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Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

**Lecture with Computer Exercises:
Modelling and Simulating Social Systems with MATLAB**

Project Report

Study on the Model for the Resilience of Electric Power Supply System Subjected to Seismic Hazards

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Li Sun

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Abstract

The resilience of Electric Power Supply System (EPSS) is strategically significant to the modern communities under natural hazards like strong earthquakes. The simulation of the seismic recovery behavior of EPSS has become a key issue to the resilience risk evaluation for the system and the community which it serves. In order to rationally quantify the recovery process of the seismically damaged EPSS, one Agent-Based Modelling (ABM) framework, was put forward and applied on an example network in this thesis. The two individual agents, which are the Operator of EPSS and the Community Administrator (Government), were predefined firstly. The corresponding rules for the interaction between them were then clarified. The ensuing parametric studies were conducted to examine the influence of the different interference modes of the Government Agent. It can be found that the interaction and coordination among different sectors within the seismically affected community will have a significant influence on the recovery behavior of the EPSS after strong earthquakes. The results demonstrate that the agent-based modelling method can become an effective and practical tool for the assessment of the seismic resilience risk for EPSS.

Individual contributions

This project was preliminarily divided into three parts which will be finished by Li Sun, Jose Espejo and Lea Furer respectively. But during the process of the project, Lea and Jose decided to drop out of the project successively. Consequently, Li Sun became the only one of the group.

Since the very beginning, Li Sun familiarized himself with the Agent-Based Modelling (ABM) method itself step by step. Basing on the existing fragility data, an ABM framework for the seismic recovery model for EPSS was put forward and applied on one example benchmark network.

The parametric study as well as the corresponding interpretation of the results was done by Li Sun in the ensuing step. The writing of this thesis was done by Li Sun finally.

Introduction and Motivations

Electric Power Supply System (EPSS) is the backbone for the modern societies. Its resilience is significant to the security and sustainability of communities being much more sophisticated and integrated than before. Unfortunately, as exemplified by many incidences during the recent history, the EPSSs were shown to be vulnerable under natural hazards as well as the random failures. Consequently, serious economic and societal losses of the community will be aroused. More importantly, due to the intrinsic characteristics of EPSS, a seemingly not serious local damage can propagate and lead to a phenomenal global failure of the system and even other connected infrastructure systems.

Against this backdrop, the development of the resilience risk evaluation model for EPSS under natural disaster hazards is of paramount urgency and utmost significance.

Bruneau et al. (2003) firstly proposed a conceptual framework to evaluate the seismic resilience of community from technical, organizational, social and economic perspective. Furthermore, this framework was applied for the acute care networks. The probability functions, fragilities and resilience were related together in a single integrated method (Bruneau et al. 2007).

It should be pointed out that, according to the current resilience risk assessment framework, the evolution of the resilience behavior of EPSS will be examined by a single parameter which is usually the delivered power supply. But it can be misleading for many cases as the demand from the community will also be fluctuating during the post-earthquake period.

In order to address this challenge, it was attempted in this project to track the functionality loss of seismically damaged EPSS basing on the evolution of supply capacity of the EPSS and demand capacity of the communities and users it serves. The difference between the supply and the demand provides a measure of EPSS resilience.

During the immediate "Absorb" stage after the earthquake disaster, the decrease of the demand and supply can be evaluated basing on the fragility data. But it can be much more challenging to capture the recovery process, which will be stochastic and case-specific, of the EPSS as well as the corresponding community.

To come up with the “well-founded” results for each different EPSS and its served community, one pertinent framework for the simulation of the seismic recovery process was developed. The following fundamental questions will be answered:

(1) How long the seismic recovery process will be?

(2) How much the power deficit will evolve over time?

(3) How will the interaction among different sectors influence the recovery behavior?

Description of the Model

The Multi-Agent Model was employed to fulfil the research goal. The specific agents as well as the rules for the interaction among them were predefined. The parametric studies were then carried out to examine the influence of different behavior characteristics and the seismic intensity measures.

The seismic recovery process of communities is very dynamic, stochastic and also case-specific. It is due to the uncertainty of the seismic magnitude, the robustness of the components of EPSS and also the built environment of the community, the preparedness of the community, the interaction among different sectors and et al.

Starting from the simplest case, as illustrated in Fig. 1, it can be found that as the strong earthquake happens, the components of EPSS (e.g. transformers, switches, circuit breakers and et al.) and the built environment (e.g. the office and apartment buildings, factories as well as the schools) will be damaged to some degree which is commensurate with the robustness of they themselves and also the different seismic intensity measures. The information of the status of the damage will reach the Operator of the EPSS afterwards and then the rescue team will start their restoration campaign according to the command of the Operator. Due to the interdependency among different critical infrastructure (CI) systems, the functionality of many other CIs (like the telecommunication system and the water pipeline system and etc.) will also be affected if the power supply cannot be restored. Therefore, the Government will also take part in the campaign as they will concern about the holistic recovery process of the community.

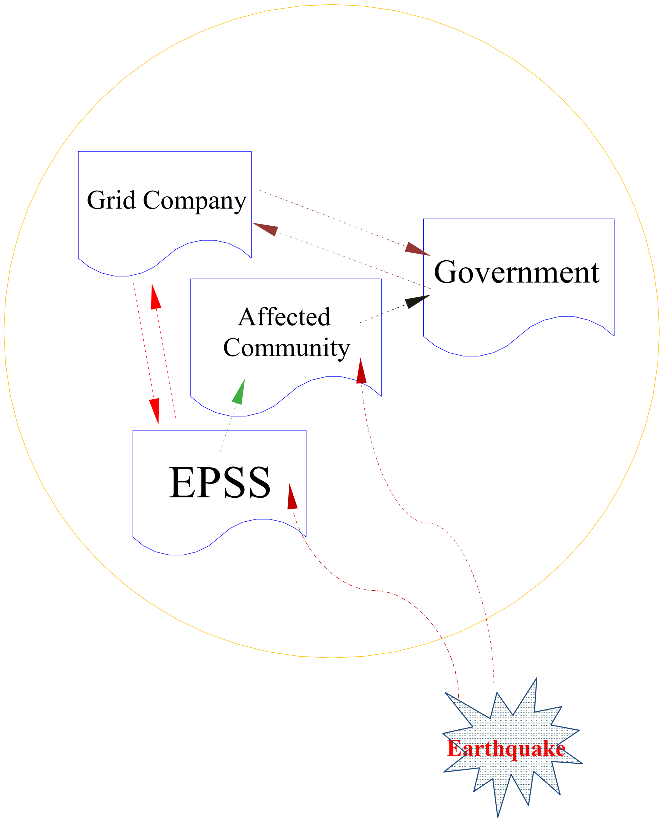


Figure 1. The post-earthquake interaction within communities

In this sense, in the proposed ABM Framework, two corresponding agents: the Grid Company and the Government, were defined as the following:

1. **Grid Company**: totally three parameters, which are the Speed, Efficiency and Toughness, were adopted to define the behaviour of the agent.

Specifically, “Speed” here means the travelling velocity of the rescue team while “Efficiency” quantifies that to which degree the team can restore the functionality per hour.

The “Toughness” refers to the enforcement power by which the agent can stick to their own rescue plan.

2. **Government**: Only one parameter, which is the “Toughness”, was used to define this agent. Similarly to the agent “Grid Company”, the parameter also indicates how powerful the government can be during the entire recovery process.

Updating the agent's state: The interaction rules were made clear as the agents have been defined hereinbefore. Since the beginning of the simulation, the rescue team will start to do their jobs only after a short response time of the **Grid Company**. To the preference of the Grid Company, the team will first go to the least seriously damaged substations. It can be justified as, first, the transportation system over those area also tend to be least damaged. Second, for those substations suffering very severe failure, it can be more efficient and economical to replace the damaged equipment with new ones, or even rebuilt the entire substation afterwards.

But the priority of the **Government** Agent will go in the totally different direction. For those people who live in the areas close to the most severely damaged substations, the initial damage they’ve incurred has already been quite serious. Moreover, it can be easily predicted that the operation cannot be conducted to treat the injured people in the hospital as the power supply is totally, or at least very greatly, disrupted. The resulting fire can’t be extinguished because the pump can’t work without the reliable power delivery. The people have no way to communicate with their relatives or friends by cell-phone as the system will be suspended if there is no enough electric energy…The discontentment will mean a great pressure to the government because it can potentially lead to the political unrest. So in this framework, the “Critical Moment” was defined for the government to become "tougher" if some "threshold" value for the percentage of people being still out of power were exceeded.

The simulation will last for 480 hours for all the cases.

Implementation

In order to examine the feasibility and applicability of the proposed framework, it was implemented to conduct one case study of one example network. This Power Grid was extracted from the IEEE 39 Benchmark System. As illustrated in Fig. 2, the Grid consist of 5 High-Voltage Generation Substations and 12 High-Voltage Distribution Substations.

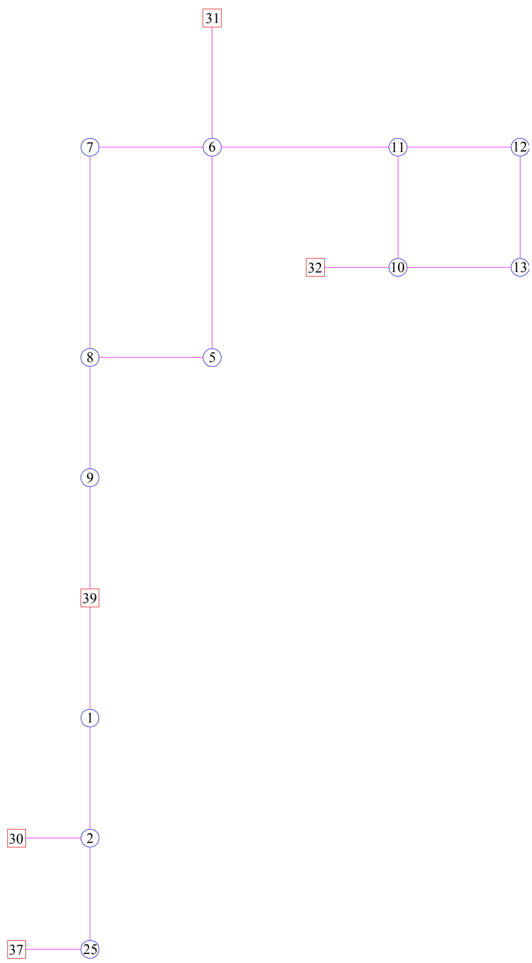


Figure 2. The topology of the example network

In order to determine the seismic failure probability for different substations, the developed fragility data by SYNER-G Project (UROMA 2010) was employed in this project. In should be noted that for the sake of simplicity, only the damage of the generation substations were considered as the distribution substations are usually very close to the urban area and therefore they can be repaired by the city emergent rescue staff in a much faster way.

The functionality decrease for the Power Supply was quantified in Fig. 3. As illustrated, if the probability of the failure P_f is smaller than 0.25, the performance will decrease to (1-P_f) percentage of the pre-disaster level. As P_f is between 0.25 and 0.5, the decreased performance will amount to (0.5-P_f) percentage of the pre-disaster level. Finally, if P_f is larger than 0.5, it means the generation substation can't deliver any electric power.

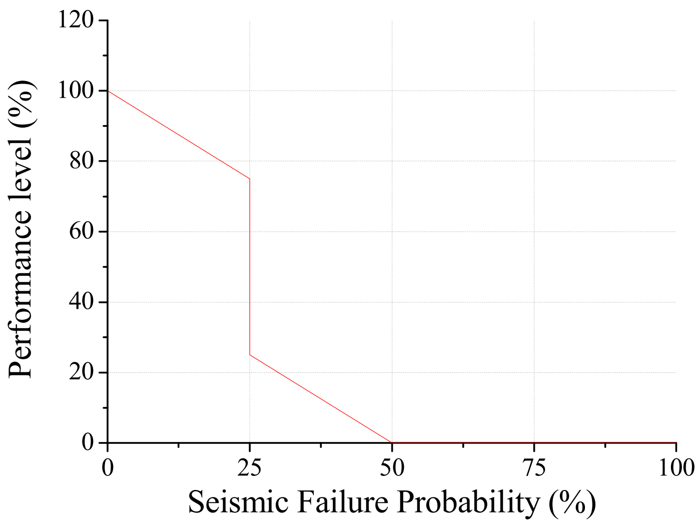


Figure 3. The post-earthquake performance level versus seismic failure probability

The distribution of the defined parameters in the simulation was plotted in Table 1. It should be pointed out that, for most of the cases, the original toughness of the Grid Company was set to be uniformly distributed between [0.4, 0.5] and therefore larger than that of the government which was between [0.3, 0.4], simply because EPSS is directly managed by the Grid Company. But if the company can't let the specific percentage of the affected people back to the normal life, the Government will be more powerful and can potentially force the Gird Company to change their own rescue plan. In the developed Matlab codes, it was done by increasing the "Toughness" of the government by 0.1.

	Distribution Type	Lower Limit	Upper Limit
Speed (km/h)	Uniform	30	50
Efficiency (h^{-1})	Uniform	0.01	0.02
Toughness of Grid Company	Uniform	0.4	0.5
Toughness of Government	Uniform	0.3	0.4

Table 1. The distribution of the parameters in the simulation

Simulation Results and Discussion

1. The case of one Agent only

As shown in Fig. 4, for the case of Magnitude 9, the evolution of number of people out of power over time was tracked by the run of 10000 Monte-Carlo Simulations.

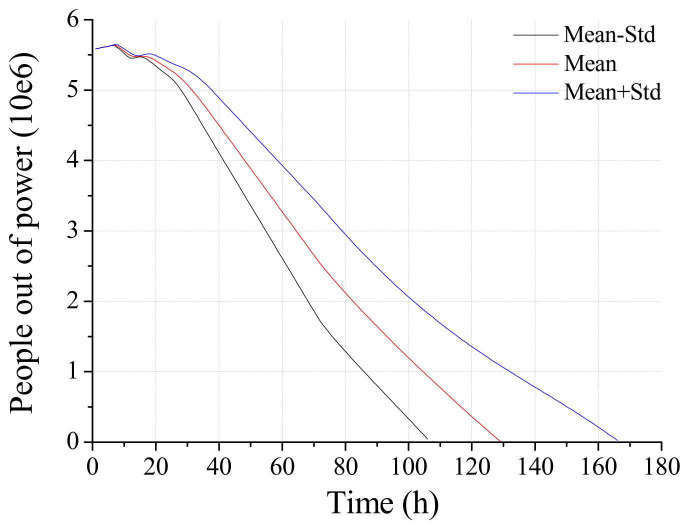
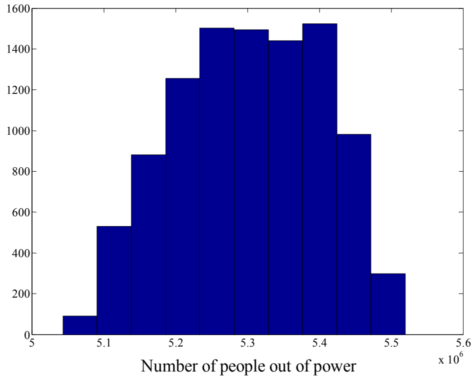
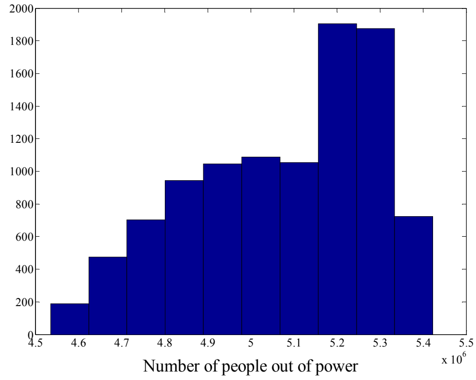


Figure 4. The evolution of number of people out of power

The number of the affected people was determined by the instaneous power deficit divided by the average power demand of individual people at every time step of the simulation. In order to be clearer, the curves for the mean value as well as (Mean ± Standard Deviation) were plotted together. From the perspective of mean value, it will take about 130 hours for all the affected people to get recovered from the earthquake.



(a) After 24h



(b) After 30h

Figure 5. The recover process for the power demand after earthquake disaster

To facilitate examining the status of each moment, the histogram for 24 h and 30 h were shown in Fig. 5. It can be used to quantify the probability for the exceedance of some predefined threshold values at any critical moment.

2. The case of two Agents

In order to consider the influence of the interaction between the two agents, the corresponding results were compared with that of the case of only one agent in Fig. 6. Here, the "critical moment" was set as 30 h and the "threshold values" were chosen as 0.8, 0.85 and 0.9 respectively. It can be found that, at the first about 70 hours, the four curves almost overlapped with each other. It indicates that the inference doesn't make the substantial difference. But after that, as the government be more and more "strict", the recovery process can be finished much more quickly. For the case of 0.9, all the people can get the power supply about 115 hours after the earthquake. It will save 15 hours, which amounts to 11.5 % of the duration of the case of no interference.

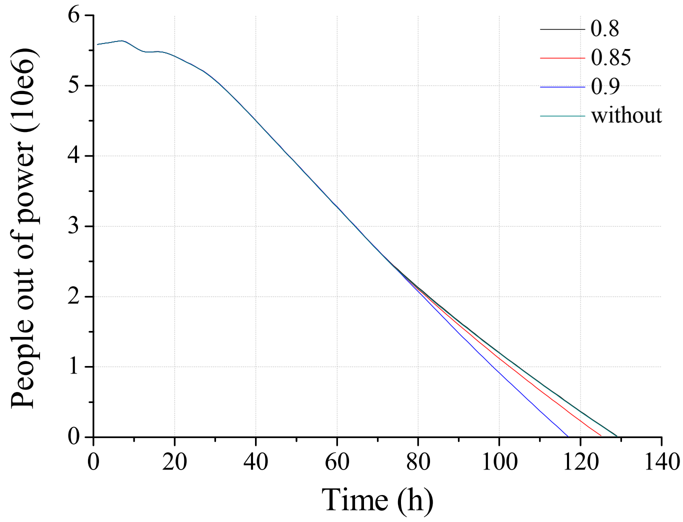


Figure 6. The recover process for the power demand after earthquake disaster

Summary and Outlook

In this thesis, the seismic recovery process of Power Electric Supply System was simulated by the Multi-Agent Based Modeling (MABM) strategy. For the first step, only the one agent, the Operator of EPSS (or Grid Company), was considered. Then in order to examine the influence of the interaction among different agents, another agent which is the Community Administration (or Government) was also taken into account. Series of parametric studies were carried out to investigate the sensitivity of different characteristics of the behavior rule of the two agents. It can be found that:

1. The interference of the government agent, as well as its resulting interaction with the Grid Company, can have a substantial influence on the recovery process of EPSS;
2. The MABM can become an efficient tool for capturing the very complex and stochastic recovery behavior of the damaged EPSS after seismic hazards.

In the long run, basing on the results described hereinbefore, the more agents involving in the rescue campaign (e.g. the operator of transportation system and the military and et al.) should be added to improve the fidelity of the proposed framework.

References

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