Utilization of Multi-Criteria Influence Diagrams in Simulation Metamodelling

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Introduction of Multiple Criteria Decision Making (MCDM) perspective to simulation metamodeling

Complex system dynamics
- Very large discrete event simulation model
- Monte Carlo analysis
- Interactive use inefficient and laborous

Simulation inputs

Simulation outputs for the DM

Metamodel
- Constructed based on a large sample of simulation computations
- Simplified auxiliary input-output mapping

Easy
Simulation metamodelling with MCDM

Complex system dynamics
- Discrete event simulation model
- Uncertainty

Objectives
- Multiple criteria
- Uncertainty

Metamodal

Multi-Criteria Influence Diagram

Metamodal allows easier analysis of the complex decision problem
Increasing complexity of models increases the need for metamodeling

- Metamodel helps
  - Sensitivity and what-if analysis
  - Optimization of a simulation output
  - Model validation

- Several existing approaches, seminal book by Friedman 1996
  - Regression models, neural networks, splines, kriging models, games, dynamic Bayesian networks, ...

New features allowed by multi-criteria influence diagrams

- Inclusion of preferences of the decision maker (DM)
- Solving efficient decision alternatives
- Selection of the most preferred decision alternative
- Sensitivity with respect to preferences
Multi-Criteria Influence Diagram (MCID)

Influence diagram (Howard and Matheson, 1984)
  Modeling decision problems under uncertainty

Nodes:
  Decision $D$, chance $X$, and utility $U$

Utility node: DM’s utility function
  Preferences
  Scores on the objectives

MCID (Diehl and Haimes, 2004)
  Modeling multi-criteria decision problems under uncertainty
  Multiple utility nodes $U_i$
MCID in simulation metamodeling

Simulation inputs described by:
- Decision or chance nodes

Simulation state described by:
- Chance nodes

Simulation outputs described by:
- Chance nodes

Objectives and preferences of DM:
- Utility nodes and functions

Estimation of structure and probabilities?
- From raw simulation data
- Expert knowledge
- Available software: GeNle (free), Hugin, ...

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Systems
Analysis Laboratory
Use of MCID in metamodeling

• Generation of efficient decision alternatives
  – Probability distributions of utilities for each decision alternative
  – E.g. expected utilities of decision alternatives
  – Identification of the most preferred solution

• Time evolution of probability distributions in simulation

• What-if analysis – the impact of evidence
  – Probability distributions of chance nodes for fixed values (evidence) of other nodes
  – Efficient decision alternatives for fixed values (evidence) of other nodes

• Sensitivity analysis
  – Effect of the changes in the probability distributions on the set of efficient decision alternatives
Air combat example

- **Blue DM decides on**
  - Target to defend (blue target)
    - Target A or target B
  - Air combat tactics (blue tactics)
    - Tactic 1 or tactic 2

- **Uncertain strategy of Red DM**
  - Target to attack (red target)
    - Target A or target B
  - Air combat tactics (red tactics)
    - Tactic 1 or tactic 2

- **Bad situation for blue if decides to defend wrong target**

  ![Diagram showing decision paths for blue and red targets and tactics](image)
Generation of data by stochastic simulation

Multiple simulation runs

Simulation input
- Blue tactics
- Blue target
- Red tactics
- Red target

Simulation output
- Number of blue aircraft killed
- Number of red aircraft killed
- Target A survives?
- Target B survives?

Aircraft, weapons, and hardware models

Decision making logic
Introducing objectives to the MCID

Simulation inputs

Simulation outputs

Objectives of DM

• Maximize probability that target A survives (Tgt. A)
• Maximize probability that target B survives (Tgt. B)
• Maximize kills-losses (Kill diff.)
Simulation inputs in the MCID: decisions

Blue target

| Target A | Target B |

Decision nodes contain DM’s decision alternatives

Blue target → Blue tactic → Red target → Red tactic

Target A survives → Tgt. A
Target B survives → Tgt. B
Num. red killed → Num. blue killed
Kill diff.
Simulation inputs in the MCID: chance nodes

Red target

<table>
<thead>
<tr>
<th></th>
<th>Target A</th>
<th>Target B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>0.7</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Red tactic

<table>
<thead>
<tr>
<th>Red tactic</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactic 1</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Tactic 2</td>
<td>0.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Uncertain strategy of red DM represented by probability distributions
Simulation outputs in the MCID

Simulation output probability distributions estimated from generated data.
Utility functions in the MCID

Utilities of outcomes elicited from DM

<table>
<thead>
<tr>
<th>Num. blue killed</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Num. red killed</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>…</td>
</tr>
<tr>
<td>Utility</td>
<td>0.500</td>
<td>0.625</td>
<td>0.750</td>
<td>0.875</td>
<td>1.000</td>
<td>…</td>
</tr>
</tbody>
</table>

Utilities of outcomes elicited from DM

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Efficient decision alternatives

Efficient decision alternatives marked with x
What-if analysis: red uses tactic 1

No evidence

Evidence

Probability of red attacking target A decreases from 0.7 to 0.37
Sensitivity analysis: probability of red attacking target A decreases from 0.7 to 0.3
Conclusion: Simulation metamodeling benefits from new tools - MCDM and MCID

- MCDM provides
  - DM’s preferences with respect to multiple criteria
- MCID provides
  - New analysis capabilities
  - Flexible and transparent modeling
- Efficient calculation: Easy-to-use software available
- Our case: Simulation analysis of air combat
- Future work
  - Dynamic decision making
  - Multiple DMs
  - Input modeling – the impact of correlated inputs
References