A New Approach to Risk Assessment

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Introduction
Outline

- Uncertainty and risk
  - Objective risk
  - Subjective risk
- A new methodology
  - Fuzzy set approach
- Examples
  - Water supply risk
  - Flood disaster risk
- Conclusions
Uncertainty

- **Current context**
  - The dangers are more difficult to understand
  - Technical, social, economic and environmental systems are becoming increasingly complex
  - Information is shared much more rapidly

- **Consequences**
  - Larger damage
  - Instead of gradual and local damage much more widespread loss accumulation
  - Need for more active dialogue among stakeholders
Uncertainty

- Uncertainty – lack of certainty
- Implication is risk
  - Significant potential unwelcome effects of system performance
  - Knowledge of potential losses
- Risk reduction
  - Understanding the nature of the underlying threats in order to identify, assess and manage the risk
  - Understanding the value systems that define the risk perception
Uncertainty taxonomy
Risk dilemma

- Three fundamental types of risk
  - Objective – the property of real physical systems
  - Subjective – the degree of belief in a statement (not the property of real system)
  - Perceived – an individual’s feeling of fear in the face of an undesirable possible event

- This is perhaps the most important misconception that blocks the way toward more effective societal risk management

- The ways society manages risks appear to be dominated by considerations of perceived and subjective risks, while it is objective risks that kill people, damage the environment and create property loss.
Research context

The main objective is development of the possible methodology for the reliability analysis of water resources systems that will be capable of:

- (a) addressing water resources uncertainty caused by variability and ambiguity;
- (b) integrating objective and subjective risk; and
- (c) assisting the water resources management based on better understanding of temporal and spatial variability of risk.
Changing paradigm

**Ordinary set**
(Probability Theory)

\[ \mu_A(x) = \begin{cases} 
1, & \text{if } x \in A \\
0, & \text{if } x \notin A 
\end{cases} \]

**Fuzzy set**
(Fuzzy Set Theory)

\[ \mu_A : X \rightarrow [0,1] \]
System performance indices

\[ P_S = P(\hat{X} > \hat{Y}) \]  
probability of satisfactory performance

\[ P_F = P(\hat{X} < \hat{Y}) \]  
probability of failure

\[ \hat{M} = \hat{X} - \hat{Y} \]  
margin of safety

\[ \hat{\Theta} = \frac{\hat{X}}{\hat{Y}} \]  
factor of safety
Fuzzy sets

A fuzzy set is one which assigns grades of membership *between 0 and 1* to objects within its universe of discourse. If \( X \) is a universal set whose elements are \( \{x\} \), then, a fuzzy set \( A \) is defined by, its membership function,

\[
\mu_A : X \rightarrow [0,1]
\]

which assigns to every \( x \) a degree of membership in the interval \([0,1]\).

\[
A = \{(x,\mu_A(x))\}, \quad x \in X
\]
New definition of failure

System State

- Region of Complete Safety: $M = 0.0$ or $\theta = 1.0$
- Region of Complete Failure: $M < 0.0$ or $\theta < 1.0$
- Region of Partial Failure

Time
Fuzzy risk analysis

- Complete Failure Region
- Partial Failure Region
- Complete Safety Region

Universe of discourse

Acceptable Level of Performance

System-state

Membership value

$\chi_1$ $\chi_2$
Fuzzy risk analysis

System state

\[
\tilde{S}(D) = \begin{cases} 
0 & \text{if } D \leq D_{\text{Min}} \\
\frac{D - D_{\text{Min}}}{D_{\text{Mean}} - D_{\text{Min}}} & \text{if } D \in [D_{\text{Min}}, D_{\text{Mean}}] \\
\frac{D_{\text{Max}} - D}{D_{\text{Max}} - D_{\text{Mean}}} & \text{if } D \in [D_{\text{Mean}}, D_{\text{Max}}] \\
0 & \text{if } D \geq D_{\text{Max}} 
\end{cases}
\]

Acceptable level of performance

\[
\tilde{M}(D) = \begin{cases} 
1 & \text{if } D \leq D_1 \\
\theta(D) & \text{if } D \in [D_1, D_2] \\
0 & \text{if } D \geq D_2 
\end{cases}
\]
Fuzzy risk analysis

The compatibility measure

\[ CM_{S,L} = \frac{WOA_{S,L}}{WA_S} \]

- provides information about system reliability and vulnerability
- measure of proximity (overlap)
Fuzzy risk analysis

Reliability Index = \frac{\max_{i \in K} \{CM_1, CM_2, \ldots, CM_i\} \times LR_{\max}}{\max_{i \in K} \{LR_1, LR_2, \ldots, LR_i\}}

Robustness Index = \frac{1}{CM_1 - CM_2}

Resilience Index = \left[ \int_{t_1}^{t_2} t \tilde{T}(t) \, dt \right]^{-1}

\int_{t_1}^{t_2} \tilde{T}(t) \, dt
Implementation example 1

Friday Forum

Simonovic

Sep 21, 2007
London region water supply
# Friday Forum

## London region water supply

![Excel spreadsheet](image.png)

### Table: Water Supply System

<table>
<thead>
<tr>
<th>System</th>
<th>Units</th>
<th>Capacity</th>
<th>Requirement</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average Daily Flow</td>
<td>Design Capacity</td>
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<tr>
<td>Intake Crib</td>
<td>MLD</td>
<td>157.3</td>
<td>340.0</td>
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<tr>
<td>Clarifiers</td>
<td>mg/L</td>
<td>200.0</td>
<td>00.0</td>
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<tr>
<td>Low Lift System</td>
<td>MLD</td>
<td>157.3</td>
<td>340.0</td>
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<tr>
<td>Intake System</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Peaking Wells</td>
<td>MLD</td>
<td>157.3</td>
<td>340.0</td>
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<tr>
<td>Chlorinator II</td>
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<td>630.0</td>
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<td>Single Speed Pump</td>
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<tr>
<td>Variable Speed Pump</td>
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<td>66.2</td>
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<td>Single Speed Pump 2</td>
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<td>49.9</td>
<td>75.0</td>
</tr>
<tr>
<td>Single Speed Pump 1 (Back-up)</td>
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<td>75.0</td>
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<td>Variable Speed Pump (Back-up)</td>
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<td>Single Speed Pump 2 (Back-up)</td>
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</tr>
</tbody>
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![Graph showing membership values for different levels of margin of safety.](image)
London region water supply

![Graph showing the margin of safety for different levels of reliability and system state.](image)

- **Reliable level (level 1)**
- **Neutral level (level 2)**
- **Unreliable level (level 3)**
- **System-State (Triangular)**
- **System-State (Trapezoidal)**
## London region water supply

<table>
<thead>
<tr>
<th>Fuzzy Performance Index</th>
<th>LHPWSS</th>
<th>EAPWSS</th>
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<tr>
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<td>Triangular</td>
<td>Trapezoidal</td>
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<tr>
<td>Combined Reliability-Vulnerability</td>
<td>0.699</td>
<td>0.642</td>
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<tr>
<td>Robustness (level 2 – level 1)</td>
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<td>NA</td>
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<td>-2.473</td>
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<td>Robustness (level 3 – level 2)</td>
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<tr>
<td>Resiliency</td>
<td>0.017</td>
<td>0.017</td>
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</table>

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<tr>
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<th>Trapezoidal</th>
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<th>Trapezoidal</th>
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</thead>
<tbody>
<tr>
<td>Combined Reliability-Vulnerability</td>
<td>0.042</td>
<td>0.017</td>
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<tr>
<td>Robustness (level 2 – level 1)</td>
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<tr>
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<td>NA</td>
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<td>Robustness (level 3 – level 2)</td>
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<td>Resiliency</td>
<td>0.054</td>
<td>0.054</td>
<td></td>
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</tr>
</tbody>
</table>

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Implementation example 2

- Extension of fuzzy risk analysis to spatial problems
- Integration of GIS and fuzzy risk analysis
- Medway Creek Flooding– North London
Medway Creek flooding case study

Damage one story building

Modified curve
Medway Creek flooding case study
Instead of conclusions

- One possible methodology for risk analysis capable of:
  - addressing uncertainty caused by variability and ambiguity;
  - integrating objective and subjective risk; and
  - assisting in risk management based on better understanding of temporal and spatial variability of risk.
Instead of conclusions

- Fuzzy risk analysis provides for addressing uncertainty caused by variability and ambiguity.
- Risk is described using a combined fuzzy reliability and vulnerability, fuzzy robustness and fuzzy resiliency.
- Fuzzy risk analysis has been successfully extended into a spatial fuzzy risk analysis.
Research

- Over 10 years (postdoctoral fellows, PhD and MSc candidates)
- Support:
  - National Sciences and Engineering Research Council (NSERC)
  - Public Safety and Emergency Preparedness Canada (PSEP)
  - ICLR
- Resource:
  www.slobodansimonovic.com