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Design Optimization under Long-Range Uncertainty

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Design Optimization under Long-Range Uncertainty

Abstract
Flexibility in engineering system design: •Flexibility in system design and implications for aerospace systems (Saleh et.al 2003) •A flexible and robust approach for preliminary engineering design based on designer’s preference (Nahmet.al, 2007) •A real options approach to hybrid electric vehicle architecture design for flexibility (Kang et.al 2016) •Our research: •Simulation optimization •Long range uncertainty •Add flexibility and robustness to design

Disciplines
Industrial Engineering | Manufacturing | Mechanical Engineering | Other Operations Research, Systems Engineering and Industrial Engineering

Comments
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Design Optimization under Long-Range Uncertainty

Ramin Giahi, Cameron MacKenzie, Chao Hu

Industrial and Manufacturing Systems Engineering, Iowa State University
Engineering System Design

Global Positioning Systems

Airplane Control Room

Naval Vessel
Previous Works

- Flexibility in engineering system design:
  - Flexibility in system design and implications for aerospace systems (Saleh et.al 2003)
  - A flexible and robust approach for preliminary engineering design based on designer's preference (Nahm et.al, 2007)
  - A real options approach to hybrid electric vehicle architecture design for flexibility (Kang et.al 2016)

- Our research:
  - Simulation optimization
  - Long range uncertainty
  - Add flexibility and robustness to design
Research Framework

- Simulation
  - Black box simulation

- Optimization

- Identify key and long-range uncertainty (forecast and simulate future condition)

- Optimization with long-range uncertainty
  - Find optimal design at time zero and fix the design.
    - Design w/o flexibility

- Analysis of solution
- Complexity of the model
- Value of information

Real world application
Application: Hybrid Renewable Energy System
Application: Hybrid Renewable Energy System

- Design of hybrid renewable energy system

- Hybrid renewable system includes: PV panels, wind turbine, battery storage, electrolyzer, and fuel cell

- Design variables: capacity of the components of the system

- Identify the optimal capacity of each component to minimize the expected cost
Research Framework

Simulation
- Black box simulation

Optimization

Optimization with long-range uncertainty

Identify key and long-range uncertainty (forecast and simulate future condition)

Find optimal design at time zero and fix the design.

Design w/o flexibility

Analysis of solution
Complexity of the model
Value of information

Real world application
Simulation of Energy Demand for California, 2018-2037

Historical demand
Research Framework

Simulation Optimization

Identify key and long-range uncertainty (forecast and simulate future condition)

Optimization with long-range uncertainty

Find optimal design at time zero and fix the design.

Design w/o flexibility

Analysis of solution

Complexity of the model

Value of information

Real world application

Black box simulation

Simulation Optimization

Optimization

Design w/o flexibility

IOWA STATE UNIVERSITY Industrial and Manufacturing Systems Engineering
Mathematical Model

- Goal: Find the optimal design of hybrid renewable energy system
- Minimize expected costs
  - Investment
  - Replacement
  - Maintenance
- Decision variables: Capacity of solar, wind, battery, fuel cells, electrolyzer, and hydrogen tank
- Any energy not provided by renewable sources is provided by diesel
Simulation Optimization

Uncertainty

Demand, cost parameters, lifetime of the components, wind and solar data

Decision Variable

Capacity of the components of the system

Monte Carlo Simulation

Bayesian Optimization

Output

Cost
Research Framework

Simulation → Optimization

Black box simulation

Identify key and long-range uncertainty (forecast and simulate future condition)

Optimization with long-range uncertainty

Find optimal design at time zero and fix the design.

Design w/o flexibility

Simulation Optimization

Real world application

Analysis of solution

Complexity of the model

Value of information
## Optimal Solution

<table>
<thead>
<tr>
<th>Components</th>
<th>Capacity (million kwh)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar plant</td>
<td>0.22</td>
<td>62.5</td>
</tr>
<tr>
<td>Wind plant</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Battery</td>
<td>0.06</td>
<td>25.5</td>
</tr>
<tr>
<td>Electrolyzer</td>
<td>1.03</td>
<td>-</td>
</tr>
<tr>
<td>Hydrogen tank</td>
<td>3.2</td>
<td>-</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>0.17</td>
<td>5</td>
</tr>
<tr>
<td>Diesel</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Expected cost</td>
<td>$22.7 billion</td>
<td>-</td>
</tr>
</tbody>
</table>
Research Framework

Simulation
- Black box simulation

Optimization with long-range uncertainty

Identify key and long-range uncertainty (forecast and simulate future condition)

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Design w/o flexibility

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Real world application
Demand Fulfillment Analysis

![Graph showing total monthly demand over time]

- **Demand**
- **PV and Wind**
- **PV, Wind, and Battery**
- **Fuel Cell**
- **Diesel**

The graph illustrates the total monthly demand in million kwh from month 0 to 250.
Research Framework

Simulation

Optimization

Black box simulation

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Optimization with long-range uncertainty

Find optimal design at time zero and fix the design.

Simulation Optimization

Real world application

Design w/o flexibility

Value of information

Complexity of the model

Analysis of solution

Iowa State University Industrial and Manufacturing Systems Engineering
Parallel Coordinate Plot for Hybrid Renewable Design

* Capacities are in million kwh
Research Framework

Simulation → Optimization

- Black box simulation

Optimization with long-range uncertainty

- Identify key and long-range uncertainty (forecast and simulate future condition)

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Design w/o flexibility

Analysis of solution

Complexity of the model

Value of information

Real world application
Value of Information

How much should the decision maker pay to know whether demand will be high, medium, or low?

Value of Information

\[ \text{EV w/information} - \text{EV w/out information} = \$4 \text{ billion} \]
Conclusions

• Future work
  • Flexibility and robustness with design optimization
  • Valuate options with Monte Carlo simulation
• Design under long-range uncertainty
  • Hybrid renewable energy system
  • Monte Carlo simulation of uncertainties (e.g., demand)
• Optimize design
• Value of information
• Funding through the NSF-funded Center for e-design

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Reference


