Chapter 7

Modeling evacuation plan problems

In Section 3.1 we reviewed the recommendations that the UNESCO presented in [30] to develop volcanic emergency plans.

In [18] is presented the state of art of models and algorithms for evacuation planning. Then, in this chapter we combine the recommendations in [30] with the information which would be ideal to have in evacuation planning extracted from [18] in order to model evacuation plan problems and in particular for volcanic emergency plans.

We define a formal representation of the information using structural relationships of UML [6] corresponding to Figure 7.1.

In this chapter, we also propose a procedure to construct the hazard zone background knowledge needed for reasoning about evacuation planning as part of the contribution of this work.

Finally, in this chapter we present the geographic information about the Popocatépetl volcano.

It is worth mentioning that in this work we tested our results using only part of the information needed to model evacuation plan problems presented in this chapter since we did not get the complete real information on time. As we have mentioned the information used in this work corresponds to the volcano Popocatépetl risk zone, however we obtained the complete real information of this zone almost at the end of this work. Then, based on part of the geographic information that we had about this zone, we defined our data to test our results. Specifically, we only consider part of the geographic information about towns, roads, roads defining evacuation routes, towns in risk and towns where are the shelters.

7.1 Evacuation plan problem information

We start presenting the information which would be ideal to have in order to model an evacuation plan problem and in particular a volcano evacuation plan problem. Table 7.1 presents the lists of information needed to model the Transport problem obtained from [19], the Evacuation plan problem, and the Volcano evacuation plan problem. At the same time, Table 7.1 allows us to compare these lists of information. The list of information for transport problems was obtained from [19] where is analyzed a general *transportation* problem that generalizes planning in several classical domains such as Logistics. We are interested in information for transport problems, since evacuation planning problems may be similar cases of this family of problems. The list of information for Evacuation plan problems and Volcano Evacuation problems is a combination of the information that we presented in Sections 3.1 with the information which would be ideal to have in evacuation planning extracted from [18]. We considered [18] since in this reference is presented the state of art of models and algorithms for evacuation planning.

In an **Evacuation plan problem** it is important to know the kind of place where the evacuation has to be planned (that may be a a building, towns or regions, train, airplanes, etc.), since it defines the *network of roads* where evacuees will travel. Also, in this kind of problems there are a number of *locations in the hazard zone*. However,

Transport problem	**Evacuation Plan problem**	**Volcano Evacuation Plan problem**
Locations.	Locations in hazard zone.	Towns in hazard zone.
Initial location.	Locations in risk.	Towns in risk.
Goal location.	Safe destinations.	Shelters.
—	Source and location of hazards.	Hazard zones.
Mobiles.	Means of transport.	Means of transport.
Capacity of mobiles.	Capacity of means of transport.	Capacity of means of transport.
Initial fuel.	Initial fuel.	Initial of fuel.
Portables.	People in hazard zone.	People in hazard zone.
Goal portables.	People that must be evacuated.	People that must be evacuated.
Roadmap	Network of roads.	Network of roads.
—	Evacuation routes.	Roads in some evacuation route.
—	Availability of emergency services	Availability of emergency services
—	facilities and personnel.	facilities and personnel.
—	Alert procedures.	Alert procedures.

Table 7.1: Comparison of the information needed in three different kinds of problems

depending on the *source and location of hazard(s)*, part of these *locations are in risk*, in some cases all the locations could be in risk. It is necessary to define *evacuation routes* from locations in the hazard zone to *safe destinations*. In some cases will be necessary to use *means of transport* that have a *capacity* and need resources (such as *fuel*) to travel. Some persons have their own means of transport hence only part of them must be evacuated by government. Additionally, it is important to know the *availability of emergency services* facilities and personnel, i.e., personnel and equipment for search and rescue, hospitals and medical services. Finally it is important to have *alert procedures* and communication of public warning.

We have to mention that the list of information for Volcano Evacuation problems takes advantage of discussions with researchers in volcanology of "Laboratoire de Géophysique Interne et Tectonophysique" of Université de Savoie. They remarked that in order to define effective evacuation routes, it is necessary to consider the different scenarios at a moment of volcanic eruption and consider the different hazards that may accompany volcanoes. In particular, they recommended to take into account the hazard map at Popocatépetl [24].

As result of comparing the three lists, we can see that Evacuation plan problems and Volcano Evacuation problems consider the same information than transport problems and some information else.

We define a formal representation of the information needed to model Evacuation plan problems using structural relationships of UML [6] corresponding to Figure 7.1. In this figure, we can find the set of classes, the class `Location` represents a location. There is an association between `road` and `Location`, specifying one or more roads joins to any location and every location have one or more roads that joins to it. The relationship between `Hazard zone` and the classes `Road` and `Location` are similar. A hazard zone has one or more roads, each road should be in a hazard zone, a hazard zone has one or more locations, each location belongs to exactly one hazard zone. There is an association between `Road` and itself. A path may be part of an evacuation route and an evacuation route is formed by some paths. We can also see that there is another association between `Hazard zone` and `Hazard`, specifying that a hazard zone has one or more hazards and each hazard belongs to exactly one hazard zone.

7.2 Procedure to construct the hazard zone background knowledge

In this section we give a procedure to construct the hazard zone background knowledge needed for reasoning about evacuation planning as part of the contribution of this work. It is important to mention that this procedure resulted from our direct work over the geographic information that we have about the volcano Popocatépetls risk zone that we have. We had to extract descriptive information from geographic information, to

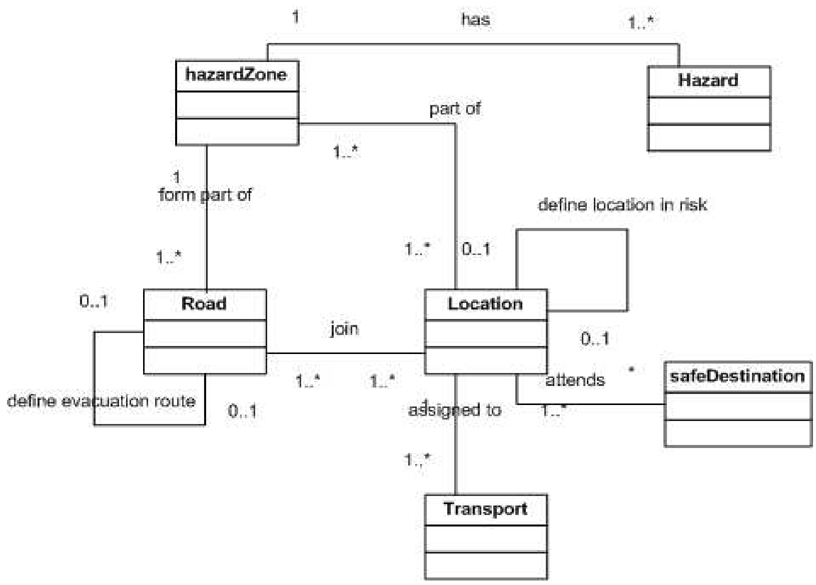

Figure 7.1: Structural relationships for evacuation plans in a volcano

repair inconsistencies, to represent the network of roads, and to add new descriptive information.

Most of the information needed to model an evacuation plan problem (see previous section) corresponds to geographic information, sometimes abbreviated as GIS information. Geographic information follows some of the standard formats (shapefile [1] or OpenGIS [2]). In general these formats of GIS information divide the data into two parts [23]. The first part contains spatial data, and the second part contains non spatial data or descriptive information. The spatial data manage the position of geometric objects within an area where the basic objects are: points, lines and polygons. The non spatial data describe what is at a point, along a line or in a polygon, and contains the socio-economic characteristics, such as demographic data, occupation data for a village, or traffic volume for roads.

The following Procedure indicates how we can construct the hazard zone background knowledge from geographic information and other kinds of files formats with useful information.

1. *Extraction of descriptive information from geographic information.* In order to construct the hazard zone background knowledge needed for reasoning about evacuation planning we use the descriptive information of geographic information. Then, we need to convert descriptive information into a format useful for the kind of programs that an Answer Set solver can read. Using a GIS tool [1], it is possible to save non-spatial data in text files. In particular, each line of the text file corresponds to the descriptive information of one segment of road. It includes the identifier of initial node, the identifier of final node, the number of lines, length, etc. And each line of the text file corresponding to the descriptive information about towns in the hazard zone includes the identifier of town, the municipality, number of habitants, identifier of hazard zone, etc.

2. *Repairing inconsistencies.* Once we have the text files corresponding to the descriptive information we have to repair the inconsistencies that this information have. For instance, some times the identifiers of nodes are repeated, or some segments that are contiguous when they are visualized have not identifiers of nodes that are contiguous, etc. Repairing inconsistencies appears to be a long work since it is done in a semi-automatic way or sometimes data by data.

3. *Representation of the network of roads.* As soon as we have the text files with the consistent descriptive information, we can use the information about towns and roads to define the network of roads in the hazard zone. The network of roads is represented as an *undirected graph* where its set of edges and the set of descriptive information about roads should be in one-to-one correspondence. Moreover, we know that locations are connected with other locations by roads and each road is made up by segments then some nodes of the set of directed graph edges have a

relationship with identifiers of towns. An evacuation route is a path on this directed graph.

4. *Adding more descriptive information.* Part of the information used to model the hazard zone could be in a format different to geographic information. For instance statistical information about the number of buses and fuel liters needed to evacuate the hazard zone or the information about shelters such as, capacity, number of liters of water. Hence, we have to translate this information into text files and define the relationships between roads and towns in the undirected graph and the new information.

7.3 Popocatépetl volcano information

In the particular case of Popocatépetl volcano we have geographic information about roads, evacuation routes and towns. Additionally we have partial information about shelters, buses, quantity of fuel needed, and number of habitants in each town.

In particular geographic information about the Popocatépetl volcano uses:

- *polylines* to represent segments of road with the following descriptive information associated: *segment ID, name, initial node, final node, number of lanes, speed limit, kind of pavement, length* and *route ID*; and
- *polygons* to represent towns with the following descriptive information associated: *town ID, Municipality ID, route ID, risk zone ID, number of habitants, number of people with their own vehicle to evacuate the zone in risk, number of people that government must evacuate, number of vehicles needed, number of kilometers to travel, quantity of combustible needed* and *shelter ID assigned to the town.*

Table 7.2 shows the quantity of information about the hazard zone of Volcano Popocatépetl corresponding to Puebla state. This geographic information was pro-

Volcano Popocatépetl Information about	**Quantity**
Hazard zones	3 (high, medium, and low)
Towns in hazard zones	37
Towns in high risk	16
Towns in medium risk	2
Towns in low risk	19
Shelters	63
Shelters Capacity	60751
Means of transport	2098 buses
Capacity of means of transport	unknown
Gasoline	32650 liters
Diesel	53150 liters
People in hazard zones	92123
People that must be evacuated	58678
Network of roads	510
Roads in some evacuation route	109 (segments of roads)
Availability of emergency services facilities and personnel	unknown
Alert procedures	four stages of danger(see Section 3.2)

Table 7.2: Information about the hazard zone of Popocatépetl (only Puebla state)

vided by Plan Operativo Popocatépetl Office and by INEGI (Instituto Nacional de Estadística, Geografía e Informática).

7.4 Example: Background knowledge of a hazard zone

As mentioned, we represent the network of roads between towns in the hazard zone as a directed graph. We define a directed graph where some nodes represent towns, and evacuation routes are paths in the graph. Each segment is represented by `road(P,Q,R)` where `P` and `Q` are nodes and `R` is the route number. Segments with route number different to zero belong to some evacuation route. Some nodes correspond to a refuge or a position out of risk.

Example 7.1. For instance, let the directed graph in Figure 7.2 be a short representation of three evacuation routes in a particular zone. Therefore, we shall define the directed graph as follows:

```
route(2). route(1). route(0). risk(0). risk(1). risk(2). risk(3).

% node(point,route,risk)
node(1,1,3).   node(2,0,3).  node(2,1,3).  node(4,0,2). node(5,0,1).
node(11,0,2).  node(8,1,1).  node(9,1,0). node(12,0,3).
node(12,2,3). node(15,0,2).  node(16,0,1). node(16,0,1).
node(13,0,3).  node(13,2,3). node(17,2,2). node(19,2,0).

% segment (initial,ending,route)
segment(1,2,1).  segment(2,11,0).  segment(2,4,0). segment(4,5,0).
segment(4,9,0). segment(2,8,1). segment(8,9,1). segment(12,15,0).
segment(12,17,2). segment(15,16,0). segment(16,19,0).
segment(13,15,0). segment(13,17,2). segment(17,19,2).

% townAt(town, node)
townAt(p1,1).   townInRisk(p1). townAt(p2,12).  townInRisk(p2).
townAt(p3,13). townInRisk(p3).

% busIniAt(bus,point).
bus(b1).   busIniAt(b1,p1). bus(b2).   busIniAt(b2,p2). bus(b3).
busIniAt(b3,p3).
```

□

7.5 Complexity of evacuation plan problems

The specification of an evacuation problem can vary from country to country according to political, social, legal and economic conditions and to the level of technological

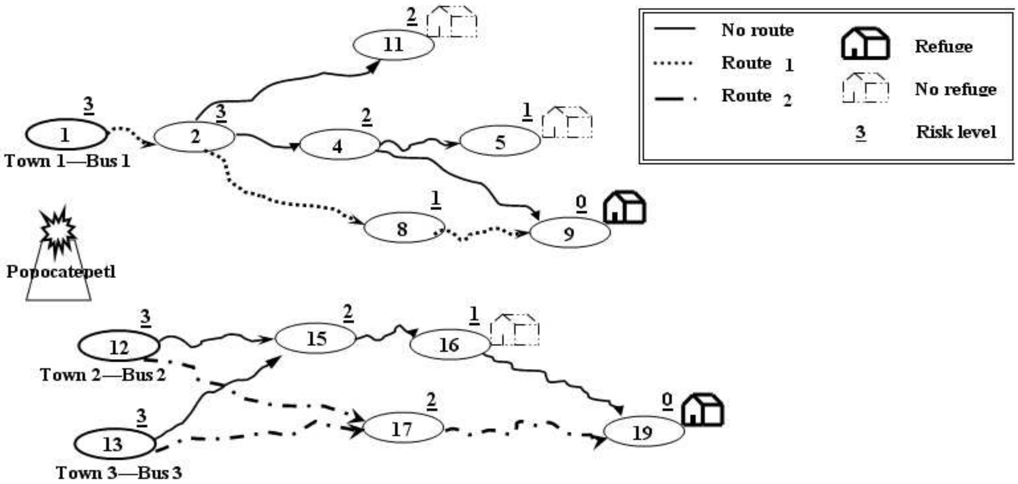

Figure 7.2: Two evacuation routes: A short example.

development. Additionally, an evacuation problem also depends on the cause of the evacuation (fire alarm in a building, volcano eruption, etc.) Then is possible that some evacuation plan problems in a given domain have polynomial complexity and some others result to be NP-complete.

In this subsection we describe a simple example that results to be NP-complete. This problem is particularized in order to see their connection with the problem of find a Hamiltonian path. However we can define a generalization of problems where a particular case would be this problem.

Let us suppose that in a particular hazard zone there are a set of locations V that should be evacuated. Each location have an average of forty habitants. Each location has assigned a different location out of risk where people in risk should be moved, i.e., for each $v \in V$ there are one v' (location out of risk). Additionally, there are roads between v and v' for all $v \in V$ and between each v' to each location v. Since the economical conditions and service facilities are very limited, there is only one bus with a capacity of forty persons used to evacuate people and this bus has only $|2V|$ units of *fuel to travel among these locations. Finally, it is known that at the beginning of the disaster the bus is always parked at one of the locations, for instance v_0.*

Then, the decision problem about if there exist an evacuation plan to take all people to their respective location out of risk results to be NP-complete.

The proof of this is based on a reduction to the problem of find a hamiltonian path and also is similar the proof of the plan existence problem for the problem called $Transport_{111}$ in [19].

7.6 Conclusion

In this chapter we proposed a way to model evacuation plan problems and in particular for volcanic emergency plans. We proposed a procedure to construct the hazard zone background knowledge needed for reasoning about evacuation planning as part of the contribution of this work, specifically when we define and give solution to the alternative evacuation plan problem (see Chapter 8). Finally, in this chapter we presented the geographic information about the Popocatépetl volcano.