Exercise 06T: Technological risk assessment

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Expected time:	3 hours
Data:	data from subdirectory:/exercise07
Objectives:	In this exercise we would like to evaluate the risks arising out of an industrial facility located in the city using the set of spatial data provided with this exercise and the basic knowledge of technological risk assessment acquired from the guidebook.

Input data

The following data are used in this exercise.

Name	Type	Meaning
Elements at risk		
Building_map_1998	Raster	Map showing individual buildings.
Building_map_1998	Table	Table showing buildings characteristics: landuse, nr of floors, building type, area building, floor space, persons per day, persons per night, size class.
Technological Data		
Accident Map	Point	Map representing the location of the Accident
Other data		
High_res_image	Raster	High resolution image of the study area.
Ancillary Data	Data	Information about the calculation of the magnitude of the explosion / blast according to the nature and the quantity on the hazardous material

The city, in addition to being very vulnerable to natural hazards (floods, earthquakes and landslides) may also be affected by technological risks, either triggered by natural hazards or due to a stand alone industrial accident.

On noticing carefully, you will observe that there are a number of sites with hazardous materials storage located within the city boundaries located in the middle of densely populated areas. In the domain of the land use there is one class called: **Ind_hazardous;** which indicates: Hazardous material storage or manufacture.

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- Open the domain **landuse** and check the presence of this class.
- Open the table **Building_map_1998,** and select the option Column/ Sort. Sort by **Column: landuse.** Check if there are buildings that have the name **Ind_hazardous**.
- How many buildings have hazardous materials? There are many strategies to extract this information. We will follow a method that will allow us to display the buildings in a map. In the table **Building_map_1998**, write in the command line this expression:

    Hazardous = iff(landuse="Ind_hazardous",%K,?)

- Check the new column; what does the expression produce? What does the code **%K** stand for? Now go to *Column / Aggregation*, chose Column: Hazardous, Function: Count, Group by: Building_Type; store the new column in a new table called **Hazardous_buildings** and name the column Nr_**buildings.**
- How many buildings are present in RiskCity in total? To which building type do

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they belong and how many for each building type? Which is, in your opinion, the most vulnerable type in case of earthquake or technological hazard?

- Create an attribute map from the **Building_map_1998** by choosing the column **Hazardous**. Call the map **Hazardous_Buildings**.

7.1 Hazard scenario modeling

Now you see the locations of the sites with hazardous materials. In the building **B_29211** the company "*RiskyStorage*" is located. The bulk facility stores a huge amount of Pentane, a highly hazardous inflammable chemical for supplying to downstream users. The facility has been declared as a Major Accident Hazard (MAH) facility according to local bylaws of RiskCity. According to land-use specifications laid down by the legislation no new MAH industries should come up within the city limits. However, because of socioeconomic (employment and economic) considerations, RiskyStorage was allowed to continue operations after implementing necessary engineering safeguards and controls. For understanding the chemical properties of Pentane, please refer to the Material Safety Datasheet (MSDS) of Pentane Annexed with this Case Study.

The facility recently has been acquired by a different business group and as a result has undergone a major management reshuffle with change in operational responsibilities of key people. The emphasis on plant level safety has been reduced in order to cut costs.

On 15th of November, 05 at around 3 o'clock in the evening, an operator riding a vehicle within the plant premises (which was not allowed before) accidentally crashed into an over ground pipeline that is used for transferring Pentane from the Storage. The impact of the crash resulted in a fire in the pipeline and which started spreading towards the main storage. The fire is noticed by an onlooker outside the plant and is reported to the Industrial Emergency Management Centre (IEMC) of RiskCity by telephone. The IEMC has a GIS setup and all the data that is required to make a spatial analysis of an accident and take appropriate response decisions (the same data has been provided in the RiskStorage Folder). It must be understood here, that time is a major constraint in such emergencies as they typically evolve very fast (typically within an hour) and right decisions have to be taken quickly.

The site is indicated in the point map Accident.

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- Open the **New_high_res_image**, and add the point map **Accident.**

The consequences of technological accidents depend on a number of factors including nature of the chemical (physical and chemical properties), storage conditions (refrigerated or pressurized), nature of release conditions (through rupture of pipe or breach of containment of storage), atmospheric conditions, etc. The accident discussed in the overview section has a high probability of being a Pool Fire which is caused when a liquid inflammable substance like Pentane escapes from a refrigerated container and catches fire. The primary hazard resulting from such a fire is exposure to resultant heat radiation.

However, if a pool fire spreads to the main storage, an event called a Boiling Liquid Expanding Vapor Explosions (BLEVEs) may happen with very serious consequences. A BLEVE can be caused when flames impinge upon the vapor space of the tank causing excessive pressure in the tank causing the entire tank to explode. It will result in a huge fireball and involves the violent rupture of the container, with rocketing fragments. Though the explosion results in considerable overpressure, the most damaging impact is caused by the heat radiation, because it persists for quite some time.

Taking this into consideration, the following accident probable consequence scenarios were considered by the modeler's in the IEMC for the analysis of endpoint distances:

- **Scenario 1:** Rupture of the Pentane pipeline caused by the car crashing into an over ground valve located beside a site access road. The pipeline releases Pentane at the flow rate of the pipe for 10 minutes and forms a pool that spreads to 1 cm depth. The released pool is assumed to ignite and burn after 10 minutes of spreading.

- **Scenario 2:** The pool fire in the vicinity spreads to the Pentane tank and causes the tank to fail catastrophically resulting in a "fireball" or BLEVE. 10% of the contents explode as a vapor cloud.

The endpoints for the two scenario's has been calculated using US Environment Protection Agency (EPA) Equations for Consequence Analysis are presented below.

Pool Fires

The EPA equation is based on factors for estimating the distance to a heat radiation level that could cause second degree burns from a 40-second exposure. This heat radiation level was calculated to be 5,000 watts per square meter. The equation for estimating the distance from pool fires of flammable liquids with boiling points above ambient temperature is:

$$X = H_c \sqrt{\frac{0.0001A}{5000 \Pi (H_v + C_p (T_B - T_A))}}$$

Where:

HC = heat of combustion of the flammable liquid (joules/kg)

X = distance to the 5 kilowatt per square meter endpoint (m)

HV = heat of vaporization of the flammable liquid (joules/kg)

A = pool area (m2)

CP = liquid heat capacity (joules/kg-ºK)

TB = boiling temperature of the liquid (ºK)

TA = ambient temperature (ºK)

Boiling Liquid Expanding Vapor Explosion

The equations used by the EPA to estimate impact distances for BLEVEs are summarized below:

$$X = \sqrt{\frac{2.2 \, t_a \, R \, H_c \, W_f^{0.67}}{4 \, \Pi \left[\frac{3.42 \times 10^6}{t} \right]^{0.75}}}$$

Where:

X = distance to the 5 kilowatts per meter squared endpoint (m)

R = radiative fraction of the heat of combustion (assumed to be 0.4)

tA = atmospheric transmissivity (assumed to be 1)

HC = heat of combustion of the flammable liquid (joules/kg)

Wf = weight of flammable substance in the fireball (kg)

t = duration of the fireball in seconds (estimated from the following equations)

For W_f < 30,000 kg

$$t = 0.45 W_f^{1/3}$$ For Wf > 30,000 kg

$$t = 2.6 W_f^{1/6}$$

Calculate the results in terms of endpoint distances for the two scenarios in Excel based on the information given above:

Scenario 1 = ………. m

Scenario 2 = ……….. m

What are the most important variables in this calculation, and how do they affect the results?

7.2 Evaluating the areas affected

We know, for both the scenarios, how far from the source the hazardous events can affect the buildings. The distances for the two scenarios have been previously calculated through an Excel sheet. The effects of the explosions are inversely proportional to the distance to the source; therefore, the vulnerability should decrease with the increase of the distance. First of all we have to calculate the area around the source hit by the explosion using for each scenario the distance we calculated.

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- Rasterize the point map **Accident** using the georeference **Somewhere.**

- Select *Operations / Raster Operations / Distance Calculation*. Select the input map **Accident**, and the output map **Distance_Accident_2** Select value range 0 to 1410 and precision of 1.

- Follow the same procedure but set the value range between 0 and 395. call the output map **Distance_Accident_1**. The two distance maps represent the areas affected by the two events (scenario 1 and 2).

- Open the map **New_high_res_image** and display the resulting map **Distance_accident_2** on top with 75 percent transparency. Make sure that the map is displayed on top; otherwise you will not see it. Do the same for the other scenario and visually evaluate the result.

We can now see the area that will be affected in scenario 1 and 2. Unfortunately the area is not a perfect circle due to the raster distance algorithm which is used in ILWIS (see ILWIS help for more explanation: search for Distance algorithm). Different kinds of buildings have different behaviors when hit by an explosion; moreover the presence of a tall building can protect a smaller one that is located behind it in relation to the source. These interactions would be too much complicated to be modeled; hence we assume that the vulnerability for each building is dependent on the distance from the source and on the building type and size. We will now evaluate the effect of the distance, by assuming that the vulnerability will decrease from 1 (source) to 0 (perimeter of the area in the distance maps).

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- Transform the distance maps into a map with value 1 for the center and value 0 at the boundary. For the scenario 1, write in the main ILWIS command line the following exression; give to the new map precision of 0,05.

    Vuln_Accident_1:=(395-Distance_Accident_1)/395

    What does the operation create? What is the lowest value in the map?

- The new map can already represent the vulnerability related to the distance to the source. To avoid vulnerability values equal to zero, a further correction is needed. Type an expression to exclude all the zero values. Use a precision of 0.05. This can be an example:

    Vulnerability_Accident_1:=IFF(Vuln_Accident_1=0,?,Vuln_Accident_1)

- Follow the same procedure for the Scenario 2 using the map Distance_Accident_2 and its related value.

We have now the affected area; the next step is to estimate the buildings affected and the vulnerability rate related to the distance to the source.

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- In the main ILWIS menu go to *Operations / Raster Operations / Cross*; chose the maps **Building_map_1998** and **Vulnerability_Accident_1**. Call the new table **Building_Damage_1.** Open the table and check the content.

- In the new table menu, go to *Column / Aggregation* and chose Column: Vulnerability_Accident_1, Function: Predominant, Group by: Building_map_1998, Weight: Area. Call the new column **Vulnerability_Building_1**

- Does the new column differ from the Vulnerability_Accident_1? Why? What did we calculate?

- Open the **Building_map_1998**, go to *Columns / Join* and chose the table we just created; select the column **Vulnerability_Building_1**.

- Create an attribute map from the map **Building_map_1998** by choosing the column **Vulnerability_Building_1**; Call it **Vulnerability_Building_1**, open it and check the content.

- Go to Columns / Aggregation and choose Column: Vulnerability_Building_1, Function: Count; store the new column in the table **Buildings_affected** and call it **nr_buildings_1**. Check the results and fill the table: **Technological** Risk in the next page.

- Follow the steps for scenario 2 and store the values in the table.

7.3 Calculating buildings losses

As stated before, in this case we consider the vulnerability as related to the distance to the source and to the buildings characteristics. A building made in wood or other poor materials is likely to be destroyed / damaged by the blast than a building in reinforced concrete. Furthermore, the more a building is high, the more surface is exposed to the blast; thus the building is more vulnerable. From previous similar events, historic data have been collected and, based on them, the vulnerability rates for different building types with different floors numbers have been provided in the table below.

Vulnerability per building type and height

Building type	1 floor	2 floors	3 floors	4-10 floors	> 10 floors
Adobe	1.0	1.0	1.0	1.0	1.0
Brick with Cement	0.7	0.7	0.8	0.9	1.0
Brick with Mud	0.8	0.8	0.9	1.0	1.0
Fieldstone	0.8	0.9	1.0	1.0	1.0
Reinforced Concrete	0.3	0.4	0.4	0.5	0.6
Wood and others	1.0	1.0	1.0	1.0	1.0

In the next step we will build a table in ILWIS containing the vulnerability values. Then we will estimate the vulnerability per building for each scenario.

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- Go to the main ILWIS menu: *File /Create / 2 Dimensional Table*. Chose as 1st domain **Building_type**, as 2nd domain **Nr_Floors_Clas**; value range: 0 – 1. Call the new table **Vulnerability**.

- Open the 2D table and fill it using the values in the values above. What kind of table is it? Try to describe its meaning and its use (read the ILWIS help).
- Open the table Building_map_1998 and type in the command line the following expression:

    Vuln_building_type:=Vulnerability[Building_type, Nr_floors_class]

- Check the column **Vuln_building_type** and try to explain what the expression calculates.

Now we can combine the vulnerability value related to the distance to the source and the vulnerability value related to the building type and the number of floors. With the total vulnerability we will be able to calculate the total losses for the two scenarios.

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- In the table Building_map_1998; type the following expression:

    Building_losses_1:=Vulnerability_building_1*Vuln_building_type

    This column represents the losses per building for the scenario 1, the sum represents the total losses for that scenario.
- In the table **Building_map_1998** go to Column /aggregation; chose Column: Building_losses_1. Function: Sum and Group by: Building_type. Store the new column in the output table **Buildings_Affected** and call it **Losses_1**.
- Follow the same procedure for scenario 2.
- Check the total amount of losses for each scenario and fill the two empty columns in the table below.

Table: Technological Risk

Building Type	Scenario 1		Scenario 2	
	Affected Buildings	Buildings Losses	Affected Buildings	Buildings Losses
Adobe				
Brick with Cement				
Brick with Mud				
Fieldstone				
Reinforced Concrete				
Wood and others				
Total				

We have calculated the losses per building and the total losses for each scenario. We can also display it in a map.

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- Create an attribute map from the map **Building_map_1998**. Right click on the map, chose Raster Operations / Attribute table and chose the column **Building_losses_1**. Call the map **Building_Losses_1**.
- Do the same with the column **Building_losses_2**. Display the new maps in transparency on top of the High_Res_Image. Check the result.

7.3 Evaluating the impact on the population

Information about the population living in RiskCity is available in the table **Building_map_1998**. Now that we have extracted the losses for each building we can also evaluate how many inhabitants would be "at risk" by the event, and how many buildings would collapse in both the scenarios. To do this, some assumptions are required. A person has to be considered "at risk" (affected by the event) if the losses to the building are more than 15%. If the losses for a building are higher than 40% then the building is considered to be evacuated. To evaluate the number of inhabitants at risk we can create two different time sub-scenarios for each event: night-time and day-time. For the calculation of the population evacuated (and the buildings) we will use the night-time population because it represents the number of person that live in each building.
First of all, we will calculate the number of people at risk in day-time and night-time.

To add new classes in the domain window, click the button in the figure below.

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- Open the **Building_map_1998** and type in the command line the following expression:

Affected_pop_1 = IFF(Building_losses_1>=0.15,Persons_day,?)

   The expression returns the day-time number of persons for those buildings with losses higher than 15%. Activate the statistics pane, if not visible, by going to *View / Statistics Pane* and fill the table below with the total number of people affected.
- By slightly changing the formula, calculate the number of people at risk in the nighttime scenario.
- Calculate the number of buildings that have to be evacuated. Create a new domain by going to the main ILWIS menu *File / Create / Domain;* chose group domain and call it **Evacuated_buildings**; the domain must have two classes:

> 0.39 (upper boundary) Not Evacuated (class name)
> 1.00 (upper5 boundary) Evacuated (class name)

- Close the domain and go back to the table Building_map_1998; type the following expression:

Evacuated_buildings_1:= clfy(Building_losses_1,Evacuated_buildings)

- Go to *Columns / Aggregation* and chose Column: Evacuated_buildings_1, Function: count, Group by: Evacuated_buildings_1. Call the new column **Count_evac_1.** In the column you can find the number of buildings that have to be evacuated.
- Calculate the number of people to be evacuated by typing the following formula:

Evacuated_pop_1=IFF(Evacuated_buildings_1="Evacuated",Persons_night,?)

- Read in the statistic pane the total number of person evacuated.
- Now you have all the values to fill the table below for the 1st scenario.
- Repeat the procedure for the second scenario: note that you don't have to calculate the domain **Evacuated_buildings** again!
- Fill the table below with the correct values for the 2nd scenario.

Building Type	Affected Population		Evacuated buildings	
	Day-time	Night-time	Nr of buildings	Nr of people
Scenario 1				
Scenario 2				

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- Can you explain the large difference between the daytime and the nighttime population involved in the disaster?

This information can be helpful in response activities; according to the number of people evacuated we can plan how many shelters we will need in case that such event happens. Moreover the number of people at risk can be used to plan first aid activities like health assistance, water and food provision, or the number of people that has to be involved in rescue and first aid activities: police, fire service, and hospital staff.

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- We can also show the buildings to be evacuated in a map for the first accident scenario; create an attribute map and chose the map **Building_map_1998** and the column **Evacuated_buildings_1**. Call the map **Evacuated buildings_1**.
- Do the same using the column **Evacuated_buildings_2** and show the map for the second scenario.