Transmission Investment Assessment Under Uncertainty

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CERTS Program Review 2015; Thanks to CERTS, WECC, NARUC, NSF for support
1. What is the impact of model simplifications?  
   (a) Uncertainty, (b) Generator flexibility constraints,  
      (c) KVL?

2. Should we build the Champlain-Hudson line now?  
   Or wait 10 years (or more)?

3. How does including physical line options change the  
   optimal mix of transmission?

4. Do plans based on a few extreme (“stratified”) scenarios  
   perform as well as (or better than!) full stochastic  
   programming?

5. Would co-optimization lead to different transmission  
   plans for the 2011 EIPC project?
Method: JHSMINE
(Johns Hopkins Stochastic Multi-stage Integrated Network Expansion)

**Stage 2014:** “Today’s Choices”

Choose Yr 10 investments in:
- Transmission
- Generation

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**Stage 2024:** “Tomorrow’s Choices”

Choose Yr 20 investments in trans / gen
- Operations

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Choose Yr 20 investments in trans / gen
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**Uncertainty (Multiple Scenarios):**
- $ Fuels
- Load growth
- Technology
- Policies

**Deterministic Approach:**
*One model for each scenario*

**JHSMINE:** Solve all cases at once in one model
Optimize the **objective:**
Minimize (probability-weighted, present worth) of cost over 40 yrs

**By choosing values of decision variables:**

- Transmission investment (0-1)
  - 10 yr “portal” (optional) lines (in addition to Common Case lines)
  - 20 yr lines
- Gen investment & dispatch (*co-optimized*)

**Respecting constraints:**

- Kirchhoff’s laws (linear OPF)
  - Load by hour
- Generator operating constraints
  - Variable renewable availability by hour
- RPS
- Siting restrictions

**Accounting for uncertainties:**

- load/renewable conditions (hourly variability)
- **IN STOCHASTIC MODEL:** long-run study cases
Mathematical structure
(van der Weijde & Hobbs, 2012; Munoz et al. 2014)

\[
\begin{align*}
\text{MIN} & \quad C_1 X_1 & + & \sum_{\text{scenarios } S} P_S \ast C_2 X_{2,S} \\
A_{1,1} & \quad X_1 & + & \{A_{2,1,S} X_1 \} \leq B_1 \\
\{A_{2,2,S} X_1 \} \leq B_{2,S} \}, \ \forall S
\end{align*}
\]
Two versions of JHSMINE-WECC

21 TEPPC Zone “Pipes-&-Bubbles”

300 bus network: Both Linearized DC OPF & “Pipes-&-Bubbles” versions
(Thanks Yujia Zhu & Dan Tylavsky!)
1(a) Do solutions change if we ignore:

- Uncertainty?
  - Deterministic vs. stochastic
  - Effect of # of scenarios
  - Effect of probability of scenarios

- YES
- NOT MUCH
- LITTLE
Alternative Study Case/Scenario Sets: 1, 5, and 20

Deterministic

Base Case

Stochastic (5)

Base Case

Study Case 1: Econ Recovery
Study Case 2: Clean Energy
Study Case 3: Short-term Consumer Costs
Study Case 4: Long-term Societal Costs

Stochastic (20)

Base Case

2013 Study Cases (4)

Technical Advisory Cases (9)

“Gap” Scenarios (6)

Three groups of uncertain parameters (24 parameters):

- P-Carbon, P-Gas, Energy growth
- RPS, Renewable capital cost
- Peak growth, storage
Example: Optimal “Portal” 10 yr Transmission (21 Zone model)

Optimal under just **Base Case** (100% probability)

*Heuristically* combine deterministic results:
Optimal in ≥3 of 5 2013 Study Case models

**Stochastic Optimum** under 5 (and also 20) study cases (equal chance of each scenario)

Stochastic line not chosen in any single scenario model!

- Expected PW cost under 20% chance of each of 5 study cases:
  - $681.4B
  - $680.3B
  - $678.5B (optimal)
Compare Yr 10 Lines Under Alternative Scenario Sets (300 bus case)

Optimal under **Base Case**

Optimal under **5 Scenarios (20% Probability Each)**

Optimal under **20 Scenario Case (5% Probability each)**

Expected suboptimality cost penalty under 5% chance of each of 20 scenarios:
- **$14.2B**
- **$1.8B**
- **$0B Optimal**
Compare 1st Stage Lines Under Alternative Probabilities of 20 Scenarios (300 bus network)

**Differentiated** Probabilities for 20 Scenarios

**Equal** Probabilities

20 Case Stochastic Adjusted Probability

20 Case Stochastic Equal Probability
1(b) Do solutions change if we ignore unit commitment constraints on generator flexibility? *In some cases*
What if we include Generating Unit Commitment constraints?

• What is impact of more accurate production costing upon 1\textsuperscript{st} and 2\textsuperscript{nd} stage transmission?

  \textit{Simple “load duration curve” method (assumes infinite flexibility) versus Unit commitment (UC) approximation (captures flexibility limits)}

• Simplified “relaxed” UC preserves computational efficiency of linear program \cite{KasinaWogrinHobbs2014}:
  – Approximates start-up costs, Pmin constraints
  – Imposes ramp constraints
  – 72 hours (3 days) x 5 scenarios x 2 stages x 21 zones
Sample 24 hr energy profile from Colo.: *Without UC operational constraints (2035, Econ Recovery Scenario)*
Example gen profile (CO) with UC operational constraints

**Periods when ramp rate or \( P_{\text{min}} \) constraints bind**
No change in 2025; 2035 Transmission change with UC constraints (Econ Recovery Scenario)
1(c) Do solutions change if we ignore KVL? YES
21 vs 300 bus network: Recommended regional interconnections

5 Study Case 21 Zone

5 Study Case 300 Bus
Compare 300 bus network: “Pipes & bubbles” vs. KVL

86% of P&B investment also made in KVL

49% of KVL investment also made in P&B
Should we build the CHPE now?  **No**

Or should we wait 10 yrs, and see what happens to Indian Point, $P_{\text{gas}}, P_{\text{CO}_2}$?  **Yes**

Biao Mao, Dan Shawhan, William Schulze, Ray Zimmerman
*Cornell University*

Saamrat Kasina, Ben Hobbs
*Johns Hopkins University*
Real Options Analysis

Assumptions

1. Transmission is longest lived & most irreversible investment. We decide whether to build it now, wait 10 years to build (depending on what is learned), or never build.

2. Gen investment & operations “follows” transmission. We anticipate how the CHP line affects both.

3. Gas & Carbon prices, and Indian Point Retirement decisions are uncertain.
Decision Node:
Build CHP

Decision Node:
Build, dispatch Gen

Social net benefits of path (decisions/scenarios) from E4ST
Socially Optimal 2\textsuperscript{nd} Stage (2035) CHP Decisions, Conditioned on 2025 Uncertain Outcomes

*(Tentative results, not for citation)*

### If line costs $0B:

<table>
<thead>
<tr>
<th>Chance Node</th>
<th>Indian Point and Gas Price Outcomes</th>
<th>IP Open</th>
<th>IP Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>LP_{co2}</td>
<td>L P_{gas}</td>
<td>L P_{gas}</td>
</tr>
<tr>
<td>Price</td>
<td>MP_{co2}</td>
<td>H P_{gas}</td>
<td>H P_{gas}</td>
</tr>
<tr>
<td>Outcomes</td>
<td>HP_{co2}</td>
<td></td>
<td></td>
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### If line costs $1.5B:

<table>
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<th>IP Closed</th>
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**Optimal Policy for $1.5B line**

- Wait for now
- Then build for 2035:
  - IF gas prices go up, OR
  - IF \{IP open \& CO2 price high\}

### If line costs $3B:

<table>
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</table>
Does including physical options change the optimal mix of transmission lines? **YES**
Includes “Flexible Expand” option of 2-circuit towers but only install conductors for single circuit  
  • *Gives option of cheap 2\textsuperscript{nd} circuit addition later*

Optimized using 5-stage optimization (MILP)  
  • \(~1M\) variables for California
Preliminary Results (Not to be cited)

T=0 Decisions

- Permit Nonflexible (2/2)
- Permit Flexible (1/2)

T=5 Decisions

High Demand

- Defer (2/2)
- Build now (2/2)

Low Demand

- Build now (1/2)
- Defer
4. Clever Selection of Scenarios

Do plans based on a few extreme ("stratified") scenarios perform as well as full stochastic programming? Almost
Or even better (in terms of min-max regret)? Yes

Sang Woo Park and Pearl Donohoo
Actual Performance (against 20 Scenarios) of First Stage Transmission & Generation Plans

Expected Cost Against 20 Scenarios

- Three stratified scenarios (e.g., “HHH”, “MMM”, “LLL”) do consistently well!
Stratified (3 Scenario) Plans Do Better than Stochastic (20 Scenario) in “Min Max Regret”

Next: More cases to establish robustness of (& reasons for) stratified solution performance
Would co-optimization lead to different transmission plans & costs for the 2011 EIPC project (under the high carbon future)?

YES

Evangelia Spyrou & Jonathan Ho
Strategic transmission planning for the Eastern Interconnection:
- Planning horizon: 2011-2030
- High carbon tax scenario: $27/t (2015) → $140/t (2030)
- Declining load

Eastern Interconnection:
- 24-node transportation network
- 47 interfaces

Mixed-Integer LP:
- Lumpy investments
- Linear dispatch meeting a 20-block load duration curve

Compare 3 Approaches to Coordinating Gen and Trans

Traditional Planning

- Generation Planning
  - Generation Siting/Mix Scenario
- Transmission Planning
  - Transmission Plan

Iterative Cooptimization

- Optimize Generation
  - Generation Scenario
- Optimize Trans
  - Transmission Expansion
- Optimize Generation
  - Generation Scenario
- Optimize Trans
  - Transmission Expansion

Simultaneous Cooptimization = Proactive Planning

- Optimize Generation & Transmission Investment Together
  - Transmission Plan & Consistent Generation Siting/Mix

Simulates “proactive planning” (Sauma & Oren)

Etc.
Eastern Interconnection results

- **Anticipative/Proactive planning saves:**
  - ~56 $bn compared to EIPC approach
  - ~13 $bn compared to iterative approach

- **Savings achieved by investment in more & higher quality wind:**
  - Avoided fuel and carbon tax costs
  - But increased capital costs
Eastern Interconnection results

EIPC heuristics mainly identified expansions of direct links, while co-optimization identified indirect links.
Conclusions

➢ Stochastic plans are different & likely better
  • Distinct lines not picked by deterministic models
  • $3B-$14B is value of better near-term decisions in WECC – even under scenarios not considered!
  • “Robust planning” (pick lines that look good under most deterministic runs) falls short

➢ Stochastic planning is practical
  • Get most of benefits by including just a few scenarios

➢ Other approximations as important as assuming certainty
  • Failing to co-optimize
  • Network aggregation (21 vs 300)

➢ Next:
  • Economic cost of simplifications
  • Detailed regional study for BPA
  • Complete CHP analysis & line option analyses