

# Milestone 6: Sensitivity and Scenario Analysis Guide

KSU - CCSE  
CS 4632: Modeling and Simulation

## Alignment with Course Objectives

This milestone directly addresses the following course learning outcomes:

- ✓ **Perform sensitivity and scenario** analyses to evaluate system performance under varying conditions.
- ✓ **Conduct simulation runs**, evaluate, and interpret data using statistical techniques.
- ✓ **Develop professional-grade** technical documentation emphasizing clarity and accuracy.

# Contents

<b>1</b>	<b>Introduction</b>	<b>4</b>
<b>2</b>	<b>Definitions and Terms</b>	<b>4</b>
2.1	Sensitivity Analysis . . . . .	4
2.2	Scenario Analysis . . . . .	4
<b>3</b>	<b>Systematic Approach</b>	<b>4</b>
3.1	Sensitivity Analysis . . . . .	4
3.1.1	Steps . . . . .	5
3.1.2	Specific Example . . . . .	5
3.2	Scenario Analysis . . . . .	5
3.2.1	Steps . . . . .	6
3.2.2	Concrete Example . . . . .	6
<b>4</b>	<b>Common Pitfalls and How to Avoid Them</b>	<b>7</b>
4.1	Ignoring Correlations Between Parameters . . . . .	7
4.2	Insufficient Sample Size . . . . .	7
4.3	Overcomplicating the Model . . . . .	7
4.4	Poor Data Visualization . . . . .	7
4.5	Ignoring Parameter Sensitivity Ranges . . . . .	7
4.6	Failing to Validate Model Assumptions . . . . .	7
4.7	Misinterpreting Sensitivity Results . . . . .	8
<b>5</b>	<b>Report Structure and Formatting</b>	<b>9</b>
5.1	Formatting Guidelines . . . . .	9
5.2	Content Requirements . . . . .	9
<b>6</b>	<b>Examples of Good vs. Poor Analysis Presentations</b>	<b>10</b>
6.1	Good Analysis Presentation . . . . .	10
6.2	Poor Analysis Presentation . . . . .	10
<b>7</b>	<b>Sample Size Recommendations</b>	<b>11</b>
7.1	General Guidelines . . . . .	11
7.2	Recommended Sample Sizes by Model Type . . . . .	11
7.3	Statistical Justification . . . . .	11
<b>8</b>	<b>Guidelines for Data Visualization</b>	<b>12</b>
8.1	Choosing the Right Chart Type . . . . .	12
8.2	Design Principles for Effective Visualization . . . . .	12
8.3	Example of a LaTeX-generated Visualization . . . . .	12
<b>9</b>	<b>Presenting Data with Tables and Graphs</b>	<b>14</b>
9.1	Constructing Tables . . . . .	14
9.1.1	Key Components of a Table . . . . .	14
9.1.2	Guidelines for Effective Tables . . . . .	14
9.2	Using Keys and Legends . . . . .	14
9.2.1	Creating a Key . . . . .	14
9.2.2	Example of a Table with a Key . . . . .	14

9.2.3	Explanation . . . . .	16
9.3	Tailoring Tables to Your Simulation . . . . .	16
<b>10</b>	<b>Step-by-Step Checklist</b>	<b>17</b>
10.1	Before You Begin . . . . .	17
10.2	Sensitivity Analysis . . . . .	17
10.3	Scenario Analysis . . . . .	17
10.4	Report Writing . . . . .	17
10.5	Final Steps . . . . .	18
<b>11</b>	<b>Conclusion</b>	<b>19</b>
<b>12</b>	<b>Appendices</b>	<b>20</b>
12.1	Appendix A: Reference Terms . . . . .	20
12.2	Appendix B: Types of Distributions . . . . .	20
12.3	Appendix C: Stochastic and Random Numbers . . . . .	20
12.4	Appendix D: Glossary of Statistical Terms . . . . .	20

# 1 Introduction

The purpose of this guide is to assist you in performing a comprehensive sensitivity and scenario analysis for your simulation model. These analyses are critical for understanding the robustness of your model and how it responds to changes in input parameters. The guide includes definitions, systematic approaches, examples, and formatting guidelines to help you produce a professional report adhering to industry standards.

Please refer to Section 4 for common pitfalls to avoid during your analysis.

## 2 Definitions and Terms

### 2.1 Sensitivity Analysis

is a method to determine how the variation in the output of a model can be attributed to different variations in the inputs. It helps identify which input variables have the most influence on the output.

### 2.2 Scenario Analysis

is the process of evaluating possible future events by considering alternative plausible scenarios. It involves changing multiple inputs simultaneously to assess their impact on the model's outcomes.

\*See Appendix 12.4 for a glossary of statistical terms commonly used in analysis.\*

## 3 Systematic Approach

### 3.1 Sensitivity Analysis

**Definition:** Sensitivity Analysis assesses how sensitive the output of a model is to changes in input parameters. It identifies which inputs significantly affect the output and how.

### 3.1.1 Steps

#### Key Steps in Sensitivity Analysis

1. **Identify Key Input Parameters**  
List all input variables and select the most critical ones based on expected impact.
2. **Define Parameter Ranges**  
Use realistic variation ranges (e.g.,  $\pm 10\%$ ,  $\pm 20\%$ ) based on industry data.
3. **Choose Sensitivity Analysis Method**  
Decide whether to use local sensitivity analysis (one parameter at a time) or global sensitivity analysis (multiple parameters at once).
4. **Run Simulations**  
Execute systematic variations according to the chosen method and collect sufficient data for analysis.
5. **Analyze and Document Results**  
Use statistical tools (mean, variance, confidence intervals) and visualizations to interpret findings.

### 3.1.2 Specific Example

#### Example Calculation:

Assume your model output  $Y$  depends on input parameter  $X$ .

1. Original value of  $X = 100$ , resulting in  $Y = 200$ .
2. Increase  $X$  by 10%:  $X = 110$ , resulting in  $Y = 220$ .
3. Calculate sensitivity using elasticity:

$$\text{Sensitivity} = \left( \frac{\Delta Y / Y}{\Delta X / X} \right) = \left( \frac{(220 - 200) / 200}{(110 - 100) / 100} \right) = 1$$

## 3.2 Scenario Analysis

**Definition:** Scenario Analysis explores the effects of different hypothetical situations on model outcomes by altering multiple input variables simultaneously.

### 3.2.1 Steps

#### Key Steps in Scenario Analysis

1. **Define Scenarios**  
Develop at least three scenarios: baseline (current conditions), optimistic, and pessimistic.
2. **Justify Scenarios**  
Provide rationale for each scenario and link to real-world conditions.
3. **Set Parameter Values**  
Assign input values for each scenario to ensure realistic variations.
4. **Run Simulations**  
Execute the model under each scenario and record results.
5. **Analyze and Compare Results**  
Use comparative tables and graphs to highlight key differences between scenarios.

### 3.2.2 Concrete Example

#### Example Scenario Development:

- **Baseline Scenario:** Current market conditions with standard demand and supply levels. - **Optimistic Scenario:** Increase in demand by 15% due to market growth. - **Pessimistic Scenario:** Supply chain disruption causing a 20% decrease in supply.

For each scenario, adjust the input parameters accordingly and observe the impact on the model output.

## 4 Common Pitfalls and How to Avoid Them

### 4.1 Ignoring Correlations Between Parameters

- **Pitfall:** Treating parameters as independent when they are correlated.
- **Solution:** Identify and account for correlations using statistical techniques like correlation matrices and covariance analysis to avoid misleading results.

### 4.2 Insufficient Sample Size

- **Pitfall:** Drawing conclusions from too few simulation runs.
- **Solution:** Refer to Section 7 for sample size recommendations. Use at least 30 runs per scenario for statistical reliability.

### 4.3 Overcomplicating the Model

- **Pitfall:** Adding unnecessary complexity, making the model difficult to interpret and debug.
- **Solution:** Keep the model as simple as possible while capturing essential dynamics. Use modular design and incremental testing.

### 4.4 Poor Data Visualization

- **Pitfall:** Using unclear or cluttered graphs and tables that obscure key findings.
- **Solution:** Follow guidelines in Section 8. Use clear labeling, appropriate chart types, and avoid excessive detail that reduces interpretability.

### 4.5 Ignoring Parameter Sensitivity Ranges

- **Pitfall:** Assuming fixed input ranges without considering real-world variability.
- **Solution:** Conduct exploratory analysis to determine realistic parameter ranges and sensitivity thresholds before running full simulations.

### 4.6 Failing to Validate Model Assumptions

- **Pitfall:** Assuming the model structure or assumptions are correct without verification.
- **Solution:** Perform back-testing and compare results with historical or real-world data. Regularly review assumptions.

## 4.7 Misinterpreting Sensitivity Results

- **Pitfall:** Incorrectly attributing model sensitivity to certain parameters without thorough analysis.
- **Solution:** Use sensitivity indices and multiple sensitivity methods (e.g., Sobol, Tornado diagrams) to cross-validate findings.



## 5 Report Structure and Formatting

### 5.1 Formatting Guidelines

- Use single-column or double-column LaTeX via Overleaf.
- **Header:** Include the course name, milestone title, and your name.
- **Footer:** Page number aligned to the bottom right corner.
- **Title Page:**
  - Project title.
  - Your name and student ID.
  - Course information.
  - Submission date.
- **Table of Contents:** Automatically generated.
- **Sections:** Use clear and consistent headings.
- **Tables and Figures:**
  - Use the `tabular` environment for tables.
  - Place large tables on dedicated pages in landscape orientation using the `pdflscape` package.
  - All tables and figures should have captions and be referenced in the text.

### 5.2 Content Requirements

#### 1. Introduction

- Brief overview of the milestone objectives.
- Importance of sensitivity and scenario analyses.

#### 2. Definitions and Terms

- Clearly define all key terms.
- Provide context and relevance.

#### 3. Methodology

- **Sensitivity Analysis Approach:**
  - Selection of parameters.
  - Variation methods.
  - Simulation execution plan.
- **Scenario Analysis Approach:**
  - Description of scenarios.
  - Parameter settings.

- Justification for choices.

#### 4. Results

- **Sensitivity Analysis Results:**
  - Tables and graphs.
  - Interpretation of data.
- **Scenario Analysis Results:**
  - Comparative visuals.
  - Discussion of scenario impacts.

#### 5. Discussion

- Implications of findings.
- Insights into model behavior.
- Limitations and assumptions.

#### 6. Conclusion

- Summary of key takeaways.
- Recommendations for future work.

#### 7. References

- Cite all sources using a consistent citation style (IEEE recommended).

#### 8. Appendices

- Supplementary material (extended data, code snippets, etc.).
- Reference terms and definitions.

## 6 Examples of Good vs. Poor Analysis Presentations

### 6.1 Good Analysis Presentation

- Clear and concise explanations.
- Well-organized tables with keys and legends.
- Use of appropriate graphs (e.g., line graphs for trends, bar charts for comparisons).
- Interpretation of results linked back to the objectives.

### 6.2 Poor Analysis Presentation

- Overly complex or cluttered visuals.
- Lack of explanations or interpretations.
- Ignoring significant findings or anomalies.
- Mislabeling axes or omitting units.

## 7 Sample Size Recommendations

The reliability of your analysis depends on selecting an appropriate sample size. A well-chosen sample size ensures that your results are statistically significant and not artifacts of random variation.

### 7.1 General Guidelines

- **Deterministic Models:** A single run per parameter set may be sufficient if the system is non-random and predictable.
- **Simple Stochastic Models:** At least 30 runs per parameter set to achieve statistical significance, based on the Central Limit Theorem.
- **Complex Stochastic Models:** A minimum of 100 runs is recommended, with variance analysis to determine if additional runs are needed.
- **High Variability Systems:** Systems with extreme randomness may require 500+ runs to stabilize results.

### 7.2 Recommended Sample Sizes by Model Type

Table 1: Recommended Sample Sizes for Simulation Studies

Model Type	Suggested Runs
Deterministic Model	1-5
Simple Stochastic Model	30+
Complex Stochastic Model	100+
High Variability System	500+

### 7.3 Statistical Justification

**Why 30 Runs?** The Central Limit Theorem states that for a sufficiently large number of independent samples ( $n \geq 30$ ), the sample mean will approximate a normal distribution, even if the underlying population distribution is not normal. This helps ensure reliable simulation results.

**Assessing Sample Sufficiency:** Use statistical techniques such as:

- **Confidence Intervals:** Ensure the margin of error is acceptable.
- **Standard Error:** Check if additional runs significantly change the results.
- **Convergence Analysis:** Track simulation output over increasing runs to identify stability.

**Note:** Always validate whether additional runs are necessary by analyzing result variability and confidence intervals.

## 8 Guidelines for Data Visualization

Effective data visualization enhances comprehension and communication of your findings. Choosing the appropriate visualization method ensures clarity and prevents misinterpretation of results.

### 8.1 Choosing the Right Chart Type

- **Line Graphs:** Ideal for showing trends over time or how a parameter changes under different conditions.
- **Bar Charts:** Useful for comparing discrete categories, alternative scenarios, or parameter variations.
- **Scatter Plots:** Best suited for illustrating relationships or correlations between two variables.
- **Tornado Diagrams:** Highly effective for sensitivity analysis to highlight influential parameters.
- **Heatmaps:** Useful for visualizing parameter interactions and multi-dimensional relationships.

### 8.2 Design Principles for Effective Visualization

- **Simplicity:** Avoid unnecessary clutter, 3D effects, or excessive elements.
- **Consistency:** Use a uniform color scheme, font style, and legend positioning across figures.
- **Labeling:** Ensure all axes are labeled with units, and legends provide meaningful descriptions.
- **Titles and Captions:** Clearly describe what the visualization represents and include relevant context.
- **Scalability:** Use logarithmic scales if data spans multiple orders of magnitude.
- **Annotation:** Highlight key insights directly on the graph where necessary.

### 8.3 Example of a LaTeX-generated Visualization

For students using LaTeX to generate figures, the following example creates a simple line plot using PGFPLOTS:

```
\begin{figure}[h]
  \centering
  \begin{tikzpicture}
    \begin{axis}[
      title={Sensitivity Analysis Result},
      xlabel={Parameter Variation},
      ylabel={Output Response},
```

```
        grid=major]
        \addplot coordinates {(0,2) (1,3) (2,5) (3,7)};
    \end{axis}
\end{tikzpicture}
\caption{Example of a sensitivity analysis visualization.}
\label{fig:sensitivity_plot}
\end{figure}
```

**Note:** For detailed figures, consider exporting from Python (Matplotlib, Seaborn) or MATLAB and importing as an image.

## 9 Presenting Data with Tables and Graphs

Effective presentation of data is crucial in conveying your findings clearly. This section provides guidance on constructing tables and graphs, including the use of keys and legends.

### 9.1 Constructing Tables

#### 9.1.1 Key Components of a Table

- **Caption:** A brief title explaining what the table represents.
- **Columns and Rows:** Organized data with clear headings.
- **Units:** Indicate the units of measurement where applicable.
- **Footnotes:** Additional information or explanations.
- **Keys and Legends:** Symbols or color codes explained for clarity.

#### 9.1.2 Guidelines for Effective Tables

- Include only relevant data to avoid clutter.
- Use consistent formatting (e.g., decimal places, font sizes).
- Highlight significant values (e.g., boldface, italics).
- Ensure the table is self-explanatory without requiring excessive text.

### 9.2 Using Keys and Legends

Keys and legends are essential for explaining symbols, colors, or abbreviations used in your tables and graphs.

#### 9.2.1 Creating a Key

- Place the key adjacent to the table or graph.
- Use clear symbols or colors that are easily distinguishable.
- Provide a brief explanation for each symbol or color.

#### 9.2.2 Example of a Table with a Key

Table 2: Sensitivity Analysis Results for Parameter X

Parameter Variation (%)	Output A	Output B	Output C
-20%	15.2	30.5	45.7
-10%	16.8	31.2	47.1
0%	18.5	32.0	48.5
+10%	20.3	33.6	50.0
+20%	22.1	35.2	51.4

Key:

- **Red Cell:** Significant decrease compared to baseline.
- **Yellow Cell:** Moderate change from baseline.
- **Green Cell:** Significant increase compared to baseline.

### 9.2.3 Explanation

In the example above, colored cells highlight significant changes in outputs relative to the baseline scenario. The key explains what each color represents, allowing readers to quickly understand the impact of parameter variations.

## 9.3 Tailoring Tables to Your Simulation

**Note:** You may not need to include every part of your simulation data in the tables. Focus on the most critical results that support your analysis.

- Summarize large datasets by presenting averages, ranges, or significant figures.
- Exclude irrelevant or redundant data.
- Use appendices for extensive data tables if necessary.



## 10 Step-by-Step Checklist

### 10.1 Before You Begin

- Review initial simulation run document for reference.
- Ensure understanding of key concepts.

### 10.2 Sensitivity Analysis

- Identify key input parameters.
- Define realistic parameter ranges.
- Decide on analysis method (local vs. global).
- Run simulations varying parameters systematically.
- Collect output data.
- Analyze results using statistical methods.
- Document findings with tables and graphs.

### 10.3 Scenario Analysis

- Define baseline and alternative scenarios.
- Justify the choice of scenarios.
- Set parameter values for each scenario.
- Run simulations for each scenario.
- Collect and compare results.
- Analyze the implications of each scenario.

### 10.4 Report Writing

- Prepare the LaTeX document with proper formatting.
- Include all required sections.
- Insert tables and figures with appropriate captions.
- Write clear and concise explanations.
- Use technical language and industry standards.
- Proofread the document for clarity and correctness.

## 10.5 Final Steps

- Generate the table of contents.
- Ensure all references are correctly cited.
- Review the report against the requirements list.
- Submit the report in the required format.

## 11 Conclusion

Conducting thorough sensitivity and scenario analyses is crucial for understanding the robustness and reliability of your simulation model. By systematically varying input parameters and evaluating different scenarios, you gain valuable insights into the model's behavior and potential real-world applications. This milestone not only enhances your analytical skills but also prepares you for industry practices in modeling and simulation.

### Final Reminders:

- **Technical Language:** Use appropriate terminology throughout your report. Refer to course materials and textbooks for technical wording and structuring.
- **Clarity and Precision:** Be concise but thorough in explanations.
- **Sequential Steps:** Present information logically in a structured, step-by-step manner.
- **Focus on Relevance:** Include only the most pertinent data in tables and analyses.

By following these guidelines, you will produce a comprehensive and professional report that meets course expectations and prepares you for real-world applications in modeling and simulation.

## Formatting Notes

- Use the `fancyhdr` package to customize headers and footers.
- Include the `pdflscape` package in your preamble for landscape pages.
- Employ the `\tableofcontents` command to generate the table of contents.
- For tables in landscape orientation, use `\begin{landscape}` and `\end{landscape}`.
- Use the `caption` package to customize captions, include keys, and legends.
- Ensure all sections and subsections are properly numbered and labeled.
- Maintain consistent formatting for fonts, figure captions, and section titles.
- Reference all tables and figures using the `\ref` command for cross-referencing.

## 12 Appendices

### 12.1 Appendix A: Reference Terms

- **Ceteris Paribus:** Latin for "all other things being equal."
- **Robustness:** The ability of a model to remain effective under different conditions.
- **Tornado Diagram:** A bar chart that represents the sensitivity of an output variable to changes in each input variable.
- **Spider Plot:** A line graph that shows the effect of varying each input parameter on the output.

### 12.2 Appendix B: Types of Distributions

- **Normal Distribution:** Symmetrical, bell-shaped distribution.
- **Uniform Distribution:** All outcomes are equally likely within a range.
- **Exponential Distribution:** Describes time between events in a Poisson process.
- **Poisson Distribution:** Probability of a given number of events occurring in a fixed interval.

### 12.3 Appendix C: Stochastic and Random Numbers

- **Stochastic Processes:** Processes that are probabilistic in nature.
- **Random Number Generators (RNGs):** Algorithms or devices used to produce sequences of numbers that lack patterns.
- **Seed Value:** An initial value that determines the sequence of numbers generated by an RNG.

### 12.4 Appendix D: Glossary of Statistical Terms

- **Mean:** The average value of a dataset.
- **Variance:** A measure of how much values in a dataset differ from the mean.
- **Standard Deviation:** The square root of the variance, indicating data dispersion.
- **Confidence Interval:** A range of values within which a population parameter is estimated to lie.
- **Elasticity:** A measure of the responsiveness of one variable to changes in another variable.

## Submission Guidelines

- **Deadline:** Refer to D2L for official submission dates and guidelines.
- **Submission Format:** Upload a well-formatted PDF report using LaTeX.
- **Collaboration Policy:** Individual effort required; conceptual discussions are encouraged.
- **AI Tool Usage:** Any AI-assisted content must be explicitly cited as per course policy.