

Aalto University

MS-E2177: Seminar on Case Studies in Operations Research

Probabilistic Seismic Hazard Analysis for a Nuclear Power Plant

Project plan

Project Manager: Tran Quang Anh Tuan

Team Members: Anh Dao, Eeli Asikainen, Einari Stenberg, Waldemar Sorjonen

Date: April 2, 2025

Contents

1	Background	3
2	Objectives	4
3	Tasks	5
3.1	EPRI Bayesian method	5
3.2	Kijko's method	6
3.3	Methods combination	6
3.4	PSHA background literature review	6
3.5	Report and presentation	6
4	Schedule	7
5	Resources	8
6	Risks	9

1 Background

Given the push for renewable energy sources around the world, it is no surprise that nuclear energy has been heralded by many as an important addition to the array of clean solutions.

However, a major challenge to nuclear acceptance comes from its potential risks. Unlike other energy sources, nuclear energy incidents can push public sentiment against it for years, which happened with the accidents at Chernobyl in 1986 and Fukushima in 2011. This means that nuclear power plants are designed with extremely strict safety standards in mind. A major standard involves safety against seismic activity, creating Seismic Hazard and Risk Analysis as a research field. As a core aspect of the field, Probabilistic Seismic Hazard Analysis (PSHA) models the earthquake risks through recorded seismic data.

At Fortum's Loviisa nuclear power plant, Probabilistic Risk Analysis (PRA) models has been updated annually for several decades. However, Finland's low seismic activity presents challenges for accurate risk estimation. The scarcity of relevant seismic data further complicates the modeling process, necessitating the adaptation of new methods to suit Loviisa's specific conditions.

This project aims to enhance Loviisa's PSHA by addressing these limitations. We focus on developing improved models by identifying more suitable methodologies and refining existing approaches given maximum magnitudes data to ensure a more reliable assessment of Loviisa's seismic hazard.

2 Objectives

The primary objective of this project is to refine and adjust existing statistical models for estimating the maximum magnitudes of earthquakes in the context of Loviisa's PSHA. Since current models are not inherently designed for low-seismicity regions, modifications will be required to enhance their applicability. Moreover, as the methodologies underlying these models are not comprehensively detailed in the existing literature, it will be necessary to develop practical tools for their reconstruction and validation.

While the project will focus on developing robust statistical models, particular emphasis will be placed on the rigorous documentation and justification of the research process and its findings. Given the inherent complexity of the subject matter, it is anticipated that a fully definitive solution may not be attainable. Therefore, a critical aspect of this study will be to elucidate the limitations of various approaches, analyze the reasons behind their shortcomings, and assess the strategies employed to address these challenges. By documenting unsuccessful approaches alongside successful ones, this research aims to contribute to a broader understanding of earthquake modeling in low-seismicity regions, providing a foundation for future improvements.

3 Tasks

To derive alternative methods for determining the maximum magnitude weights, we aim to explore and refine the two existing methods suggested by Fortum: Bayesian method based on EPRI report [1] and Kijko’s (2004) method [2]. The specific tasks are outlined below.

3.1 EPRI Bayesian method

This method is developed in EPRI’s 1994 report. Our tasks involve reproducing the results obtained in the original report, and exploring new directions in improving the methods used. The specific tasks are given below:

Table 1: Tasks related to the development of the Bayesian method.

Task	Description	Directions	Dependency	Responsible Person(s)
Choosing prior	Literature review, EPRI method reproduction, methods exploration, documentation and justification	Modifying existing models’ assumptions, clustering method for alternative domains	None	Waldemar Sorjonen, Eeli Asikainen
Expanding data samples	Literature review, method implementation, documentation and justification	Synthetic data simulation, Loviisa’s earthquake data (original)	None	Anh Dao
Choosing update method	Literature review, EPRI method reproduction, documentation and justification	EPRI original method	Choosing prior must be done in advance	Waldemar Sorjonen, Eeli Asikainen, Anh Dao

3.2 Kijko's method

The Kijko method is a statistical approach for determining maximum magnitude weights. Based on initial research, its development is expected to be brief. Therefore, Tuan Tran will take the lead in developing the method. His responsibilities include conducting a literature review, implementing the method, documenting the process, and providing justification.

3.3 Methods combination

Once the methods have been explored and developed, we will report our results and collaborate on integrating them. This task involves all team members and depends on the completion of previous tasks.

3.4 PSHA background literature review

We believe that background information on general PSHA will strengthen our analysis and provide essential context for readers in the final report. Therefore, we will also conduct a general review of PSHA research, with a particular focus on studies conducted by Fortum. This task will be led by Einari Stenberg, with Tuan Tran contributing if the development of the Kijko method is completed ahead of schedule. The key tasks include a literature review and documentation.

3.5 Report and presentation

All members will work together to complete these tasks, ensuring proper documentation and presenting their respective contributions. Presentations are intended to be made at least a week before deadline for proper preparation.

4 Schedule

The project is structured into several phases to ensure clear execution and on-time completion. The work begins with task division and project planning in February, followed by a literature review and initial exploration phase extending until the end of March. Model implementation will start from March to mid-May, during which the Bayesian and Kijko methods will be developed and refined according with the feedback from Fortum experts.

To ensure reliability, validation and sensitivity analysis will be conducted in parallel with the model implementation. Documentation of findings will be a continuous effort throughout the project. The final report and presentation materials will be prepared in early May, with the goal of finalizing all deliverables at the end of May.

The following table outlines the key deadlines and dependencies for each phase of the project:

Table 2: Project schedule.

Phase	Start Date	End Date	Dependencies	Notes
Task Division	01.02.2025	14.02.2025	None	Tasks assigned to team members
Finalizing Project Plan	07.02.2025	21.02.2025	Task division	Ensures clarity in execution
Literature Review & Initial Exploration	14.02.2025	31.03.2025	None	Background study on PSHA & statistical models
Model Implementation	01.03.2025	15.05.2025	Literature review, method selection completed	Implementation of Bayesian and Kijko's methods
Validation & Sensitivity Analysis	01.03.2025	10.05.2025	Model implementation	Ensures reliability of results
Final Report Documentation	14.02.2025	14.05.2025	Literature review, model implementation	Continuous process throughout the project
Presentation Preparation	06.05.2025	14.05.2025	Final report draft completed	Finalizing materials for course submission

5 Resources

The team consists of three System and Operations Research students and two Data Science students. Most of the members have completed a course in Bayesian data analysis, giving us a solid understanding of how to enhance the Bayesian method. The main point of contact from Fortum is Jukka Koskenranta, Senior Engineer in Probabilistic Risk Assessment. Jukka brings extensive experience in researching and analyzing seismic risk in nuclear energy development and will provide valuable advice regarding seismic hazard analysis. Additionally, we will receive guidance on seismic risk analysis from Juhana Vehmas, who conducted his master's thesis on this topic in collaboration with Fortum. Professor Ahti Salo will offer general guidance related to project execution and Operations Research.

We have been provided with the company's private data and research papers, which will serve as our primary sources of information for the project.

6 Risks

Our goal is to meet the objectives defined in Section 2, by completing the tasks described in Section 3 and staying on the schedule defined in Section 4. Despite a holistic project plan, unexpected risks arise. Table 3 lists the main risks in terms of frequency and impact, with emphasis on concrete steps to reduce the risk.

Table 3: Main risks related to the success of the project.

Risk	Effect	Likelihood	Impact	Prevention
Insufficient validation and sensitivity analysis of the results	Results may not provide sufficient confidence for nuclear safety applications	Medium	High	Time block dedicated exclusively on validation and sensitivity analysis
Problem scoping too ambitious	Overworked team members, not staying on schedule	Medium	Medium	Emphasis on communication between team members and Fortum
Not enough relevant data available	Results not accurate / meaningful enough	Medium	Medium	Use all available data. Explore simulating methods and clustering of data.
Lack of communication with the client	Progress slowing down, project heading in an unwanted direction	Low	High	Biweekly meetings with Fortum representatives, confirmed a few days before meeting
Inactive team members due to unexpected life circumstances	Not staying on schedule, Overworked members	Low	Medium	Weekly / bi-weekly meetups, communication through Telegram, careful planning and monitoring

References

- [1] A.C. Johnston, K.J. Coppersmith, L.R. Kanter, and C.A. Cornell. The Earthquakes of Stable Continental Regions: Final Report Submitted to Electric Power Research Institute (EPRI): TR-102261. 5-volume report prepared for Electric Power Research Institute, Palo Alto, California, 1994.
- [2] A. Kijko. Estimation of the maximum earthquake magnitude, $m_{\max}$. *Pure and Applied Geophysics*, 161:1–27, 2004.