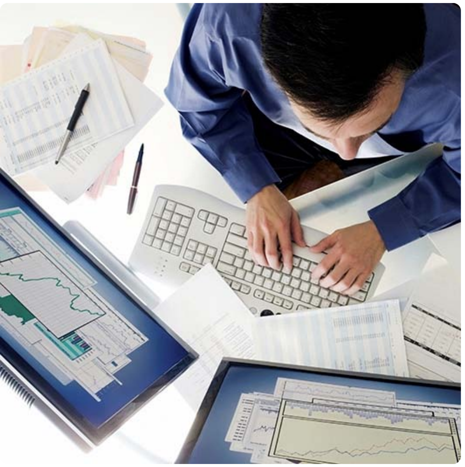
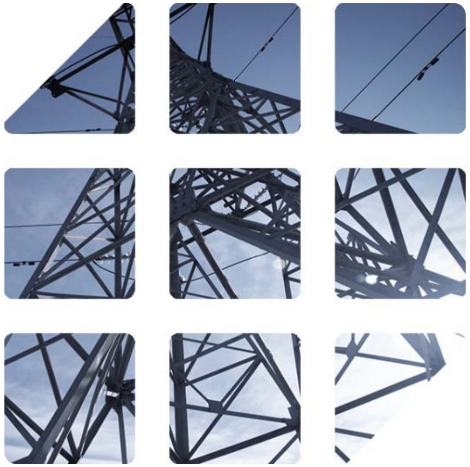
Production Cost / Resource Optimization Modeling and DSM Modeling Issues

2013 Indiana IRP Contemporary Issues Technical Conference






Outline

- Production Cost Modeling
  - What is a model?
  - Detail vs. Runtime
  - Production Cost Methods & Examples
- Resource Optimization Methods
  - Dynamic Programming
  - Linear Programming (LP) Solutions
  - Mixed Integer Programming Solutions (MIPS)
- DSM Modeling
  - Costs
  - Impacts
  - Hourly Shapes

What is a Model?

- All production cost models are mathematical models that simulate the fundamental elements of a power system.
- You cannot model with perfect precision and accuracy
  - The only 100% accurate model is called: “The Real World”
  - But it’s a very poor predictive model!
- Need to make simplifying assumptions:
  - Tradeoffs must be made!
    - Runtime vs. accuracy
    - Level of detail required
      - Outputs
      - Inputs
    - Availability of reliable data
    - The answers to the tradeoff questions vary depending on the use of the model
  - Almost all the inputs are forecasted information

What is a Model?

- Forecasts:
  - Forecasting is the process of making statements about future events whose actual outcomes can not be observed (yet).
  - Forecast accuracy is always a concern and key forecast variables should be bounded with statistically relevant sensitivities.
  - Forecasts are time dependent
    - Actual market conditions change and forecasts should be updated to reflect those changes.
- Since almost everything input into the model is a forecast…
  - Accept that forecast accuracy is a concern
  - Compensate for expected forecast error with scenarios, sensitivities, and stochastics
- Modeling is partly art and partly science

Detail vs. Runtime Considerations

- Broadly speaking; Runtime is a function of detail
- The level of detail in simulation models include:
  - Planning horizon, i.e., 15 year, 20 year, 30 year, etc.
  - Model footprint, i.e., stand alone utility, ISO, region, etc.
  - Number and complexity modeling elements
    - Breakout of customer loads and load centers
    - Number of resources, transmission areas, companies, & markets
  - Level of hourly/sub-hourly detail
    - Typical week, chronological, load aggregation
  - Modeling algorithms
    - LP/MIPS vs. DP
    - Deterministic vs. Stochastic
    - Security constrained economic dispatch

What Makes a Good Model?

- Model Detail is a function of Use
  - Short term commitment and dispatch models require the most detail
  - Long term resource optimization models require less detail
  - Near term budgetary models’ requirements fall somewhere in the middle
- No one model can do it all well, nor should it be expected to!
- A good model will estimate the direction and magnitude of differences from one set of assumptions to another

How to use the model correctly…

- The “correct” model is a balance between of the underlying purpose and adequate detail versus runtime.
  - Short Term models for commitment and dispatch decisions require volumes of operational data and constraints and are typically run hourly or sub-hourly
  - Long Term optimization models require reasonable runtimes, requiring fewer operational data and constraints and typically run with aggregated time intervals
  - Special purpose models such as LMP models, require all of the same elements of Short Term models plus the volume of detail associated with transmission modeling
- Scenarios, sensitivities, and stochastic risk analysis have their places both at the less detailed modeling level and the more detailed level

Production Cost Modeling

- The key to production cost commitment and dispatch requirement is a proper generation response to market prices.
  - All production cost models simulate the day ahead market.
  - Dispatch to price can be achieved through:
    - Detailed modeling of a market's footprint*, or
    - A hub and spoke representation

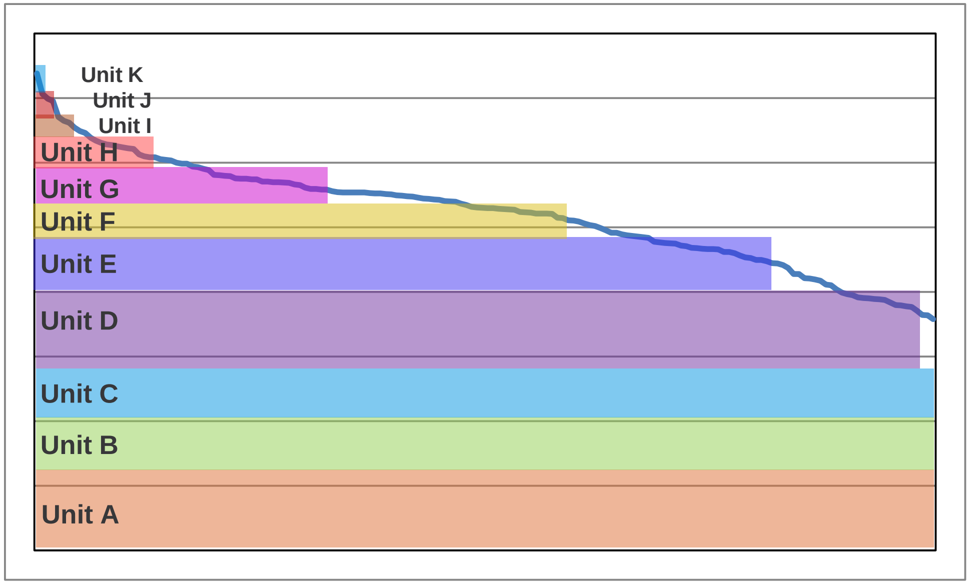
*Even detailed modeling of the MISO market requires a hub and spoke representation of New York/New England and Florida.

Production Cost Modeling

- Unit Dispatch Methods:
  - Deterministic
  - Direct Enumeration
  - Probabilistic
  - Monte Carlo
  - Security Constrained Commitment and Dispatch

Deterministic Dispatch

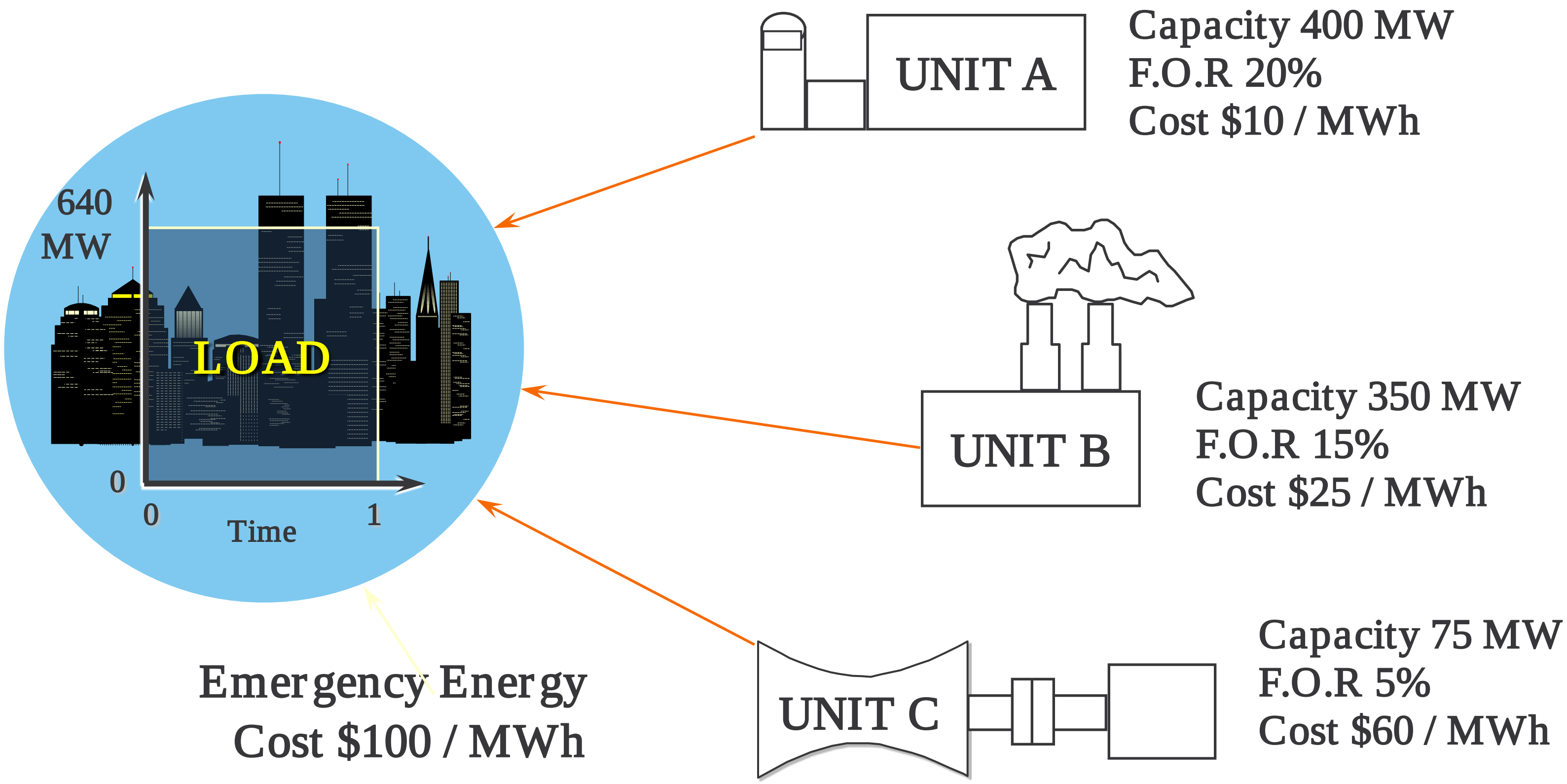
- Units Derated for Forced Outage Rates
- Derated Units "stacked" against a Load Duration Curve (LDC)
- Unit energies calculated by linear interpolation against the LDC
- Pros: Speed
- Cons: Dispatch accuracy



Random Forced Outages must be Modeled

- Probabilistic production cost modeling is a necessary complexity
  - Captures the uncertainty of unit availabilities
  - Better represents expected generation from peaking resources
- Three methods of doing this:
  - Direct Enumeration Method (Calebrese)
  - Probabilistic Simulation – Convolution Method
  - Monte Carlo Method
- Let's look at an example using all three of these methods…

Unit Uncertainty Example



Demand: 640 MW

Modeling Forced Outage Rates and Calculating Production Cost

- Direct Enumeration Method (Calebrese)
- Probabilistic Simulation – Convolution Method
- Monte Carlo Method

Direct Enumeration Method (Calebrese)

Let's Look at the Probability and Outcome of Each State for the Load of 640 MW in 1 Hour

N	Y	Y	.2 x .85 x .95 = .1615

STATE			PROBABILITY	OUTCOME				
				GENERATION (MWH)				$
A	B	C		UNIT A	UNIT B	UNIT C	EMERGENCY	
Y	Y	Y	0.646	400	240	0	0	10,000
Y	Y	N	.0340	400	240	0	0	10,000
Y	N	Y	.1140	400	0	75	165	25,000
Y	N	N	.0060	400	0	0	240	28,000
N	Y	Y	.1615	0	350	75	215	34,750
N	N	Y	.0285	0	0	75	565	61,000
N	Y	N	.0085	0	350	0	290	37,750
N	N	N	.0015	0	0	0	640	64,000
EXPECTED RESULT:			1.0000	320	222.7	22.8	74.5	17,585

Direct Enumeration Method (Calebrese)

- Direct Enumeration Method (Calebrese)
  - Calebrese's method gives correct answer ... but:
  - 3 units, each with two capacity states, yielded $2^3 = 8$ distinct cases
  - 50 units, each with 5 partial availability states would require enumeration of 5^{50} or 8.8×10^{34} cases
- At 1000 cases per second, it would take 2.8 x 1022 years to evaluate!
- Even for small systems enumeration is infeasible since load changes hourly and sub-hourly !!!

Modeling Forced Outage Rates

- Direct Enumeration Method (Calebrese)
- Probabilistic Simulation: Convolution Method
- Monte Carlo Method

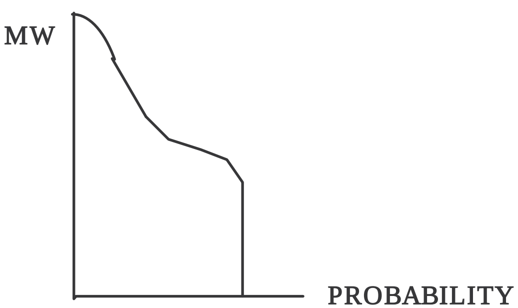
Probabilistic Simulation: Convolution Method

- Method of combining probability distributions of unit forced outages
- Procedure uses a remaining equivalent load distribution function
- Produces results that are mathematically equivalent to direct enumeration

Probabilistic Simulation: Convolution Method

Probability Distribution Functions

LOAD PROBABILITY DISTRIBUTION FUNCTION X UNIT CAPACITY AVAILABILITY PROBABILITY FUNCTION = EXPECTED LOAD DISTRIBUTION FUNCTION AFTER DISPATCH OF CAPACITY



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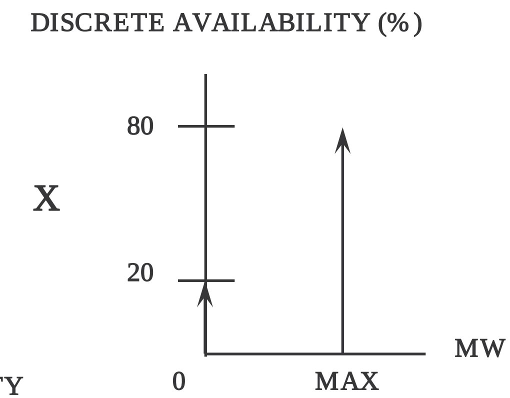

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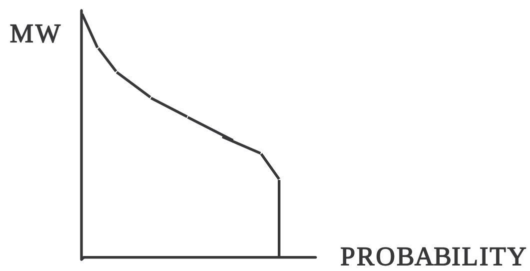
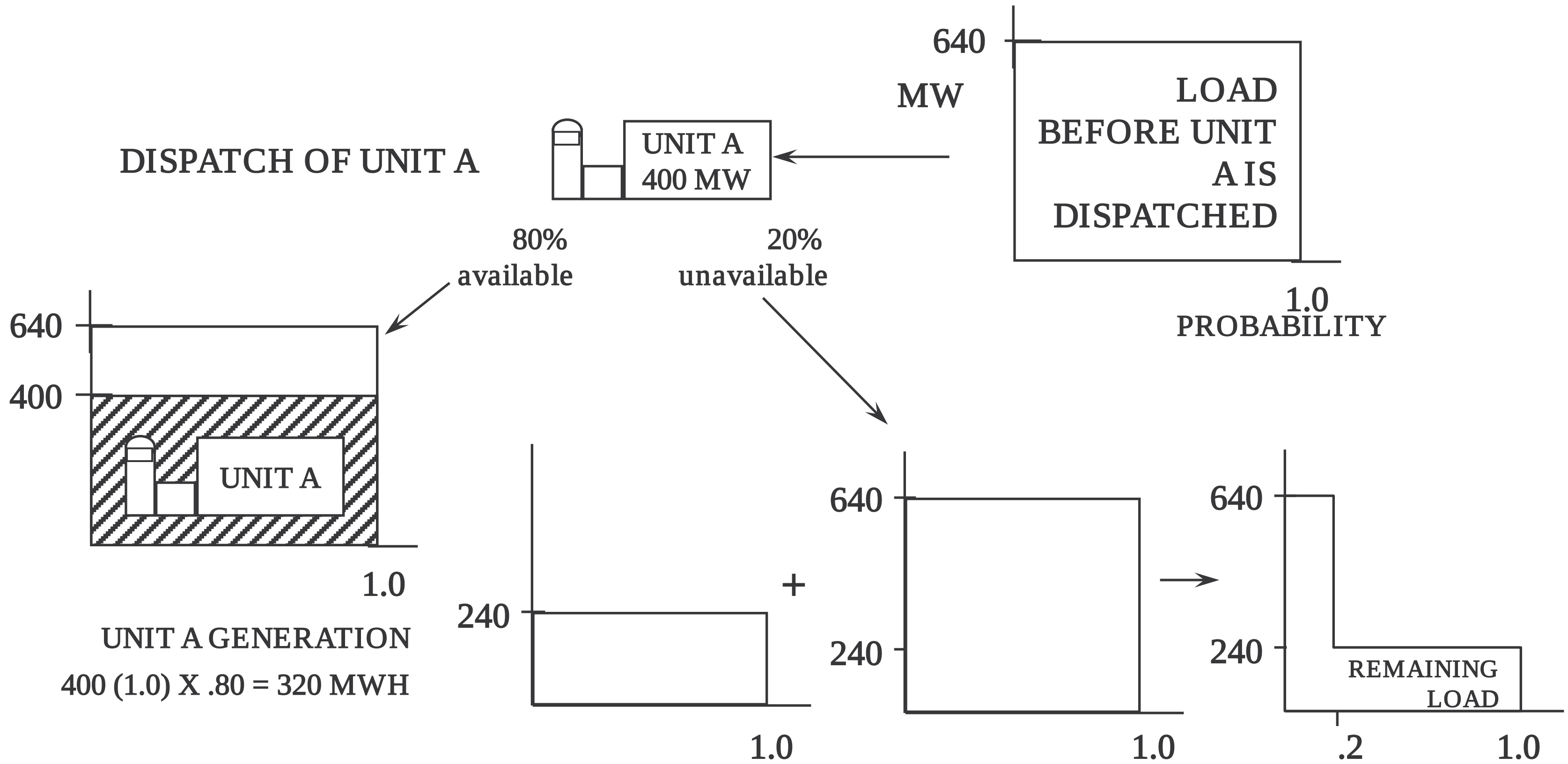


Probabilistic Simulation: Convolution Method



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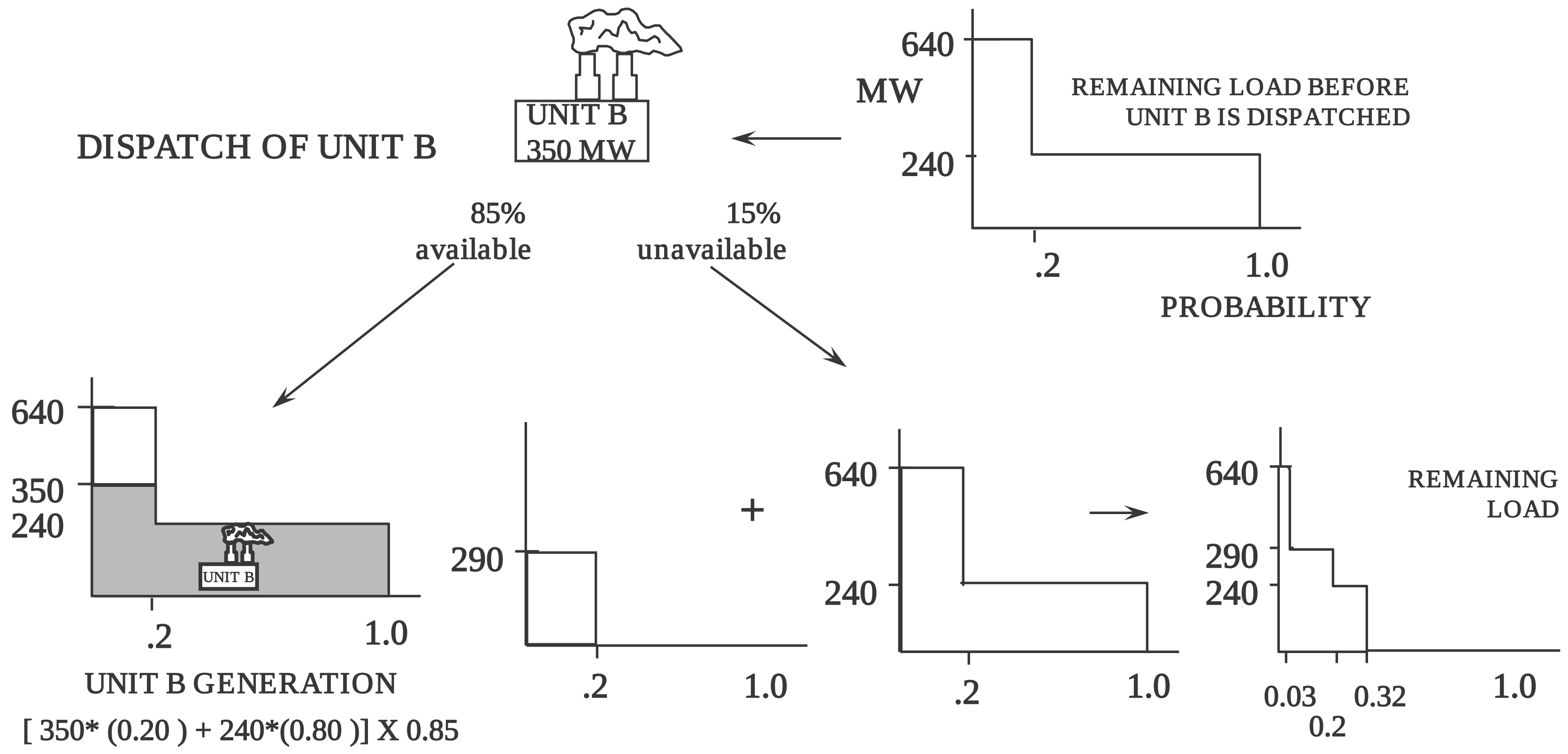
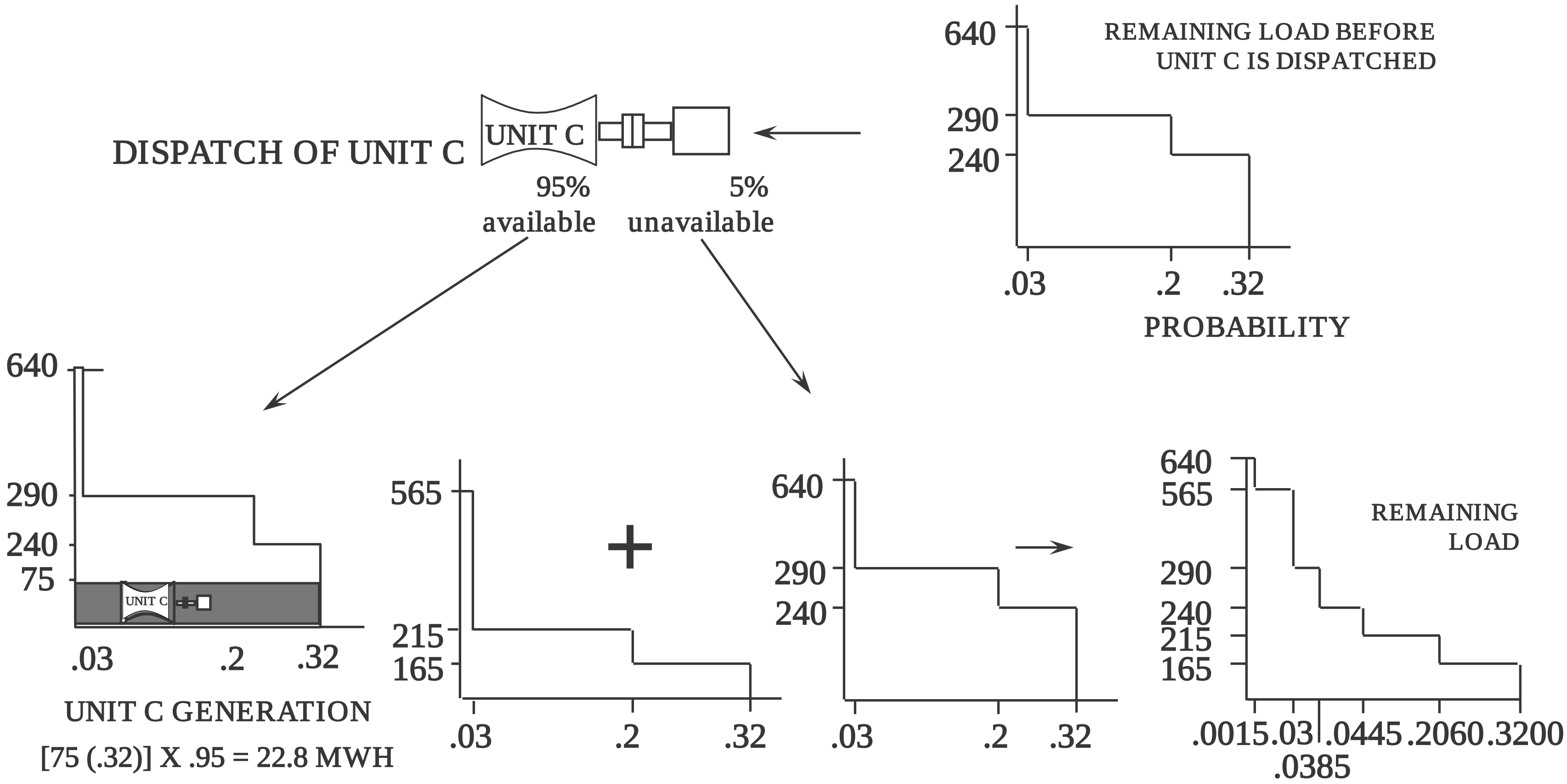


Probabilistic Simulation: Convolution Method



Probabilistic Simulation: Convolution Method

- Expected Generation
  - Unit A = 320 MWH
  - Unit B = 222.7 MWH
  - Unit C = 22.8 MWH
  - Emergency= 74.5 MWH

- Expected Production Cost
  - (320 x 10) + (222.7 x 25) + (22.8 x 60) + (74.5 x 100) = $17,585.50

- It can be shown that convolution is mathematically equivalent to direct enumeration
- Expected Marginal Cost
  $ 49 / MWH

Modeling Forced Outage Rates

- Direct Enumeration Method (Calebrese)
- Probabilistic Simulation: Convolution Method
- Monte Carlo Method

Monte Carlo Method

- Estimate probability function of random variables; e.g. Forced Outage Rate of Each Unit
- Simulate the system by using a random number generator to produce a sample from the probability functions (simulate generating unit forced outages)
- Process is repeated a large number of times (typically dozens to hundreds of draws)
- Results from all draws are averaged together
- Average approaches the expected value as the number of draws (sample size) increases

Monte Carlo Method: Example

- Suppose twenty draws were taken as follows from the 8 possible combinations: 1, 3, 4, 1, 1, 1, 5, 1, 1, 5, 6, 1, 1, 2, 1, 7, 1, 3, 1, 1
- Frequency for each outcome:

		State		
Outcome	Frequency	Unit A	Unit B	Unit C
0	0	N	N	N
1	12	Y	Y	Y
2	1	Y	N	N
3	2	Y	N	Y
4	1	N	Y	N
5	2	N	Y	Y
6	1	N	N	Y
7	1	Y	Y	N
Total	20			

Monte Carlo Method: Example

- **Estimate the expected values by the direct average of results “Expected” Generation of:**
  - Unit A= [(0x0) + (12x400)+ (1x400)+ (2x400)+ (1x0)   +(2x0)   +(1x0)   +(1x400)] / 20 = 320
  - Unit B= [(0x0) + (12x240)+ (1x0)   + (2x0)   + (1x350) +(2x350) +(1x0)   +(1x240)] / 20 = 208.5
  - Unit C= [(0x0) + (12x0)   + (1x0)   + (2x75) + (1x0)   +(2x75)   +(1x75) +(1x0)   ] / 20 = 18.75

					Load = 640 MW								
					Cost $/Mwh								
					10	25	60	100					
					Capacity MW								
					400	350	75						
		State			Generation Mwh					Expected Generation			Expected
Outcome	Freq	Unit A	Unit B	Unit C	Unit A	Unit B	Unit C	Emerg Engy	Cost $	Unit A	Unit B	Unit C	Uns.Energy
0	0	N	N	N	0	0	0	640	$ 64,000	0	0	0	0
1	12	Y	Y	Y	400	240	0	0	$ 10,000	4800	2880	0	0
2	1	Y	N	N	400	0	0	240	$ 28,000	400	0	0	240
3	2	Y	N	Y	400	0	75	165	$ 25,000	800	0	150	330
4	1	N	Y	N	0	350	0	290	$ 37,750	0	350	0	290
5	2	N	Y	Y	0	350	75	215	$ 34,750	0	700	150	430
6	1	N	N	Y	0	0	75	565	$ 61,000	0	0	75	565
7	1	Y	Y	N	400	240	0	0	$ 10,000	400	240	0	0
Total	20									6400	4170	375	1855
										320	208.5	18.75	92.75

Monte Carlo Method: Example

- **"Expected" Production Cost =**
  - [(0x64,000)] +(12x10,000) + (1x28,000) + (2x25,000) + (1x37,500) + (2x34,750) + (1x10,000) (1x61,000)] / 20 = $18,812.50

					Load = 640 MW					
					Cost $/Mwh					
					10	25	60	100		
		State			Expected Generation			Expected		
Outcome	Freq	Unit A	Unit B	Unit C	Unit A	Unit B	Unit C	Uns.Energy	Cost $	Expected Cost
0	0	N	N	N	0	0	0	0	$ 64,000	$ -
1	12	Y	Y	Y	4800	2880	0	0	$ 10,000	$ 120,000.00
2	1	Y	N	N	400	0	0	240	$ 28,000	$ 28,000.00
3	2	Y	N	Y	800	0	150	330	$ 25,000	$ 50,000.00
4	1	N	Y	N	0	350	0	290	$ 37,750	$ 37,750.00
5	2	N	Y	Y	0	700	150	430	$ 34,750	$ 69,500.00
6	1	N	N	Y	0	0	75	565	$ 61,000	$ 61,000.00
7	1	Y	Y	N	400	240	0	0	$ 10,000	$ 10,000.00
Total	20				6400	4170	375	1855		$ 376,250.00
					320	208.5	18.75	92.75		$ 18,812.50

Modeling Forced Outage Rates - Comparison of Results

Dispatch	Enumeration Method	Convolution Method	Monte Carlo
Unit A	320.0	320.0	320.0
Unit B	222.7	222.7	208.5
Unit C	22.8	22.8	18.75
Unsupplied	74.5	74.5	92.75
Cost ($)	17,585.5	17,585.5	18,812.5
($/MWH)			
Average Cost	27.48	27.48	29.39
Exp.Marginal Cost	49.00	49.00	51.25

Modeling Forced Outage Rates - Comparison Modeling Techniques

- Enumeration is computationally intensive and considered not feasible as load changes hourly and systems generally have many more units
- Convolution is mathematically equivalent to enumeration without the computational burden
- Monte Carlo's deterministic algorithm benefits some commitment and dispatch applications, but it requires iteration for convergence

Load Representations

- All Production Cost models must represent the load to be served:
  - Customer load (utility sales)
    - Energy
    - Peak demand
    - Time series consumption data
      - Hourly 8760 covering the entire year
      - Typical Weeks (168 hours per month)
      - Aggregations of hours by time bucket or sub-period within the week or month
  - Losses
    - Transmission & Distribution
    - Can vary by customer class
  - Customer Load + Losses = Generation Requirements

Glossing over…

- Differences in how specific models handle:
  - Bilateral Transactions
  - Market Energy and Capacity Purchases
  - Hydro & Energy Storage Resources
  - Transmission & Distribution
  - Distributed Generation
  - Etc.
  - Etc.
  - Etc.
  - DSM…

Optimization

- Optimization models seek the optimal solution for a system
- With one or more objective functions:
  - Minimize revenue requirements
  - Minimize societal cost
  - Maximize shareholder benefit
- Subject to constraints
  - Reserve Margins
  - Unit X is not available for construction until xx/xx/20xx
  - Unit X and Unit Z are not allowed to occur simultaneously
  - No more than 3 Unit Y's may be built over the time horizon

Resource Optimization

- Optimization models evaluate the key cost components of new generation: Cost of construction, Cost of production, Cost (or Benefit) of Market Interaction, etc.
  - Models require an imbedded production cost model
  - Models require a capital expenditures model
- Optimization Methods
  - Dynamic Programming (DP) Solutions
  - Linear Programming (LP) Solutions
  - Mixed Integer Programming Solutions (MIPS)

Dynamic Programming (DP) Solutions

- Dynamic programming generates possible solutions (states) in each year that satisfy the optimization problem's constraints
- Iterates forward generating each year's states based on all the states that passed in the previous year
- All possible combinations are explored
  - Only those combinations that meet all constraints are saved
  - Pathways that reach the same state in any one year are converged and only the least expensive pathway is saved (Bellman's Principle of optimality)
  - Possible to generate an optimization problem that it is infeasible to solve with available computing resources
  - Each additional prototype option adds to the size of the solution set, and to runtime

Dynamic Programming (DP) Solutions

- At the end of the time horizon the paths are traced backward to determine the timing of resource additions.
- End Effects analysis may be performed
- This methodology yields multiple plans
- Plans are then sorted in rank order on the Objective Function

- This method is called Forward Propagation – Back Trace
- It is theoretically possible to do Back Propagation
  - This would be computationally more efficient
  - This has only been demonstrated in simplified models
  - The number of variables in models with sufficient detail to be reasonably accurate for real systems makes this infeasible in practice

Linear Programming (LP) Solutions

- Uses a mathematical method that solves for all years and all possible combinations of prototype resources simultaneously
- The result can put in “partial” units
- Yields only a single “optimal” answer
- That answer is only “optimal” for the specific set of assumptions
- Must change the optimization problem’s constraints and/or assumptions to generate “sub-optimal” answers
- The result can be considered a representation of the optimal mix of resources from among the prototypes offered
- More efficient (than DP) when used with stochastic uncertainty modeling (Risk Analysis)

Mixed Integer Programming Solution

- Uses same mathematical methods as LP, but requires that “whole” units be added
- Yields a solution that represents a potential “real” future resource plan

Why does this matter?

- Theoretically, optimal is optimal no matter how you get there
- In practice, resource optimization models may yield slightly different optimization results
- This depends on:
  - The underlying production cost engines
  - The problem constrains available/employed
  - The level of detail in the models
    - Convolution methods preferred to Monte Carlo
    - Simplified hourly representations of the load and dispatch generally used (i.e. – Typical Week, Time Block Aggregation)
- Need to run detailed models to fully capture operational details and interactions

DSM Modeling

- DSM in integrated resource planning models
  - Ways to include DSM
  - Associated pros and cons.
- Costs
- Impacts Analysis
- Hourly Impact Shapes

Incorporating DSM in Production Cost Models

- Subtract it from the load before running the production costs
  - Advantages: simple and can be done with spreadsheets
  - Disadvantages:
    - Have to assume how much DSM there is beforehand
    - Assessment of individual programs possible but hard
    - No direct capture of associated costs
- Roll all the DSM together and represent as a single purchase transaction
  - Pros:
    - Again it's pretty straightforward and most of the work is done off-line in spreadsheets
    - You can capture the costs in aggregate
  - Cons: Same as fist two "Disadvantages" above

Incorporating DSM in Production Cost Models

- Model DSM as a Load Modifying Resource
  - In aggregate including costs…
  - Individual programs
    - Pros:
      - Much more detail on individual program impacts and costs
      - Can turn programs on & off to assess individual impacts
    - Cons:
      - Need more detailed data on each program, so data maintenance burden goes up
      - Sometimes that additional detail results in inconsistencies
- The better resource planning models allow modeling of individual resources

DSM Costs

- Utility Company Costs
  - Program operation/administration costs
  - Marketing/advertising costs
  - Implementation costs
  - Verification and measurement costs
  - Customer sign up costs
  - Incentives
- Customer Costs
  - Equipment
  - Operating Costs
  - Maintenance Costs
  - Fuel Costs
- Externality and Societal Costs

DSM Costs

- The more detail you have on costs the more refined your cost/benefit modeling can be
- Supports all the California Standard Practice Manual B/C Tests
- The more “slots” you have for the various costs the more separated you can keep them in the model – ease of tracking inputs
- But that can lead to modeling inconsistencies between programs – the modeler has to be focused and disciplined

DSM Impacts

- Energy Savings
  - Annual
  - Monthly
- Peak Demand Savings
  - Program Peak
  - Coincident Peak
- Hourly Load Impact Shapes
  - 8760 Hours
  - Model Granularity
  - Diversified vs. Undiversified

Going Back to the Question of Hourly Load Shapes

- Production costing models all need a representation of the pattern of customer demands, as well as forecasts of their energy consumption and peak demand
- Why? Because depending on the model's level of detail:
  - All of them need to "stack" the resources to serve the load
  - Some models do everything on an hourly basis (Hourly Monte Carlo)
  - Others use Typical Weeks to represent the load for the dispatch period
  - Still others use hour "buckets" to simplify the dispatch
  - Sub-periods: Weekday, Weeknight, Weekend
  - Hour to hour load differences drive the way units are committed – regardless of the underlying load representation

The Issue with DSM Impact Shapes

- For production cost models diversified hourly customer load shapes are assumed
- By definition any measurement of load at an aggregated level is “diversified”
- What is “diversified load?”
  - Represents an average across a large number of customers
  - Some individual customers will be “on” more than others in any given hour due to equipment cycling (e.g. – AC)
  - Engineering estimates generally represent “undiversified” load
    - No variance from customer to customer in hour to hour usage
    - You can’t just multiply by the number of customers!
    - Results in an overestimation of impact at peak

Diversified Impacts vs. Undiversified Impacts

- DSM analysis models frequently use an hourly impact representation called “T36”
  - Typical Days – the “T” part
  - Each month in the year represented by a typical weekday, and typical peak day, and a typical weekend day – 3 day types times 12 months = the “36” part
  - Day types are strung together to get 8760 shapes – usually the weekdays and weekend days to estimate overall energy savings
  - The peak day shape is adjusted for diversity to correct for overestimation by simple multiplication
  - The problem: really only three days types

Why is this an Issue for Resource Planning Models?

- Resource additions are driven (mostly) by capacity reserve needs
- This is measured at the time of the peak
- If the impact of the DSM at the time of system peak are wrong this results in an incorrect estimate of capacity need
- The weekday + weekend day doesn’t capture the peak day so it needs to be overlain on the correct day
- But the Diversity Adjustment applied suppresses its hourly impacts
- Sometimes the resulting “Peak Day” impacts are less than comparable hours from the Weekday!

Worse yet…

- The hourly impacts for Weekdays and Weekend Days are the undiversified load shapes "grossed up" for the number of participants
- So the hourly impacts may be under or overstated depending on the error vs. a diversified hourly impacts shape
- Again; this can have profound and potentially detrimental impacts on the dispatch of the system's resources against the remaining load after DSM is applied
- So the costs calculated from that dispatch can be wrong too
- This can either overestimate the costs and/or savings from a program, or underestimate them
- There is no way to know for sure if you have it right unless the underlying load shapes are all based on Diversified shapes

Finally

- Incorrect hourly impact shapes can cause even more error in models that can capture Time of Use and Block Rate Structures
- This is also true for hourly dispatch models
- Error is less for aggregated load models, but these are less accurate to begin with
- Models with load precision somewhere in the middle will have less error – but the error didn't go away completely.

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