SPATIAL KNOWLEDGE CONSTRUCTION FOR THE FIRE ACCIDENT PROCESS OF THE LONG ROAD TUNNEL

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ABSTRACT:

There are many kinds of public transportation systems, e.g. Xue-shan tunnel, high-speed railway, and airport shuttle are developed in Taiwan recently. The risk hidden in the space of long road tunnel could cause serious life loses and transportation system damage. Therefore, how to prevent and decrease the impact of disaster should be considered for the disaster precaution and security management in the long road tunnel area.The paper conducts an approach to the spatial knowledge construction of decision making support for fire disaster treatment in the long tunnel. The approach is based on the ontology method that assumes three levels of information integration, e.g. application domain, abstract context, and operational context. The application domain is described with an application ontology using the formalism of scenarios in long tunnel disaster. The disaster events are described with an abstract context that is obtained as a result of the slicing operation on the application ontology. Finally, filling the abstract context with triggering information and responding information produces an operational context. Both types of contexts share the same knowledge representation formalism that is used by the application ontology. As a result the operational context can be considered as a constraint satisfaction problem.

1. INTRODUCTION

The fire risk hidden in the space of long road tunnel could cause serious life loses and transportation system damage. Therefore, how to prevent and decrease the impact of disaster should be considered for the disaster precaution and security management in the long road tunnel area. Although concern about safety in road tunnels did not start with the fires of 1999 in the Mont Blanc and Tauern tunnels, these dramatic accidents brought the risks in tunnels to the fore, and led political leaders to get involved. The aegis of the Inland Transport Committee of the United Nations Economic Commission for Europe was created on safety in Tunnels with many of experts. The major task of the Group of Experts was to develop: "recommendations for minimum requirements concerning safety in tunnels of various types and lengths" (PIARC Committee on Road Tunnels, 1999). The fire accidents in the World's of road tunnel record comprised of 15 cases from 1990 to September, 2006, which resulted in a total of 78 deaths and 169 wounded (as shown in Tab.1). These fire accidents sourced from the Centre d'Etudes des Tunnel (CETU), the Road Tunnels Committee of the World Road Association (PIARC) and the Federal Highway Administration (FHWA) always caused serious damage. We indicated serve examples as following: First, On 24 March 1999, a truck loaded with margarine and flour caught fire in the Mont Blanc tunnel between Chamonix (France) and Aosta (Italy). The blaze spread rapidly to other vehicles, with the result that 39 people died due to the development of intense heat and smoke. On 29 May 1999, a collision took place in the Tauern tunnel in Austria, between a lorry that collided with four light vehicles and another lorry loaded with different spray-tins, standing in front of a traffic light inside the tunnel. The collision caused a fire, which spread rapidly. Twelve people died: 8 due to the collision and 4 due to the smoke (United Nations Economic Commission for Europe Inland Transport Committee, 2001).

Fires in tunnels not only endanger the lives of road users, they can also cause damage to structural components, installations and vehicles, with the result that the tunnel concerned may have to be closed for a considerable length of time. The capacity of a fire expressed in terms of heat development in megawatts can differ greatly depending on the type of vehicle and load. PIARC cites the examples shown in the following table 1 (PIARC Committee on Road Tunnels, 1999).

Vehicle type	Typical fire loads (MJ)	Typical fire powers (MW)	Remarks
Passenger car	3 000 – 3 900	2.5-5	Fire loads used in fire tests in Finland
Bus Truck load Heavy goods vehicle	41 000 65 000 88 000	20 20-30 **30**	Fire loads used in EUREKA fire tests. Heat release rates without very combustible goods
Tanker carrying $50m^3$ of gasoline	1 500 000	300	Levels assumed by Dutch authorities for fires of extreme dimensions

Table 1. The Capacity of Fire Type and Load

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In the event of an incident, the first ten minutes are decisive when it comes to people saving themselves and limiting damage. The prevention of critical events is therefore the number one priority, which means that the most important measures to be taken have to be of a preventive nature(United Nations Economic Commission for Europe Inland Transport Committee, 2001). According to the purpose, this paper focuses on the disaster scenario simulation by using the time-delay properties of the system dynamic theory. Through the verification of the performance and emergency operation architecture, the disaster precaution and security management of a long road tunnel can be built. A solution for the complicated disaster emergency operation planning and disaster management not only can be accomplished, evacuated and routing planning also consider in the research.

For furnishing emergency facilities, tunnels are categorized into the five classes as shown in Figure 1 in relation to the tunnel length, the traffic flow volume and characteristic features. This classification was determined by the probability of accidents and fires based on the past experiences. Long tunnels with a high design speed on national expressways, or tunnels with bad perspective owing to especially winding horizontal or vertical alignment should be ranked higher than standard level (United Nations Economic Commission for Europe Inland Transport Committee, 2001).

The Hsueh-Shan Tunnel (abbreviated as HST) is a 12.9km long tunnel that penetrates through the Hsueh-Shan Mountain Range. The Hsueh-Shan Mountain Range blocked a 13km long section of the Taipei-YiLan Expressway between Ping-Lin and Tou-Cheng. For the west end of the tunnel located in Ping-Lin area, the land available for route alignment is limited. On the other hand, the East end, which is located in the Lan-Yang plain, has more choices for the location of the portal. The feasibility studies completed in 1988 assessed three routes with Yi-Lan, Jiao-Hsi and Tou-Cheng as the possible locations for the east portal (Lee, 2005).

The Hsueh-Shan Tunnel are classified level AA tunnel based on its length as Figure 1 shows. Therefore, the tunnel emergency facilities must be to deal with all kinds of disaster by the tunnel classification AA. Since commencement of construction in 1991, there had been many serious accidents resulting in much delay to the projected progress. Under great effort from all concerned, these seemingly insurmountable difficulties were overcome, and the pilot tunnel (as shown in the Figure 2 and 3) was broken through on October 2003, and construction of the two main tunnels had been accomplished at the end of 2005 (Tsai et al., 2005).

Geographic ontologies are receiving increasing interest and are growing in recent GIScience conferences (e.g. GIScience 2002 and COSIT 2003) and the organization of a series of ‘Ontology in Geographical domain’ workshops are indicative of the increasing enthusiasm and participation in this subject among GIScientists (Agarwal, 2005). Ontology has been discussed in GIScience as a standardization procedure through which easier translation between different information sources can be achieved (Chandrasekaran et al. 1999, Smith 1999). Ontology can be applied as a systematic approach to capture the universal concepts and meanings that define the geo-spatial domain to prescribe theories for the discipline in GIScience (Bateman 2003, Frank 2003). Moreover, it was also used to inform designs of data models and information systems to make them better equipped for handling geographic concepts (Agarwal, 2005, Kuhn 2001). However, the use of ontology in GIScience has been associated with confusion concerning the semantic and terminological implications of this approach to the overall scientific paradigm in the discipline (Agarwal, 2005).

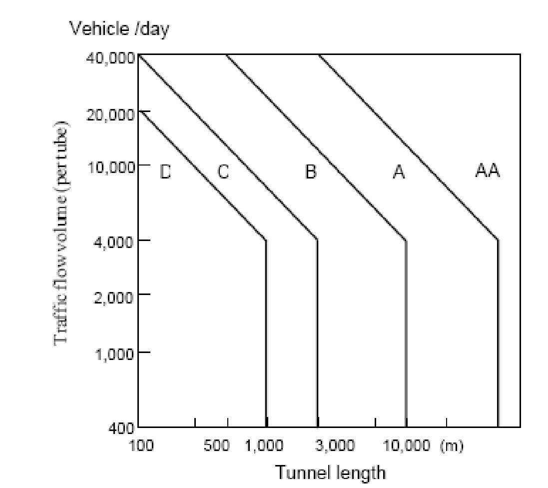

Figure 1. Tunnel classification

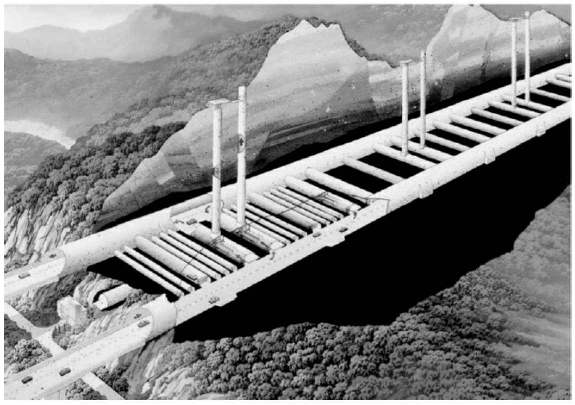

Figure 2. Ventilation System of Hsueh-Shan Tunnel

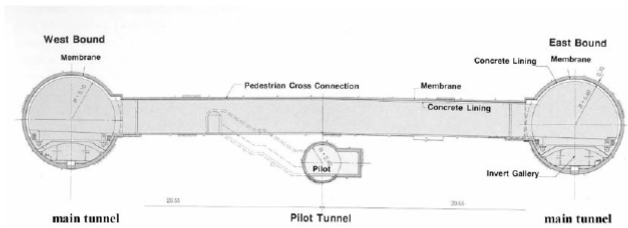

Figure 3. Relationships of Hsuehshan Tunnel and Pilot Tunnel

2. METHODOLOGY

The Ontology is a noun in the Philosophy means how to determine its existence behind the phenomenon. A tree structure and relationship can be used to character events and rules between one and another event in the world. In the 90's, the ontology was applied on the artificial intelligence to describe knowledge in a given domain. Otherwise, how many objects, ancillary attributes, and their relations will be determined in the problem domain. It provides a shared media to exchange the knowledge for person interaction or inter-operability for different systems (Uschold and Gruninger, 1996).

There are three major elements mean classes, slots, and relations for the construction of an ontology. A class presents a concept for the domain knowledge. And a slot is used to describe an attribute for the class. Moreover, a relation represents the relationship between a class and another one. The following six steps were used to establish an Ontology for the safety management of tunnel fire features (Natalya and McGuinness, 2001):

(1) To define the problem domain: According to the problem what the tunnel fire faced, the motivation and possible solutions for the ontology should be considered in this step.

(2) To extend from the existing ontology: Approaching to sharing and recycling knowledge, the corresponding literature, e.g. Matteo's research report (Matteo, 2003), was reviewed to find a few appropriate and relative ontology knowledge.

(3) To list the used terms: Owing to some words in different problem domain having different meaning, therefore the used terms should be determined for the fire accidents process in the tunnel.

(4) To construct a hierarchical structure between classes and their subclasses: There are three methods, e.g. Top-Down, Bottom-Up, and combinatorial method to build up this kind of structure.

(5) To do Axiom definition: In this step, semantic rules, axiom, limitation, and logical relations will be clearly and completely defined. It contains attributes for the class, facets of each attribute, and extreme values for them.

(6) To build instances of domain knowledge: According to the above steps, the instances of the Ontology could be used to describe objects in the real world. This procedure can also be called knowledge hypostatization.

3. RESULTS AND ANALYSIS

There is no doubt that it is very important to carefully setup the safety infrastructure in the tunnel for the driving safety of vehicles. Especially, when a fire accident happened in the tunnel, how to lead people exit to a place away from the disaster by emergency pathways is one of important things for the emergency rescue.

According to the above six ontology build-up steps and equipment categories reported on Taiwan freeway bureau website (Taiwan freeway bureau, 2006), a hierarchical structure of the fire ontology for the Hsueh-Shan Tunnel can be constructed. Next, this structure was consisted of six subsystems as following illustration:

(1). Fire Detection Subsystem

A major purpose of this subsystem is whether a fire event can be detected in time or not. When a fire accident is occurred, an alarm signal will be passed to the control center by the fire detectors and fire alarms. In-situ images will be show on the monitors of control center by the closed-circuit television (CCTV) set in the lane's left side every 175 meters immediately. Let the controller know how to deal with based on the messages came from sensors, e.g. visibility meter, thermometers and hygrometers, and car-flow detector, etc.

(2). Traffic Control Subsystem

When fire occurs in the tunnel, aside from using the tunnel adit barrier to restrict additional vehicle entry, the vehicles cross passageway tunnel barrier will also be used to stop vehicles moving toward the fire and allow them other alternate evacuation routes to exit the tunnel. Also, passing vehicles should drive away as soon as possible. There are the following equipment in this subsystem including lane control, speed limit, adjustable information signs, radio, horns, and loudspeakers.

(3). Fire Fighting Subsystem

The fire fighting equipments in the HST including fire hydrant, fire fighting boxes contain extinguishers, 40 mm calibre of water outlet set in the main tunnels every 50 meters, and two reservoirs located at the northern entrance of the HST and at the southern entrance of the Peng-Shan Tunnel (PST), respectively. During the initial stage for a fire accident, the vehicle drivers can use the extinguisher in the fire fighting box to put out a fire. Except for that, the fire fighters can use a 65 mm calibre of outlet which its water supplied with the reservoirs to put out a fire.

(4). Emergency Exit Subsystem

Between the two main tunnels, emergency walkways are available for people to exit every 350 meters, and emergency pathways for vehicles every 1400 meters. And two pilot tunnels located vertically below and parallel with the two main tunnels. Each pilot tunnel has stairwells leading to the main tunnel to allow for emergency and rescue workers. The stairwells between the pilot and main tunnels, as well as the emergency walkways, maintain independent air pressure and ventilation separate from the main tunnels so that people following the emergency evacuation directions have safe passage from one main tunnel to the other, as well as safe access to the pilot tunnel.

(5). Saving Subsystem

When a fire occurs, the exhaust system, emergency traffic control, monitor, and emergency lights all activate, The Hsuehshan Tunnel has three sets each of vertical shafts, interchange station, and terminal stations, six axel fan system, 112 jet fans located in the main line, and unidirectional (with the traffic flow) ventilation system. Also, at any given fire location, the ventilation system 300 meters to the left and 250 meters to the right is deactivated to avoid breakage and distribution of the smoke layer. Aside from this inactive tunnel distance, the unidirectional (with the traffic flow) ventilation system will drain the smoke into vertical exhaust channels, which cooperating with the axial-flow fan system, will expel the smoke out the main tunnel. Except for the above mentioned ventilation equipments, the electrical and mechanical facilities, e.g. power supply or lighting equipments, are contained in this subsystem.

(6). Rescue Subsystem
This subsystem is to represent a rescue organization, including Ping-Lin control center, fire fighting, construction, health, police, and environmental protection department. In the peacetime, 24 hours driving monitoring of vehicles, regular maintenance and operation of tunnel's infrastructure, and fire drills will be handled by Ping-Lin control center. During the treatment of a fire accident, the control center plays an emergency resource center to establish contact with other departments in the organization, e.g. fire fighting, medical treatment, police, etc.

According to the above discussion, class categories for the fire ontology of the HST are shown as Figure 4 and Figure 5.

4. CONCLUSION

This paper presents a knowledge construction of the fire ontology with the long road tunnel. Until now, six classes and their subclasses had been categorized for the infrastructure of the tunnel safety management. The slots and the relations between classes will be defined in the future. Moreover, a fire Ontology construction tool, e.g. Protégé 2000 (Noy, et al., 2001), also can be used to perform complete spatial knowledge for the fire accident process of the HST. By the way, the scenario simulation of fire drills will be evaluated by a system analysis method.

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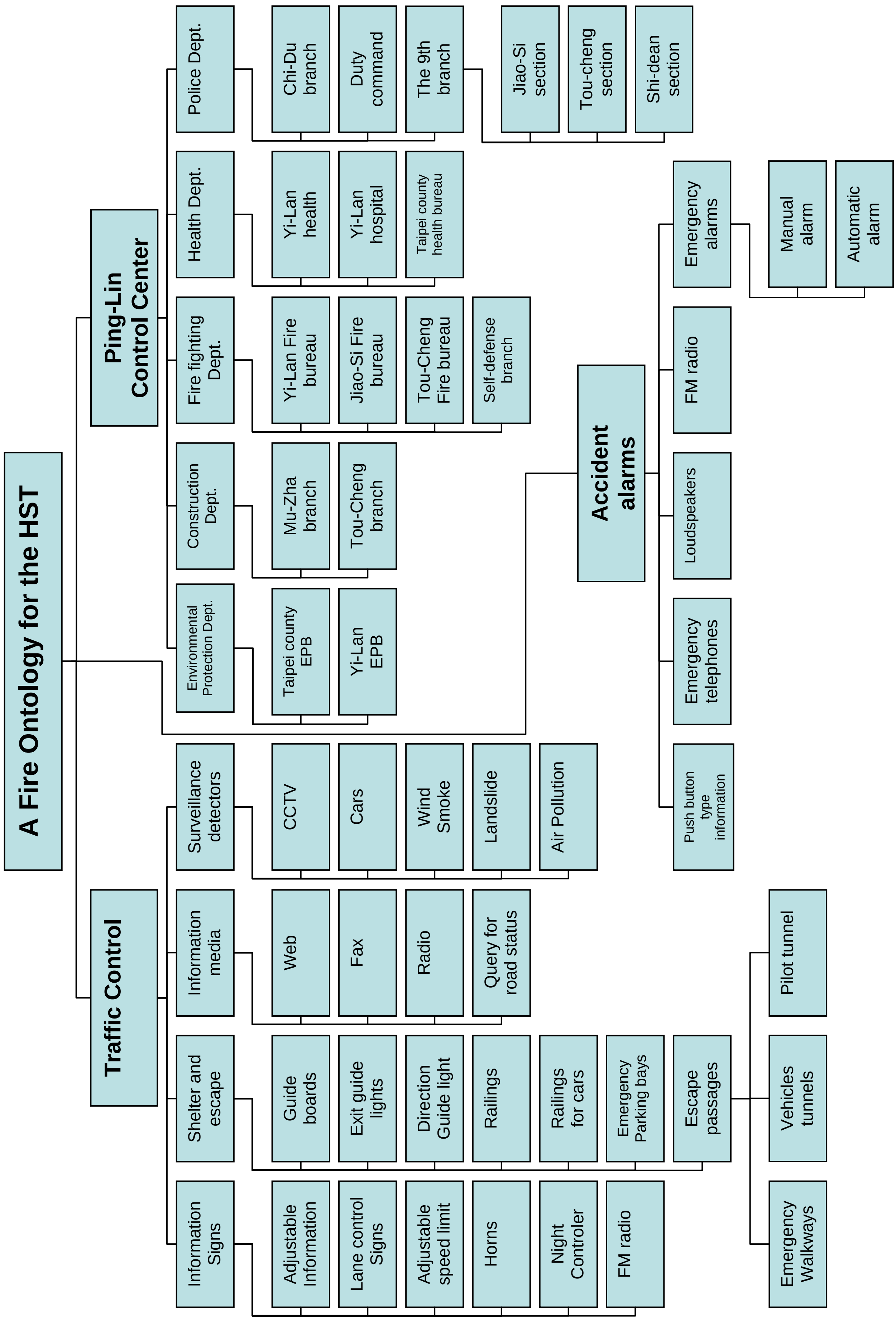

Figure 4. An Ontology for safety features of the Hsueh-Shan Tunnel (HST) (1/2)

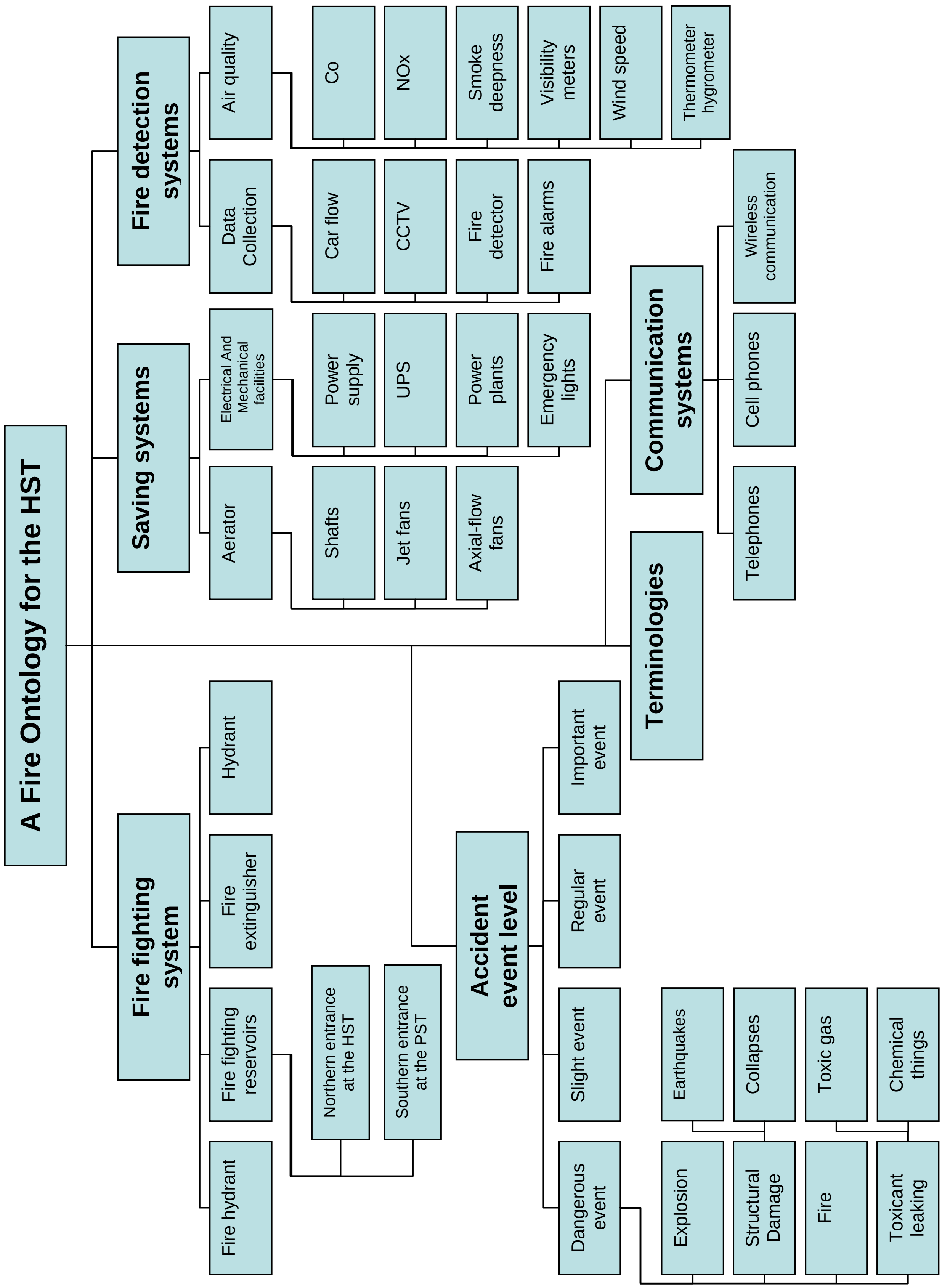

Figure 5. An Ontology for safety features of the Hsueh-Shan Tunnel (HST) (2/2)