SEN1211 Final Project 2022/2023

Emergency response and rescue operations after an earthquake

Dr. Ir. Omar Kammouh, Dr. Ir. Igor Nikolic

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1. Background

1.1 Context

In this project, you will model the emergency response and rescue operations in a city of Turin, Italy, hit by an earthquake using agent-based modeling. This will allow you to understand the effect of such a hazard event on the city and whether the community is prepared to respond. Some of the questions you will be able to answer is whether there are enough hospitals and ambulances to deal with such a situation. You will also try different policies to mitigate the effect of the hazard event.

2. Purpose of the model

2.1 Goal

The goal of your final project is to:

Model and understand the emergency response of communities after earthquakes

2.2 Your task & research questions

Construct and analyze an agent-based model that answers the following research questions:

1. What is the behavior of the model under various parametrizations, and how does it relate to the reality of emergency response?
2. What is the influence of [different policies] or [restoration of physical assets] on the effectiveness of rescue operations?

We would like you to apply an exploratory modeling approach in answering question 1 and a hypothesis-driven approach in answering question 2. For question 2 you need to choose specific policies/technologies and the meaning of *[restoration of physical assets]*. A non-exhaustive list of examples of policies or technologies could be:

- *Prioritizing quick recovery of roads over emergency health care*
- *Call first responders from other cities (e.g., ambulances)*
- *Use schools as hospitals.*
- *Drones for identifying building collapse and road closure to help with prioritizing emergency response*

You need to formulate a hypothesis about their influence on the model outcome *before* you create your model. Communicate your a-priori hypothesis in your report, as well as an interpretation why your results did or did not confirm your initial hypothesis.

3. Model elements

3.1 Model description

You will model the emergency response of a city hit by an earthquake. The city is based on the city of Turin, Italy. The city can be represented by a graph with links and nodes. Links represent roads and nodes are the intersections of roads. The graph of the city is already built for you. You will also find a minimal mesa/NetLogo model that imports the graph and puts a few agents on a grid.

In the city, there are buildings and hospitals. These are objects (not agents) and are distributed over the nodes. One node can have one or more buildings. Think about a node as a small neighborhood. For simplicity, you can assume one building per node, but you are free to assume more.

An earthquake can occur at any location and will cause damage to buildings. For this assignment, the earthquake occurs at the node with coordinate (0,0). Buildings are directly affected by the earthquake's shaking and can get severely damaged. The degree of building damage is determined by several factors, such as the earthquake magnitude, the building type, the construction year, etc. The degree of building damage can be determined following the instructions in Appendix A.

Each building has a number of resident agents living in it. The degree of building damage determines the number of injured people and the degree of injuries (i.e., how bad the injuries are). For example, a stronger and closer earthquake will induce more damage to buildings (Figure 1), and therefore more injuries and death cases. You should assume a relationship function between the damage level and the number of people injured/dead (e.g., linear, exponential, etc.). The relationship between building damage and the number of injured/dead people can be probabilistic (e.g., if a building collapses, there is a higher probability that a person is injured or dead). A Dead person can be modeled by removing the agent from the model. Dead people do not have to go to hospitals. You should always keep track of the numbers.

Roads can be closed due to debris falling from collapsed buildings. If a road is closed, ambulances cannot use it until it is fixed. You should assume a (probabilistic) relationship between building damage and a closed road. For example, if a building collapses, there is some chance that every road linked to it is closed. A closed road can be modeled by removing an edge from your graph.
Optional: If a road is closed, it can become available again after some time steps. In this case removed roads should be kept in memory so you can add them later when repair takes place.

There are several hospitals in the city (in the real city of turin there are around 20 hospitals and medical centers). You are free to distribute them the way you want but we suggest placing them randomly. Each hospital has ambulance agents that transport injured people through the road network. If a road is closed, the ambulance cannot use it to reach a certain building and must find another route. If you use mesa, you may use the standard NetworkX graph algorithms for routing and finding the shortest path. For Netlogo, we provided some examples in the netlogo model on how to find the shortest path between two points.
Each hospital has a capacity represented by the number of beds. Hospitals are usually not empty before the earthquake event. If the hospital is full, no more people are accepted. People who could not be transported to the hospital will die after some time. People get cured after

spending some time at the hospital. It is not of interest to transport them back home when they are cured.
Optional: People have different knowledge of disaster preparedness which can reduce the probability of them getting injured compared to people with no knowledge.

Note that you should make your own assumptions. For example, where should the ambulances go if there are no injured people? How does the ambulance decide which citizens to pick up first? What is the capacity of ambulances? How should the immovable agents be distributed in the city? etc...

The description above is not comprehensive. You may also adapt the above description (simplify it or make it more complex) to what makes sense to you and matches your modeling skill level and ambition. You must carefully and explicitly document your assumptions.

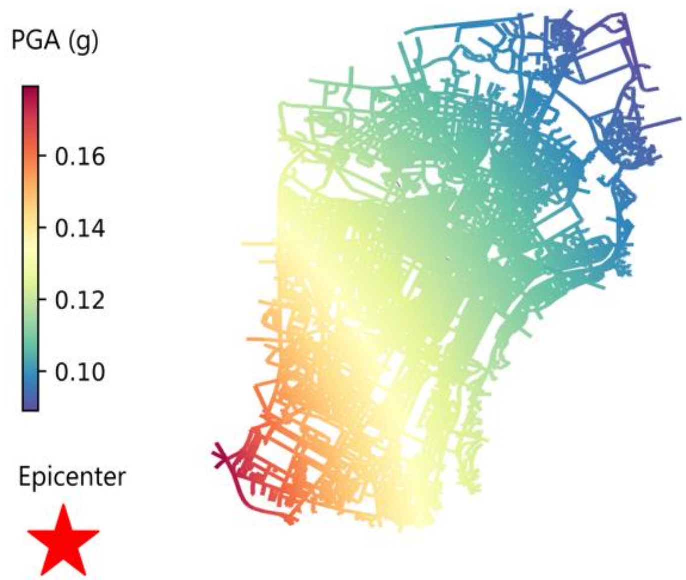

Figure 1 Earthquake attenuation: far distances from the epicenter experience less shaking than close distances

3.2 Agents

There are (a minimum of) the following agents that you need to model: **residents** and **ambulances.** Their (minimal) properties and behaviors are as follows. You can adjust and extend these.

Residents

Have	Do
• Health status: healthy/Injured/dead • Optional: have different levels of disaster preparedness knowledge	• Get injured • Recover depending on their injuries over time or get increasingly worse off and die in absence of treatment

Ambulance

Have	Do
• Capacity	• Transport injured citizens from buildings to hospitals

Optional agent types:

- Road maintenance/recovery trucks
- Drones

3.3 Other Entities/objects (non-agents)

Hospitals

- Have capacity/beds
- Cure people
- Optional: Decides to which building and hospital every ambulance should go

Buildings:

- Are built with certain material
    - Concrete/steel/Brick
- Are of different sizes
    - Short/Medium/Tall
- Have a damage status: intact, damaged, collapsed
- Get citizens injured
- Cause roads closure

Natural disaster: earthquake

- Can have different magnitudes
- Occurs at a specific point called the epicenter
- Hits closer buildings more than far buildings assuming the same building type/strength (this is called attenuation)

Disaster management agency

- Draws policies

Optional entities:

- Coordination center
- Road maintenance agency

3.4 Time

Time:

- Model runs for 1-3 days
- Ambulance agent moves from one node to another in 1 tick/step.
- Time resolution: 1 tick/step = 1 minute

These are suggestions. Feel free to modify them the way you feel appropriate. Please justify your assumptions.

4. Metrics, user interface, parameters, experimental design

4.1 Metrics

In your report, make sure you are explicit about the metrics you will be collecting from your model and how they are relevant to answering the research question.

4.2 User interface

Make sure that the user interface can visualize the dynamics of the system, that the key parameters of the model and the policies are settable and that the metrics you identified can be followed.

4.3 Parameters

Many parameters/numbers for your model are still missing. Please make reasonable assumptions, with a brief explanation of why you are making them. You can also look up data from online sources but please do not spend a lot of time on this!

4.4 Experimental design

Make an experimental design for exploring the model behavior and answering the research questions. Please communicate your experimental design explicitly, with brief reasoning about the choices you made.

5. Guidelines, submission, grading

5.1 Guidelines

The most important thing is to cover all steps of the modeling cycle, from initial conceptualization to reporting on the model. When you are short on time, make the model (much) less complex, but make sure you do all the steps, like verification, analysis, etc. Especially when you are not very experienced in programming, make it simple but sane. Always prioritize completeness over depth.

This project description is incomplete! There are many things you will have to decide yourselves; make your own assumption. Make those assumptions and choices very clear, especially when

significantly deviating from the base project description. Make it clear what the assumption is, and why you made it. “We had no idea what else to do, this seemed reasonable because…” is a valid reason for your report. Keep in mind, this is a modeling course, not a course of disaster recovery.
Keep the report short and to the point. It is OK for it to be quite mechanical, you are demonstrating your ability to design a model, make choices, implement, analyse, etc, not write pretty and long reports.

5.2 Submission

You will individually submit your final report during the exam, as an answer to a question. Each member of the group needs to upload the file as an answer to their own exam.

Please follow these requirements for the submission format carefully!

- Make a zip file, with the name and student number of every group member as a filename.
- Name your zip file without spaces in the filename.
  - e.g. Kammouh_314159_Nikolic_424242.zip

Inside the zip there is:

- A directory with the same name.
- In that directory:
  - There is a report in PDF format with the name and student number of every group member in the file name : Report_Kammouh_314159_Nikolic_424242.pdf
  - Please make sure you use the **"embed all fonts"** options, which is the same as using the PDF/A format, when you generate the pdf
  - Make sure you do not put all of the model code in the report, you can of course use snippets if needed for your story
  - a **model/** directory, containing the python/nlogo file(s) of the model and all data needed to run the model.
  - an **output/** directory, containing all the generated result files. Please **zip these files** before adding them to the package
  - an **analysis/** directory, containing all code (R/python/Excel/whatever) that you have used to generate your report, and all output images that you created.
  - Maximum file size is 100 MB. If you have generated more than that you need to reconsider your modelling practices.

5.3 Grading

The grading will be determined based on the following criteria:

- Do you have a concise but complete overview of the conceptual model?
- Do you explain formalization and implementation of your conceptual model?
- Are all model assumptions clear?
- Did you perform model verification?
  - If yes, how thoroughly?
- How did you set up your simulation experiments?
- How well did you do the analyses?

- How well are you interpreting the data?
- Do you answer the research questions?
- Does your model run?
- Does it break if the parameters are changed?
- Does it generate recognizable criteria?
- How well are you using the Netlogo/Python language?
- Is the report complete, clear, and readable?

Appendix A

Several factors contribute to the degree of building damage. Each of these factors is associated with a multiplier. The multiplier can take a value between 0 and 1, with 0 minimizing the chance of building damage and 1 maximizing it. Multiplying all these multipliers will give us an idea of the building's vulnerability. Below are the steps to determine the building damage.

- Building Vulnerability VM:

$$VM = TM \times HM \times DM \times EM$$

  - Building Type Multiplier TM:
    - Concrete building: TM=0.5
    - Brick building: TM=1.0

  - Building Height Multiplier HM:
    - Tall building: HM=1.0
    - Medium-height building: HM=0.6
    - Short building: HM=0.2

  - Distance from epicenter Multiplier DM:
    - DM= $\frac{Max_{distance} - Distance}{Max_{disatnce} - Min_{distance}}$

    Max distance: the distance between the epicenter and the farthest building
    Min distance: the distance between the epicenter and the closest building
    Distance: the distance between the epicenter and the considered building

  - Earthquake intensity multiplier EM:
    - Weak earthquake: EM=0.2
    - Strong earthquake: EM=0.5
    - Major earthquake: EM = 0.7
    - Severe earthquake: EM = 1.0

Once the vulnerability is determined, the damage probabilities can be calculated as follows

- Building Damage Probability distribution:
  - $CollapseProbabilityCP = 0.7 \times VM + 0.1$

- $HighdamageProbabilityHP = -0.15 \times VM + 0.3$
- $NoDamageProbabilityNP = -0.55 \times VM + 0.6$

The summation of the three probabilities is always equal to 1. Once the three probabilities are calculated for every building, the building damage is determined by randomly sampling from a multinomial probability distribution (a generalization of the binomial distribution). This can be done as follows:

a) Order probabilities in ascending order. For example, if VM = 0, the ascending order would be CP-HP-NP
b) Draw a random number x between 0 and 1
c) If x is between 0-CP → the building will be considered as collapsed
   If x is between 0-HP → the building will be considered as highly damaged
   If x is between 0-NP → the building will be considered not damaged

Note that the order of probabilities can be different depending on the value of VM.