluation Program (HSEEP), a disaster exercise can be classified as either the discussion type, such as a tabletop exercise involving key personnel discussing a simulated scenario in an informal setting, or the operations type such as a full-scale exercise, which is a coordinated, supervised activity usually employed to test specific operations within multiple agencies. Both types of exercises with well-designed scenarios can help organizations cope with a disaster. In practice, a disaster exercise can be expressed in the written form called a drill script, which should contain descriptions to mimic real-world events in accordance with a disaster's progress for a given environment. However, the relationship between a disaster exercise and its drill script is different to that between a film and a film script. A film script describes instructions for the actors and directions for filming, while a drill script does not contain instructions regarding how first responders react to a disaster. Instead, a drill script includes detailed descriptions pertaining to the status of the environment and/or evacuees as the disaster proceeds. It is first responders' responsibility to perform the so-called OODA (Observe-Orient-Decide-Act) loop to practice their responses to the disaster in the simulated environment.

Previous literature has shown that the development of an appropriate drill script plays an important role of enhancing the capability of first responders or emergency response units to handle a disaster. The level of a community's disaster preparedness and readiness are also highly dependent on the quality of drill scripts utilized. However, creating a reasonable scenario to simulate a disaster's progress is a time-consuming and error-prone task. An event described in a drill script may have an irrational location, e.g., earthquake damage spotted in an area without any buildings, or a well designed and built house described as being collapsed. Such an event may be described to occur at an impractical time point, too, e.g., post-earthquake fire occurring before buildings collapse. Additionally, since the time available to consult with all stakeholders such as disaster management officers and first responders is limited, even an experienced drill script designer may not be able to consider all possible scenarios to be prioritized into the script. Thus, actual drill scripts utilized for disaster exercises are often inaccurate, inconsistent and incomplete. Improvement of the drill scripts generation process is highly needed and has been suggested for years.

Recently, as computer programs for estimating potential losses from disasters such as the FEMA HAZUS-MH program have been improved significantly, one might be able to better forecast the impact of a disaster, provided that both the disaster and the environment-related data have been accurately and completely entered into such program. For instance, many earthquake mitigation officials in Taiwan use TELES (Taiwan Earthquake Loss Estimation System, one of the HAZUS-MH derivatives containing simplified functions and localized data for estimating earthquake damage in Taiwan) to estimate potential losses resulting from an earthquake hitting their administrative regions. TELES is currently maintained by Taiwan National Center for Research on Earthquake Engineering (NCREE), and its analysis results are usually of good quality. Nevertheless, such data are displayed in two-dimensional formats, e.g., 2D GIS, text, tables and figures, which cannot be directly utilized to develop a drill script accommodating both the space and the time dimensions. In other words, if the analysis results from such estimation programs could be well integrated into a drill script, first responders will have better situation awareness regarding how the disaster impacts are distributed and progressed in the environment, thus engaging them in deliberating upon best countermeasures.

Further, first responders often would like to practice their operation skills under different assumed disaster scenarios. Since a typical drill script can contain the descriptions for only one scenario, drill script designers may need to prepare many scripts, each with a unique scenario, so that their supervisor can randomly select one script to be exercised by first responders. As noted previously, the development of a reasonable drill script requires much time; hence, most of the scripts designed for such purposes are almost identical with a few variances, implying that first responders might use the same set of countermeasures to respond to all the disasters simulated. Therefore, in order to avoid such problems and to actually increase the situation awareness of first responders, differentiating these drill scripts is a must, in hopes of training first responders to be more confident of various real-world circumstances.

Recently, as the technology of ontology and SWRL (Semantic Web Rule Language) has evolved dramatically, many knowledge-based tools have been successfully applied to different disciplines. The drill scripts generation process might need such technology because it involves many rules that only senior drill script designers can apprehend. In order to help the drill scripts generation process, if disaster loss estimation programs as well as such rules can be combined into an ontology model with SWRL constructs, a more reasonable drill script could be generated in a more efficient way. Additionally, first responders might need to deliberate with each other to identify best countermeasures because each drill script they face will describe a sole disaster scenario that would require them utilize different sets of operation skills.

Lastly, as the serious games technology (SG) advances rapidly, there is an increasing number of disaster mitigation applications implemented using SG. Serious games, defined as digital non-entertainment games, have the advantage of offering an engaging, interactive, and collaborative virtual experience, which could lead to better situation awareness for players. Although some research studies have utilized SG to realize drill scripts for disaster mitigation, none of such studies investigates the drill scripts generation process that is based on any of the disaster losses estimation models or programs. If the output of such estimation programs can be integrated into a SG platform, its VR-driven scripts could benefit first responders greatly because each of the drill scripts resembles a reasonable and possible real-world, 3D disaster scenario. In the meanwhile, since the first responders can see the simulated disaster in a VR environment, their capability of copping with the disaster could be enhanced due to the improved situation awareness.

Therefore, this research proposed a model with tools implemented using Unity (a SG platform) for generating such drill scripts and for displaying the simulated environment hit by a disaster. For the model demonstration purpose, an earthquake disaster and an area in the city of Taipei were selected, and experts from the fire department were invited to assess the model performance. Section 2 presents the proposed

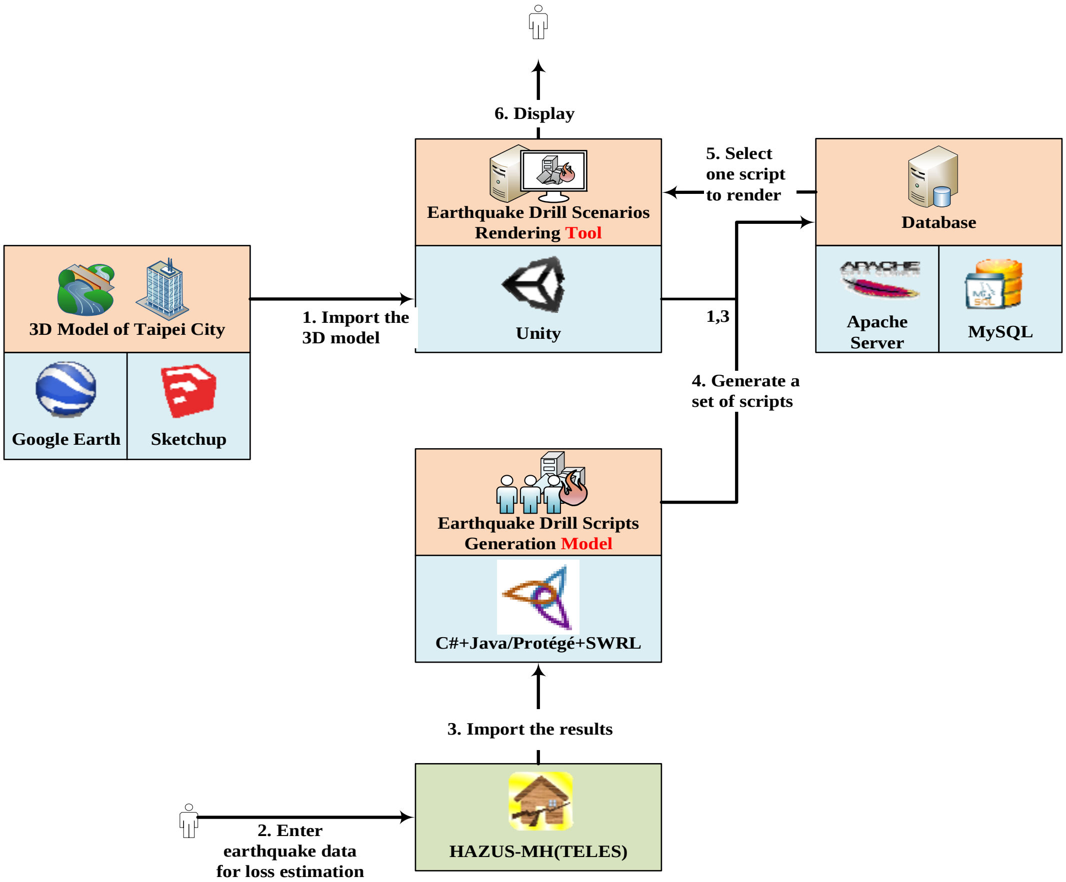

Figure 1. Software architecture of EDSS

model and the system architecture. Section 3 highlights research conclusions with recommendations for future research.

2 Related Literature

MASA Sword is a simulation platform for multi-level training for corps, brigade, battalion commanders and disaster mitigation officers. It can be regarded as an online game environment for various stakeholders of a simulated war or an emergency drill to practice their skills. One of the main components used in MASA Sword is a GIS, and users can customize many parameters defined in MASA Sword to render different disaster scenarios on the GIS output window. However, improvements of such tools have been identified, mainly about the 3D display functionality and disaster events linking to disaster impact estimation programs.

Although the use of a GIS component is a common method to display disaster events, such output information cannot be displayed in a 3D environment, implying that the users' perception about a disaster in analysis is low and first responders may not be able to recognize potential hazards in real-world settings. In addition, current GIS tools cannot accommodate the temporal requirement that disaster-related events should be displayed according to their occurrences. Finally, although users of MASA Sword can edit historical events of a disaster to simulate the scenario, a disaster usually consists of numerous events, which makes the manual editing process impractical due to less time available for the creation of a disaster drill.

TYGRON Serious Game is another game environment specifically designed for floods management. It possess 3D city models and engines so that users can navigate a city to have better situation awareness about the distribution of water resources within the area. From the disaster mitigation perspective, it simply displays potential economic or lives losses and does not simulate a disaster. Thus, further improvements may be needed to enhance first responders' capability regarding the preparation and development of potential countermeasures for disasters.

3 Proposed Model and Tool

Figure 1 shows the overall architecture of the proposed model and tool, called EDSS (Earthquake Drill Scripts generation and rendering System). It consists of five components and six usage steps. The first step requires a system administrator import the 3D model for a given region in Taipei. Currently Taipei city government has provided the 3D model in the Google Earth KMZ format, which includes a triangular meshed model with texture mapping for each building in Taipei. Once exporting the buildings to the KMZ format, the administrator can use a data pre-processing tool developed by the research team to clean missing data and to combine each building's 3D geometry with its text-based attributes. After Step1, the Unity component of EDSS can be used to render each building with the attributes information such as the number of floors and the total floor area, which come from the KMZ file and/or the EDSS database component.

Step 2 requires users or first responders enter all relevant information of an earthquake into the HAZUS-MH or TELES program. Since HAZUS-MH will generate the loss estimation data sets based on the given earthquake parameters, another data transformation component of EDSS needs to be used in Step 3 to move such data sets into the corresponding EDSS database component and to perform appropriate data conversion work. Then, the user can specify the number of drill scripts to be displayed later and perform Step 4 to actually generate a set of drill scripts, based on the ontology model and the loss estimation data sets, so that the EDSS database component can contain not only the 3D model of a given region but the set of drill scripts that can be used to describe a possible earthquake damage scenario for the buildings. Finally the supervisor of the first responders can randomly select one drill script from the EDSS database component (Step 5) and use Utility to render all the earthquake-related events (Step 6).

Figure 2 shows the proposed ontology model that will be used to generate earthquake drill scripts. A drill script can be classified as either the expected type or the randomized type. The former one contains only one instance while the later one can contain as many cases as users define. The expected type drill script is generated directly based on the loss estimation program, while the randomized type of drill scripts will contain all possible scenarios for a given earthquake, with the average impact level equal to the expected type. For example, suppose there are 100 high-rise buildings in a given region. HAZUS-MH estimates that two of such the buildings will collapse; hence, in the expected drill script EDSS will pick two building, which possess the largest floor areas, to show the collapsed events. However, in a randomized drill script, EDSS may pick more buildings to display collapsed events while in another randomized script only one building will collapse. The randomization mechanism needs to make sure that among all the randomized scripts, the average number of the high-rise buildings that collapse should be equal to two. This is because first responders would

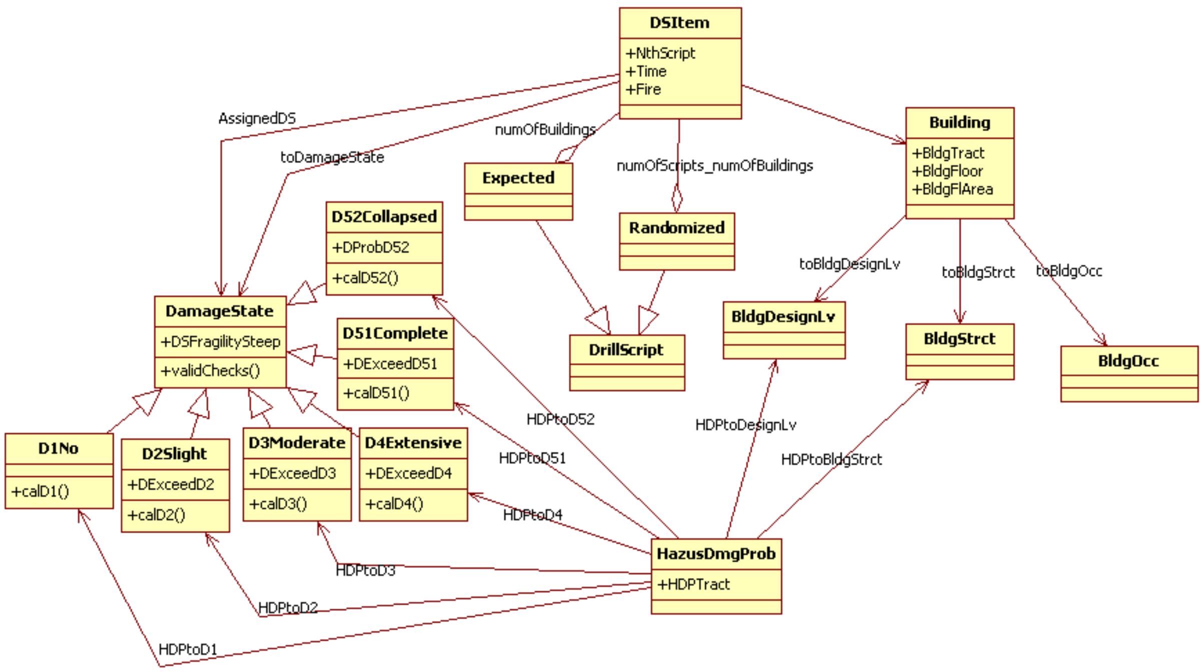

Figure 2. Ontology model of EDSS

like to practice their skills under different scenarios; hence, each randomized drill script should be unique, i.e., one collapse will be assigned to different buildings for different scripts. However, consistence and reasonableness must be maintained among the randomized scripts. For example, people injuries are less likely to occur at commercial buildings when the stores of the building are closed. Thus, a series of SWRL rules have been designed to make sure that all the events generated in a randomized script are consistent with the underlying assumptions. Finally, these events are stored in the database tables. A DSItem instance in Figure 2 will indicate when a given building will have an earthquake damage event as well as the damage level, which can be D1No, D2Slight, D3Moderate, D4Extensive, D51Complete, or D52Collapsed. Mode details can be found at the report published by the research team.

different, randomized drill script. In fact, EDSS needs more varied scenarios to be displayed and to train first responders. Ideally, first responders should not know which drill script their supervisor assigns to them for exercise. EDSS employs the ontology model with SWRL rules to generate all the events, in hope of each drill script with a unique scenario.

EDSS will render their damage scenarios at different time points. Figure 4 shows a sample fragility curve derived from HAZUS-MH. Basically, EDSS generates a randomized drill script based on the following principle: if the fragility curve for a certain damage level is steep, some of the drill scripts will contain a high probability for the given damage level, where others do not. Among all the randomized script, the average probability will be the same. But in an actual county, we cannot simply rely on the estimated probability to do calculation.

Fires and casualties will appear following building

Figure 3. EDSS user interface

4 System Output and Discussions

Figure 3 shows a screenshot of EDSS. For demonstration, an earthquake is assumed to occur near Taipei 101 with a Richter scale of 7. In the specified region for the expected drill script, there are 25 slight-damaged buildings, 21 moderate-damaged buildings, 9 extensive-damaged buildings, and 2 complete-damaged buildings. Although such damage numbers are determined by HAZUS-MH, they serve as the default scenario to be used by EDSS to create a set of 100 collapses. Basically, since HAZUS-MH can estimate the probability of each damage level for a given area, EDSS will determine the actual buildings that will suffer such damage levels, if they can be classified to the group that has the corresponding damage probability. Within the same group, a building having the largest floor area will be selected to show the corresponding damage effect. Future work includes rendering for city transportation facilities such as bridges and roads because their damage states can be obtained in the output data sets of HAZUS-MH. Specific Utility effects will be developed to simulate actual collapse events for such facilities.

It should be noted that the activities that first responders should perform to alleviate the impact of a disaster are not included in EDSS. EDSS is designed to help disaster mitigation officers dispatch first responders to the scenes. It can also help first responders better perceive the surrounding environment and the progress of a disaster. In the real world, the interaction between a disaster and first responders is dynamic. With the estimation data provided by tools such as TELES, EDSS can simulate the events but cannot help mitigate the disaster. Decision makers can learn the distribution and the extent of a disaster, thus dispatching an appropriate number of first response units to the scenes.

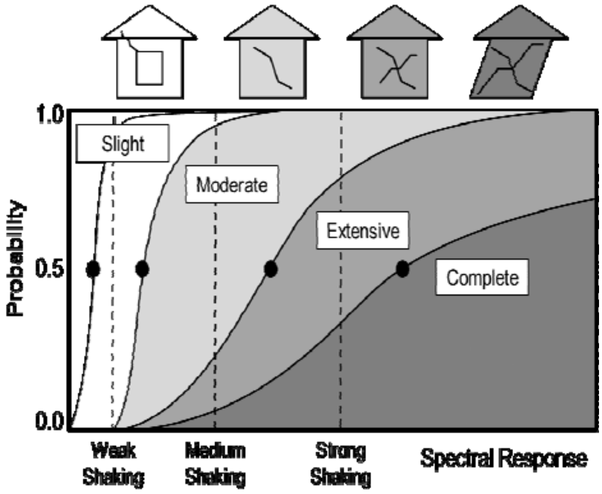

Figure 4. Sample HAZUS-MH fragility curve

5 Conclusions

A Unity-based serious game platform was designed to serve as simulation engine for disaster mitigation. A HAZUS-MH-derived version called TELES was utilized to generate data sets describing the main scenario of a disaster. An ontology model with semantic rules were developed to randomize the data sets so that different disaster scenarios can be generated. Then, the proposed system called EDSS can combine all the data sets and display them in a 3D environment so that first responders can have better situation awareness regarding the progress of a disaster. Disaster mitigation officials can dispatch response units based the information created by EDSS. Experts were invited to assess the effectiveness of EDSS and found that the scenarios displayed by EDSS can resemble real disasters and train decision makers in a more efficient way.

Future improvements of EDSS include expanding the areas and scenes created inside EDSS. This is because not only building geometries but the human activities of the buildings in the study area need to be created in the input data set for both TELES and EDSS. In addition, currently only the earthquake type of disasters can be simulated by using EDSS. Once the disaster estimation programs for other types of disasters are available and can be integrated into EDSS, both the ontology model and corresponding semantic rules need to be developed and enhanced so that the new version of EDSS can display such types of disasters.

6 ACKNOWLEDGMENTS

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