Decision Method for Unit Rehabilitation

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The PUD!

- Public utility in Washington State, 1936
- 1,988 MW nameplate
- Two dams, three powerhouses on the Columbia River
- One dam and powerhouse on Lake Chelan
- Total generation – 9,000 GWHr
- 48,000 electric customers
- Ages from 1928 to 2011

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Rock Island

Puget Power
Oldest plant on the Columbia River – 1933

First Powerhouse
4 – propellers 22MVA
6 – Kaplan 25MVA
2 units rehabilitated 2008 - 2010

Second Powerhouse added 1979
8 – bulbs 54MVA

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Rocky Reach

Initial construction
1956 - 1961
7 – Kaplan 108MVA

Rehabilitated and
uprated to 120MVA
1997 – 2003

Expanded in 1968 – 1971
4 – Propellers 132MVA

Rehabilitated, converted
to Kaplan and uprated to
148 MVA
1998 – 2003

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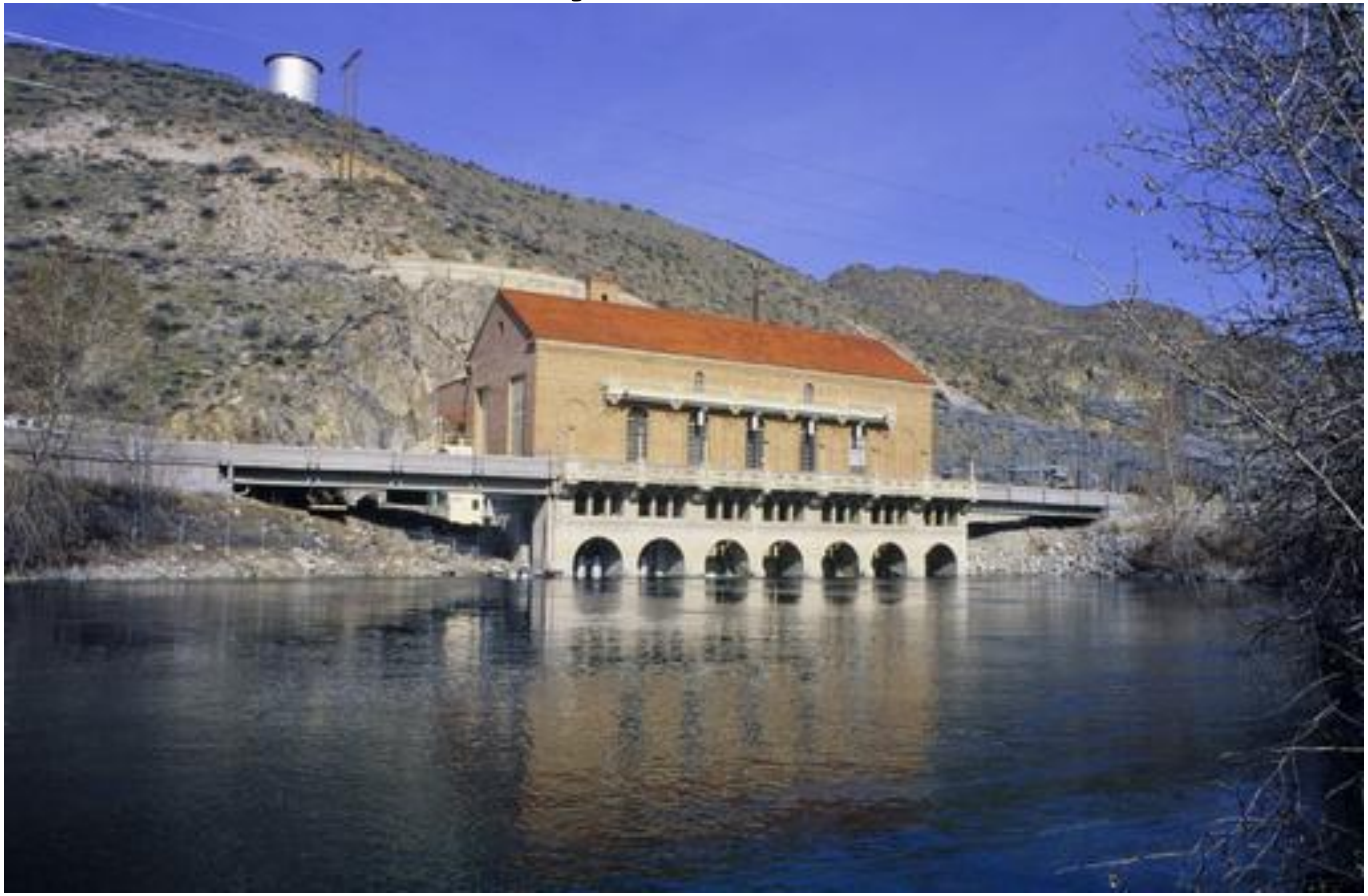

Washington Water Power
1926 – 1928

2 – Francis 28MVA

Acquired 1955

Rehabilitated 2009 - 2011

Uprated to 37MVA

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Unit Rehabilitation Decisions

Equipment is aging

Equipment still runs

- Management wants an IRR or NPV
  - What's it based on?
  - All future generation?
  - No future generation?
  - Only the generation increase?

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Traditional Approach

- Quantify increases:
  - Capacity
  - Efficiency
  - Fish benefits
  - Green value
- Enter into Economic Model

Economic Model

Insert revenues or benefits

e life 10

Discount Rate	7.0%
General inflation rate-future benefits & costs	2.5%

period =				0	1	2	3	4	5	6	7	8	9
Benefits (1)	Input	Input	Real growth	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Reduce maint by 300 hrs/yr @ $45/hr	300	$ 45	1.5%		13,703	13,908	14,117	14,328	14,543	14,761	14,983	15,208	15,436
Click to Insert row above here													
Subtotal of Benefits (2)				0	13,703	13,908	14,117	14,328	14,543	14,761	14,983	15,208	15,436
Costs (1)													
Purchase truck				100,000									
Misc fees				2,000									
Click to Insert row above here													
Subtotal of Costs				102,000	0	0	0	0	0	0	0	0	0
Net Benefit / (Cost), escalated				(102,000)	14,045	14,612	15,202	15,816	16,454	17,119	17,810	18,529	19,277
Benefit, escalated				0	14,045	14,612	15,202	15,816	16,454	17,119	17,810	18,529	19,277
(Cost), escalated				(102,000)	0	0	0	0	0	0	0	0	0

Costs

Summary Results	B/C ratio		levelized
Benefit, PV		$116,059	$16,524
(Cost) (PV)		($102,000)	($14,523)
Net Present Value (NPV)	1.1[illegible]	$14,059	$2,002
Internal Rate of Return (IRR)		9.7%	
Payback begins in Year		9	

Southside Sensitivity	
Additional Costs	10%
Reduce Benefits	10%
Revised NPV	($7,747)
Revised IRR	5.6%
Revised Payback	Exceeds service life

Adjustable Sensitivity	
Additional Costs	0%
Reduce Benefits	0%
Revised NPV	$14,059
Revised IRR	9.7%
Revised Payback	9

Results

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Sample Case

- Four 65 year old vertical Kaplan Turbines
- Issue - The generators are near end of life, rotor-stator contact is likely.
- Alternatives:
  - Rehab the generator now, turbine later
  - Complete rehabilitation now
- Two runner options
  - Rebuild
  - New with increased capacity

Results – 10% Efficiency Increase

Economic Justification Model
Option 1 - w/Encr 1st Unit Repair

Service life 40

Discount Rate	7.0%
General inflation rate-future benefits & costs	2.5%

	Input	Input	period = Real growth	0 2015	1 2016	2 2017	3 2018	4 2019	5 2020	6 2021	7 2022	8 2023	9 2024	10 2025
Benefits (1)														
Revenue est	2018	$ -	1.6%		0	0	0	0	0	0	0	0	0	0
Revenue-Add'l energy option 3	2037	3%			0	0	33,479	33,746	33,746	33,746	33,746	33,746	33,746	33,746
Revenue-Add'l energy option 4	NO	0%			0	0	0	0	0	0	0	0	0	0
Include Encroachment % of Revenue?	YES	47%			0	0	0	0	0	0	0	0	0	0
Avoided cost of decommissioning														
Lost revenue from later rotor rim, pole, turbine														
Click to insert row above here														
Subtotal of Benefits (2)				0	0	0	33,479	33,746	33,746	33,746	33,746	33,746	33,746	33,746
Costs (1)														
1. Stator, Exciter, Controls, Greaseless t	2017	8,500,000	0		3,000,000	3,000,000	0	0	0	0	0	0	0	0
2. Add rotor rim and pole	2017	0			0	0	0	0	0	0	0	0	0	0
3. Add runner replace	2017	0			0	0	0	0	0	0	0	0	0	0
4. Use new runner	2017	0			0	0	0	0	0	0	0	0	0	0
Contingency	2017	850,000			0	850,000	0	0	0	0	0	0	0	0
Rotor rim & pole replace	2035	1,400,000												
Rehab old turbine and hub	2035	4,100,000												
Additional headgate & Other costs	2013			0	500,000									
Incremental Op Ex	2018	0		0	0	0	0	0	0	0	0	0	0	0
Click to insert row above here														
Subtotal of Costs				0	3,500,000	3,850,000	0	0	0	0	0	0	0	0
Net Benefit / (Cost), escalated				0	(3,587,500)	(4,044,906)	36,053	37,249	38,180	39,135	40,113	41,116	42,144	43,198
Benefit, escalated				0	0	0	36,053	37,249	38,180	39,135	40,113	41,116	42,144	43,198
(Cost), escalated				0	(3,587,500)	(4,044,906)	0	0	0	0	0	0	0	0

Summary Results	B/C ratio		levelized	Southside Sensitivity		Adjustable Sensitivity	
Benefit, PV		$738,983	$55,430	Additional Costs	0%	Additional Costs	0%
(Cost) (PV)		($8,921,604)	($669,202)	Reduce Benefits	25%	Reduce Benefits	61%
Net Present Value (NPV)	0.08	($8,182,621)	($613,771)	**Revised NPV**	($8,367,367)	**Revised NPV**	($8,633,400)
Internal Rate of Return (IRR)		#DIV/0!		**Revised IRR**	#DIV/0!	**Revised IRR**	#DIV/0!
Payback begins in Year		Exceeds service life		**Revised Payback**	Exceeds service life	**Revised Payback**	Exceeds service life

Rehabilitation Result With Energy

Economic Justification Model
Option 1 - w/Encr 1st Unit Repair

Service life: 40

Discount Rate	7.0%
General inflation rate-future benefits & costs	2.5%

	Input	Input	Real growth	2015	2016	2017	2018	2019	2020	2021	2022	2023
period =				0	1	2	3	4	5	6	7	8
Benefits (1)												
Revenue est	2018	$1,137,810	1.6%		0	0	1,115,964	1,124,862	1,137,810	1,177,384	1,237,981	1,295,682
Revenue-Add'l energy option 3	2037	3%			0	0	33,479	33,746	0	0	0	0
Revenue-Add'l energy option 4	NO	0%			0	0	0	0	0	0	0	0
Include Encroachment % of Revenue?	YES	47%			0	0	0	0	0	0	0	0
Avoided cost of decommissioning												
Lost revenue from later rotor rim, pole, turbine												
Click to Insert row above here												
Subtotal of Benefits (2)				0	0	0	1,149,443	1,158,608	1,137,810	1,177,384	1,237,981	1,295,682
Costs (1)												
1. Stator, Exciter, Controls, Greaseless t	2017	8,500,000	0		3,000,000	3,000,000	0	0	0	0	0	0
2. Add rotor rim and pole	2017	0			0	0	0	0	0	0	0	0
3. Add runner replace	2017	0			0	0	0	0	0	0	0	0
4. Use new runner	2017	0			0	0	0	0	0	0	0	0
Contingency	2017	850,000			0	850,000	0	0	0	0	0	0
Rotor rim & pole replace	2035	1,400,000										
Rehab old turbine and hub	2035	4,100,000										
Additional headgate & Other costs	2013			0	500,000							
Incremental Op Ex	2018	0		0	0	0	0	0	0	0	0	0
Click to insert row above here												
Subtotal of Costs				0	3,500,000	3,850,000	0	0	0	0	0	0
Net Benefit / (Cost), escalated				0	(3,587,500)	(4,044,906)	1,237,825	1,278,886	1,287,327	1,365,405	1,471,570	1,578,663
Benefit, escalated				0	0	0	1,237,825	1,278,886	1,287,327	1,365,405	1,471,570	1,578,663
(Cost), escalated				0	(3,587,500)	(4,044,906)	0	0	0	0	0	0

Summary Results

	B/C ratio		levelized
Benefit, PV		$28,701,386	$2,152,866
(Cost) (PV)		($8,921,604)	($669,202)
Net Present Value (NPV)	3.22	$19,779,782	$1,483,664
Internal Rate of Return (IRR)		19.5%	
Payback begins in Year		10	

Southside Sensitivity

Additional Costs	0%
Reduce Benefits	25%
Revised NPV	$12,604,436
Revised IRR	15.6%
Revised Payback	12

Adjustable Sensitivity

Additional Costs	0%
Reduce Benefits	61%
Revised NPV	$2,271,937
Revised IRR	8.9%
Revised Payback	31

Traditional Approach Results

Option 1 - 1st Unit Repair	Yes	No	8.8%	$	3,527,658	1.31
Option 1 - 2nd Unit Repair	Yes	No	8.2%	$	1,993,376	1.19
Option 1 - 3rd Unit Repair	Yes	No	5.6%	$	(1,898,809)	0.80
Option 1 - 4th Unit Repair	Yes	No	5.7%	$	(1,127,826)	0.87
Option 2 - 1st Unit Repair	Yes	Rebuild	7.8%	$	1,890,947	1.14
Option 2 - 2nd Unit Repair	Yes	Rebuild	7.3%	$	564,398	1.05
Option 2 - 3rd Unit Repair	Yes	Rebuild	5.2%	$	(3,171,232)	0.71
Option 2 - 4th Unit Repair	Yes	Rebuild	5.2%	$	(2,219,018)	0.78
Option 3 - 1st Unit Repair	Yes	New	6.8%	$	(490,823)	0.97
Option 3 - 2nd Unit Repair	Yes	New	6.3%	$	(1,647,404)	0.89
Option 3 - 3rd Unit Repair	Yes	New	4.4%	$	(5,286,422)	0.61
Option 3 - 4th Unit Repair	Yes	New	4.2%	$	(4,198,406)	0.67

Recommendation: Replace generator, wait on the turbine.

Problem

- Without energy, value of increased capacity and energy is not sufficient – negative NPV and IRR
- Assumes all value of energy after rehabilitation
- What about age and condition of the unit?
- What about risk of not doing the turbine?

Problem - Ignores Risk

- It will fail, but when and how?
- Run to Fail **is** an option
- Can you accept the consequences?

Failure and Consequence Analysis

- Identify likely failures
- Identify consequences
- Quantify effects
- Include in model

Risk/Value Based Approach

- Value of continued operation
- Cost of forced outage
  - Lost energy/capacity/flexibility
  - Disruption
  - Reputation
- Collateral impacts
  - Physical damage
  - Workforce
  - Contracts

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Model Development

Step 1 – Define Alternatives

Step 2 – Define Values

Step 3 – Risk Evaluation

Step 4 – Build Model

Step 5 – Turn the Handle!

Step 1 – Define Alternatives

1 Run To fail and …

- 1a Retire
- 1b Rehabilitation
- 1c Rehabilitation with New runner

2 Generator now, turbine later and …

- 2a Retire
- 2b Runner rehabilitation
- 2c New runner

3 Complete rehabilitation, reuse runner

4 Complete rehabilitation, new runner

Step 2 – Define Value

- Increased generator efficiency
- Increased turbine efficiency, two runner options
- Increased capacity
- Increased operating flexibility
- Green value of increased efficiency/capacity
- Avoided risk

Step 3 - Risk Evaluation

- Forced versus planned outage
  - Length
  - Disruption
- Risks - rotor stator contact
  - Major – generator is wiped out, some collateral damage, $5,000,000
  - Minor – only parts to be rehabilitated are damaged, collateral damage limited to disruption, $500,000
  - Catastrophic failure – Significant shaft damage, turbine collides with discharge liner, headcover rupture, flooded powerhouse, $25,000,000

Step 4 – Build Model

- Build out economics for each alternative
- Assume rehabilitation date (planned)
- Decision tree provides optimum decision
- Model failures
  - Modes
  - Probabilities
  - Consequences

Uses Economic Spreadsheet

- Spreadsheet model for each alternative
  - Plus one for operating time (value) prior to failure or rehabilitation

Economic Justification Model

Run To Failure, year 2021

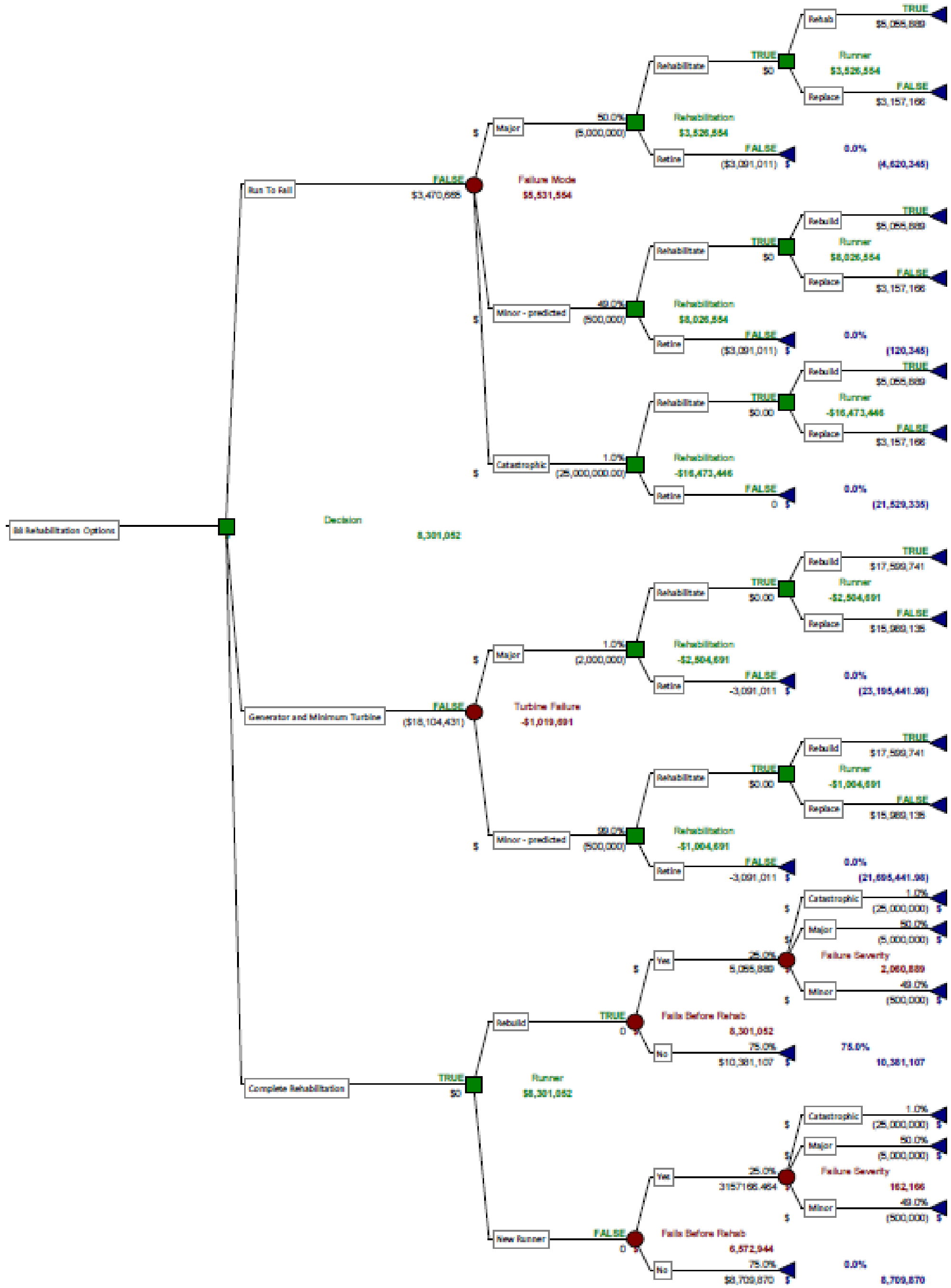
Service life 40

Discount Rate	7.0%
General inflation rate-future benefits & costs	2.5%

				period =	0	1	2	3	4	5	6	7	8
Benefits (1)	Input	Input	scale	Real growth	2015	2016	2017	2018	2019	2020	2021	2022	2023
Revenue est	2021	$ 1,491,396	100%	0.5%		1,377,127	1,436,443	1,479,934	1,491,396	1,522,459	0	0	0
Revenue-Add'l energy option 3	yes	10.0%				56,462	58,894	60,677	61,147	62,421	0	0	0
Revenue-Add'l energy option 4	no	8.0%				0	0	0	0	0	0	0	0
Include Encroachment % of Revenue?	yes	36%	0%			0	0	0	0	0	0	0	0
Powerex contract value	YES	$ 315,000		0.5%		316,575	318,158	319,749	321,347	322,954	0	0	0
REC value	no	$ -		0.5%		0	0	0	0	0	0	0	0
Cost if B1 - B4 Retired		$ -				0	0	0	0	0	0	0	0
Value if U unit is out		$ 400,000		0.5%		0	0	0	0	410,101	0	0	0
Value if C unit is out		$ 125,000		0.5%		62,813	126,253	126,884	127,519	64,078	0	0	0
Subtotal of Benefits (2)					0	1,812,976	1,939,748	1,987,244	2,001,409	2,382,013	0	0	0
Costs (1)													
1. Stator, Exciter, Controls, Greaseless turbine pit	2021	0	0	0	0	0	0	0	0	0	0	0	0
2. Add rotor rim and pole	2021	0	0			0	0	0	0	0	0	0	0
3. Add runner rebuild	2021	0	0			0	0	0	0	0	0	0	0
4. Use new runner	2021	0	0			0	0	0	0	0	0	0	0
Contingency	2021	0	0			0	0	0	0	0	0	0	0
Rotor rim & pole replace	2021	0	0										
Rehab old turbine and hub	2021	0	0										
Retirement Costs	2021	0	0		0	0	0	0	0	0	0	0	0
Backout inflation, Andritz fixed $, except new runner	76%	0	0		0	0	0	0	0	0	0	0	0
Add PUD real growth	24%	0	0	2.0%	0	0	0	0	0	0	0	0	0
Retirement Costs	2021	0	0		0	0	0	0	0	0	0	0	0

Decision Tree Method

- Uses separate economic model for each alternative
- Incorporates decisions and risks
- Mathematically models the alternatives, shows optimal decision path
- Not real $


B8 Rehabilitation Options
Decision
8,301,052
Run To Fail
FALSE
$3,470,665
Failure Mode
$5,531,554
Major
50.0%
(5,000,000)
Rehabilitation
$3,526,554
Rehabilitate
TRUE
$0
Runner
$3,526,554
Rehab
TRUE
$5,055,889
Replace
FALSE
$3,157,166
Retire
FALSE
($3,091,011)
0.0%
(4,620,345)
Minor - predicted
49.0%
(500,000)
Rehabilitation
$8,026,554
Rehabilitate
TRUE
$0
Runner
$8,026,554
Rebuild
TRUE
$5,055,889
Replace
FALSE
$3,157,166
Retire
FALSE
($3,091,011)
0.0%
(120,345)
Catastrophic
1.0%
(25,000,000.00)
Rehabilitation
-$16,473,446
Rehabilitate
TRUE
$0.00
Runner
-$16,473,446
Rebuild
TRUE
$5,055,889
Replace
FALSE
$3,157,166
Retire
FALSE
0
0.0%
(21,529,335)
Generator and Minimum Turbine
FALSE
($18,104,431)
Turbine Failure
-$1,019,691
Major
1.0%
(2,000,000)
Rehabilitation
-$2,504,691
Rehabilitate
TRUE
$0.00
Runner
-$2,504,691
Rebuild
TRUE
$17,599,741
Replace
FALSE
$15,989,135
Retire
FALSE
-3,091,011
0.0%
(23,195,441.98)
Minor - predicted
99.0%
(500,000)
Rehabilitation
-$1,004,691
Rehabilitate
TRUE
$0.00
Runner
-$1,004,691
Rebuild
TRUE
$17,599,741
Replace
FALSE
$15,989,135
Retire
FALSE
-3,091,011
0.0%
(21,695,441.98)
Complete Rehabilitation
TRUE
$0
Runner
$8,301,052
Rebuild
TRUE
0
Fails Before Rehab
8,301,052
Yes
25.0%
5,055,889
Failure Severity
2,060,889
Catastrophic
1.0%
(25,000,000)
Major
50.0%
(5,000,000)
Minor
49.0%
(500,000)
No
75.0%
$10,381,107
75.0%
10,381,107
New Runner
FALSE
0
Fails Before Rehab
6,572,944
Yes
25.0%
3157166.464
Failure Severity
162,166
Catastrophic
1.0%
(25,000,000)
Major
50.0%
(5,000,000)
Minor
49.0%
(500,000)
No
75.0%
$8,709,870
0.0%
8,709,870

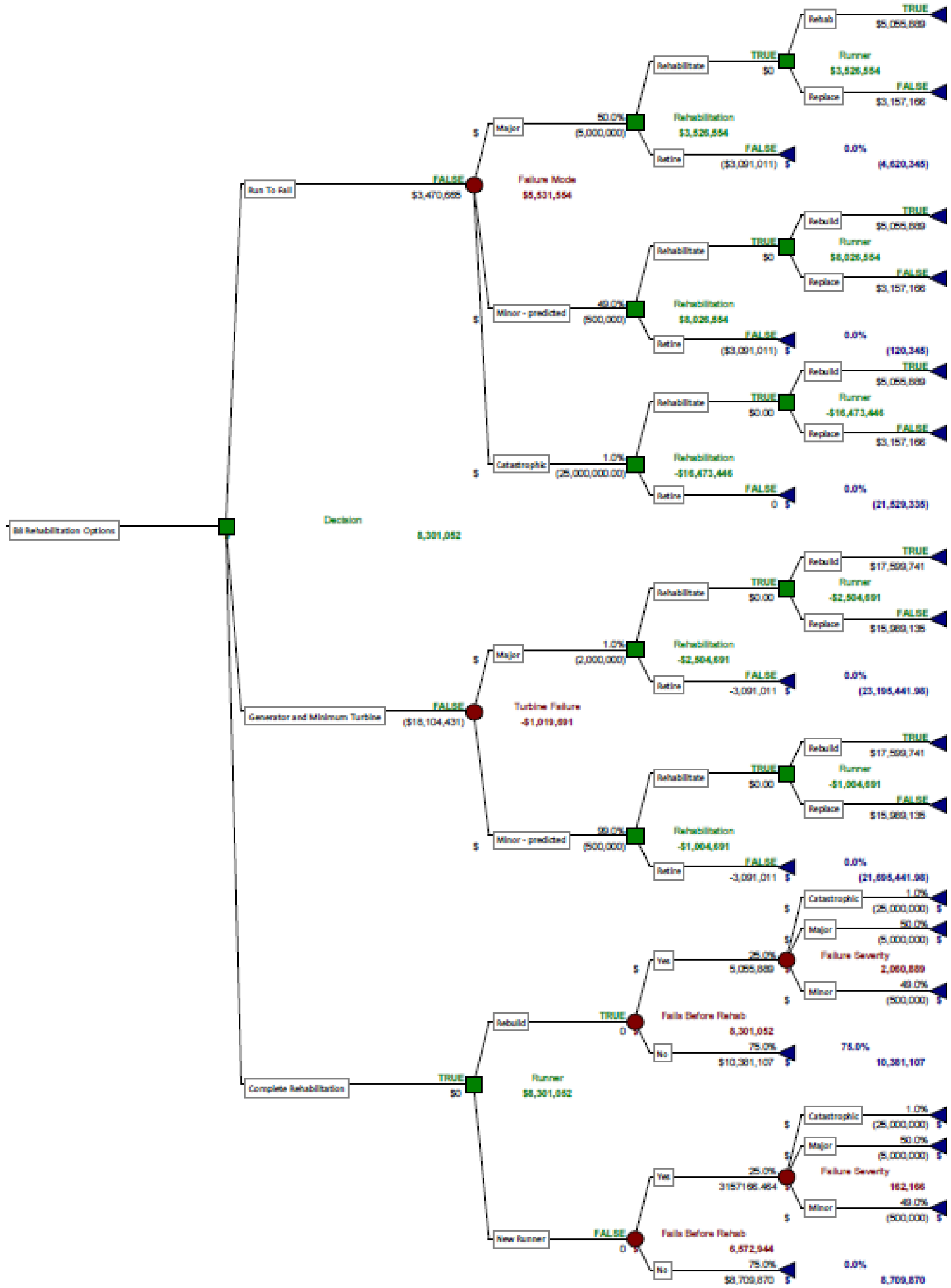
Sample Case

- Issue - The generator is near end of life, rotor-stator contact is likely.
- Alternatives:
  - Run to Failure, then rehabilitate
  - Rehabilitate the generator now, turbine later
  - Complete rehabilitation now

Sample Case Assumptions

- First Unit Rehabilitation - 2016
- Rehab Frequency - 1 years
- Failure year, after - 1st 2018
- Failure frequency, years - 1
- Probability a unit fails before rehab
  - B8 25%, B7 16%, B6 4%, B5 9%
- Cost of Unit Failure
  - Catastrophic $ (25,000,000) - 1%
  - Major $ (5,000,000) - 50%
  - Minor $ (500,000) - 49%
- Cost of turbine failure
  - Major $ (2,000,000) - 1%
  - Minor $ (500,000) - 99%

Decision Tree



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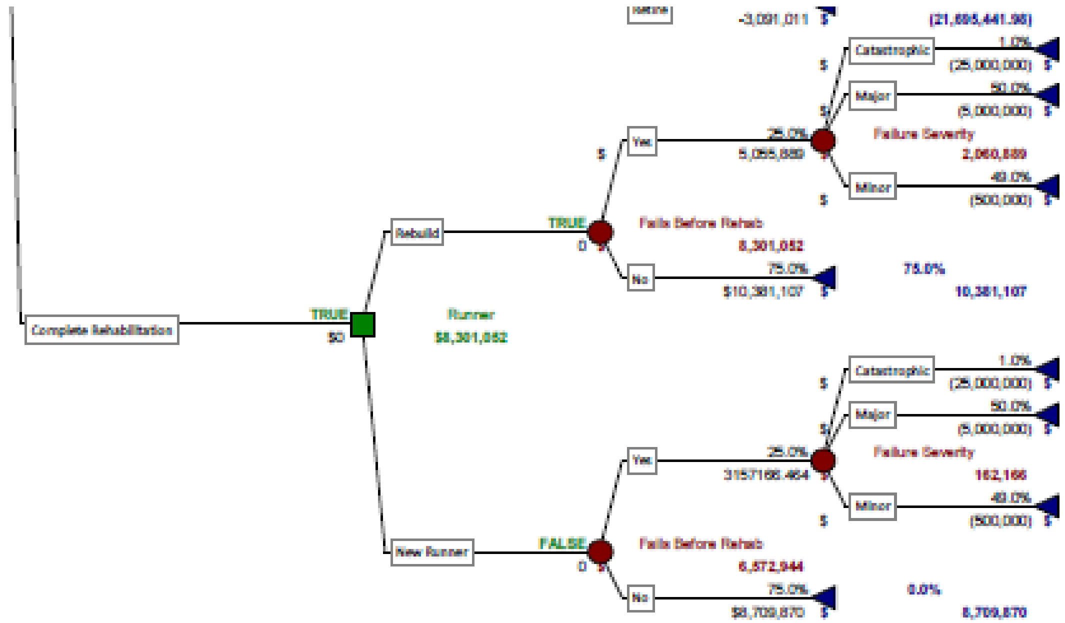
Decision Tree



Static Results

(based on assumptions)

Decision		Decision Value			
Rehab Year		2017	2016	2018	2019
Unit		**B5**	**B6**	**B7**	**B8**
1	Run To fail and				
1a	Retire	$ (581,509)	$ (907,131)	$ 2,605,299	$ 4,626,134
1b	Rehab	$ (2,684,556)	$ (6,379,144)	$ 6,370,940	$ 9,887,612
1c	New runner	$ (7,921,881)	$ (6,597,918)	$ 1,841,185	$ 8,136,304
2	Gen now, turbine later and				
2a	Retire	$ (26,951,898)	$ (20,084,910)	$ (23,865,531)	$ (14,480,330)
2b	Runner rehab	$ (16,456,335)	$ (6,997,040)	$ (8,015,421)	$ 2,460,555
2c	New runner	$ (21,411,588)	$ (25,775,697)	$ (12,258,096)	$ 966,579
3	Complete rehab, reuse runner	$ (680,153)	$ 8,341	$ 6,983,347	$ 9,401,092
4	Complete rehab, new runner	$ (5,749,863)	$ (4,453,864)	$ 2,377,229	$ 7,805,668

Not Real Money!

Recommendation: Complete Rehabilitation, reuse runner

Includes Risks, but Wait!

- Static values –
  - Best judgment of when and how severe
  - Or is it?
- Evaluate Static Values
  - Monte Carlo Simulation
  - Sensitivity Analysis

Monte Carlo

- Input – range or distribution of values
- Simultaneous variations
- Requires good model and computer
- Really tough by hand

Input

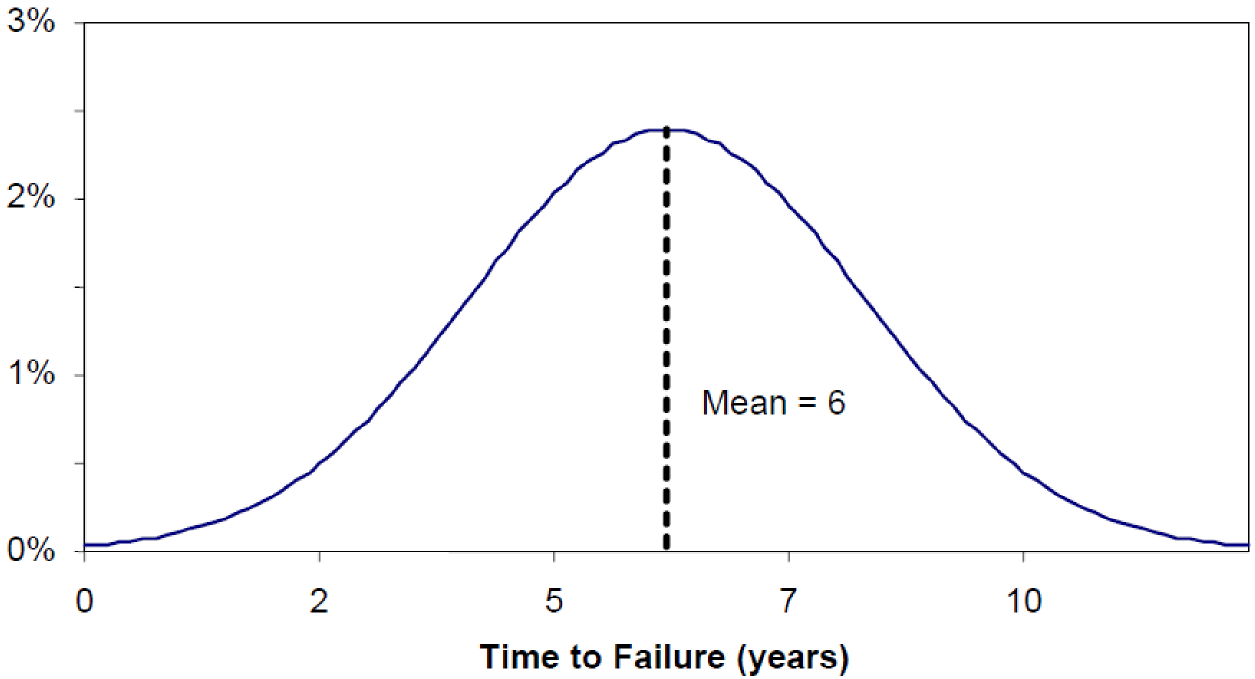


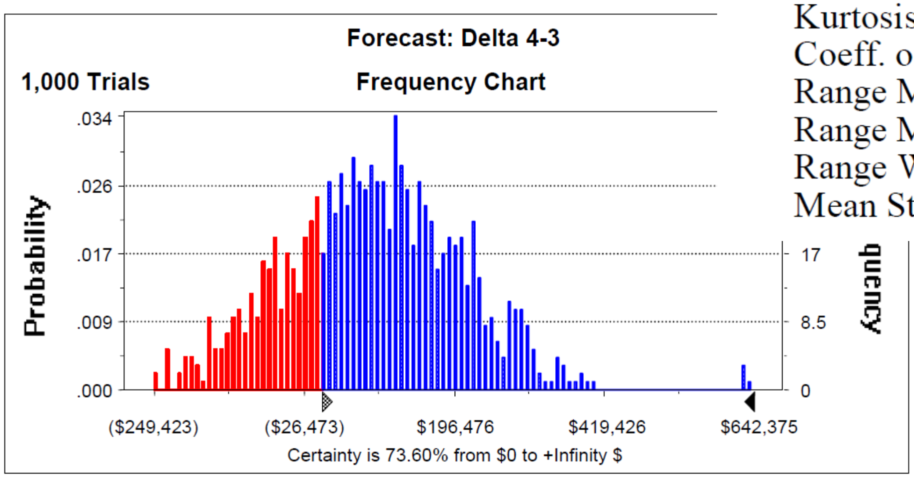
Figure 1 - Probability Distribution for Time to Failure

Output

Summary:

Certainty Level is 73.60%
Certainty Range is from $0 to +Infinity $
Display Range is from ($249,423) to $642,375 $
Entire Range is from ($270,511) to $1,238,496 $
After 1,000 Trials, the Std. Error of the Mean is $6,475

Statistics:	Value
Trials	1000
Mean	$109,791
Median	$83,994
Mode	---
Standard Deviation	$204,751
Variance	$41,922,769,804
Skewness	2.26
Kurtosis	10.65
Coeff. of Variability	1.86
Range Minimum	($270,511)
Range Maximum	$1,238,496
Range Width	$1,509,008
Mean Std. Error	$6,474.78



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Sensitivity

- Vary Range of Input
- Find out what makes the decision different
  - and by how much
- One-way
- Two-way

Sample Case Sensitivities

Table 4 Sensitivity Parameters

Parameter	Range	Base
B35 First failure year	2015 to 2025	2018
B36 Failure frequency	1 to 3 years	1 year
B33 First rehab year	2016 to 2020	2016
B34 Rehab frequency	1 to 3 years	1 year
B73 Forward price curve	50% to 150% of Nominal	Nominal - current forward price curve
B62 Capacity value	-100% to 150% of nominal	Nominal $315,000
B44 Consequence of major failure	50% to 150% of base	$5million
B47 Probability of major failure	25% to 75%	50%
B46 Probability of catastrophic failure	0 to 10%	1%
B43 Consequence of catastrophic failure	50% to 150% of base	$25 million
B71 Cost of Rehabilitation	75% to 150% of base	
B69 Efficiency of Kaplan operation	0 to 15%	10%
B70 Efficiency of new runner	0 to 15%	8%

One-Way on Risk

Figure 1 Sensitivity to Consequence of Catastrophic Failure

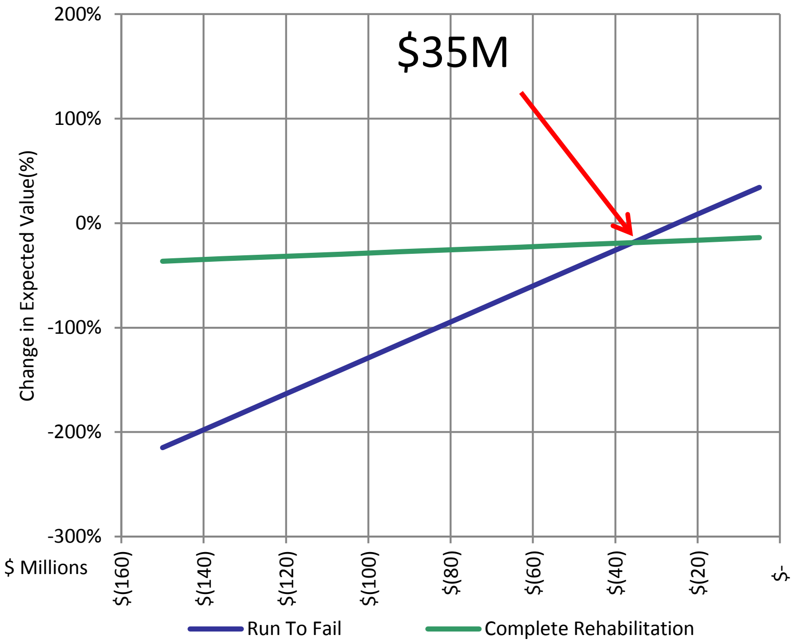
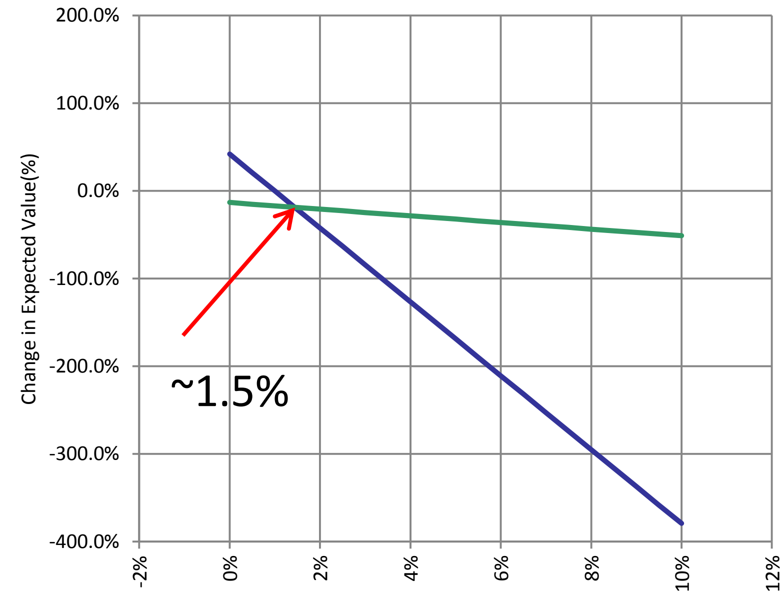


Figure 2 Sensitivity to Probability of Catastrophic Failure



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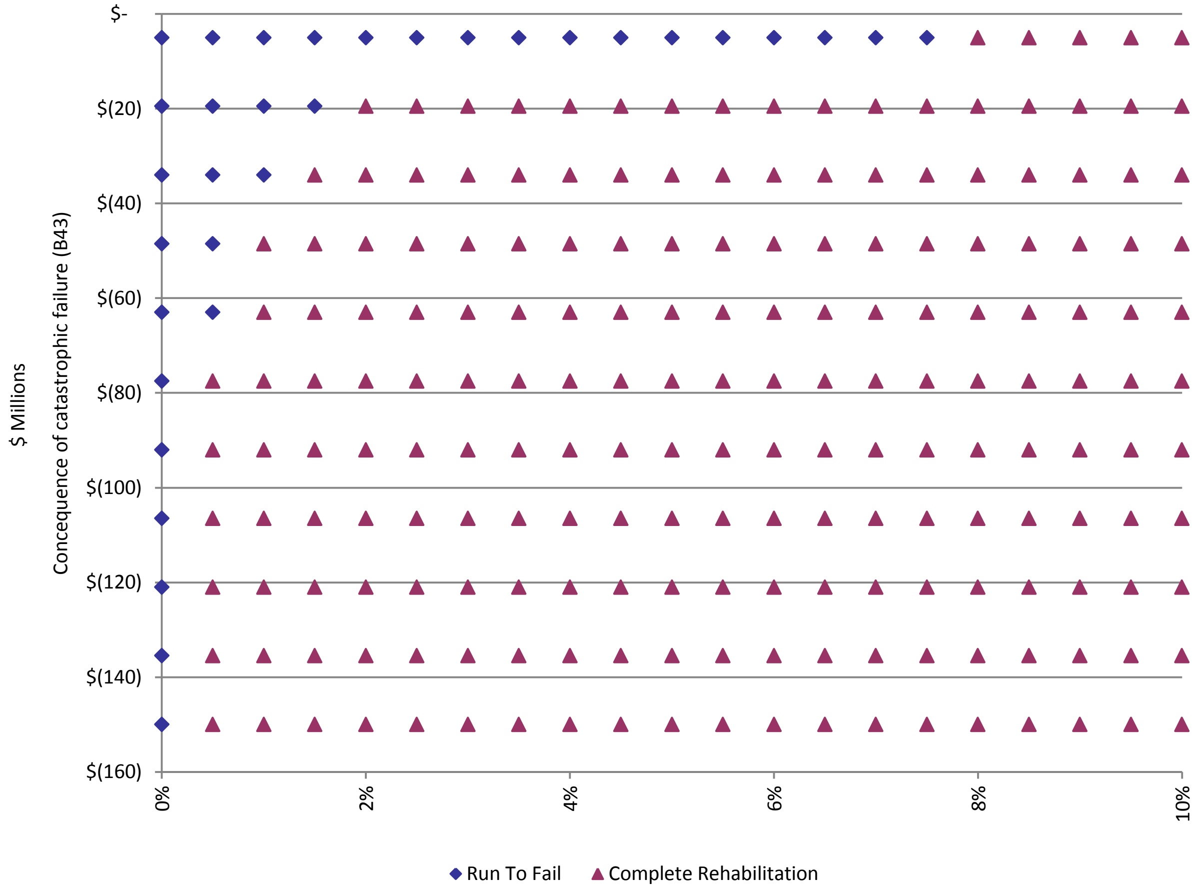
Two-Way
Risk of Catastrophic Failure



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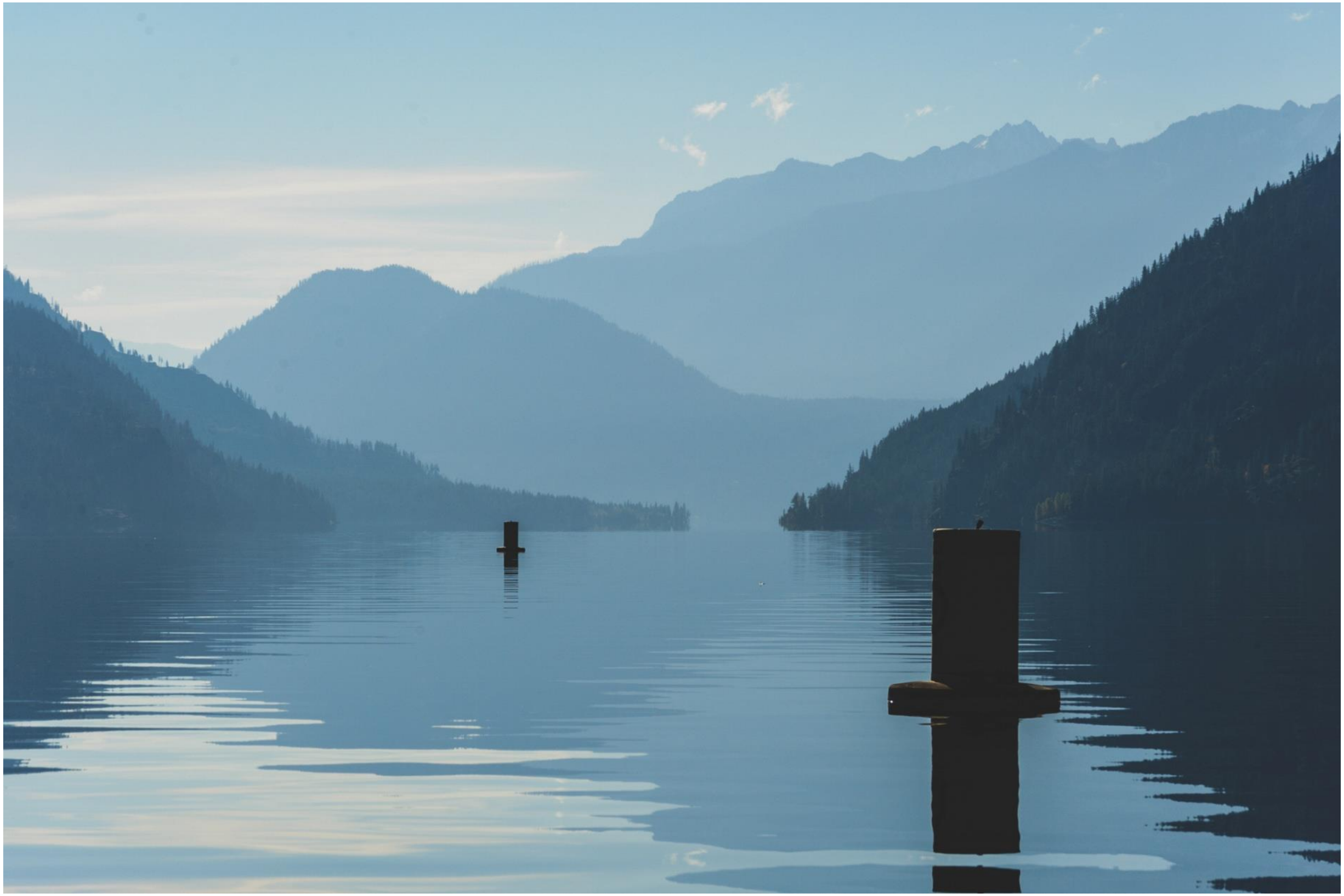
Risk/Value Approach

- Incorporates risk of failure
- Quantifies discussion of “when will it fail?”
- Condition as an indicator of risk of failure becomes part of the equation
- Quantifies risk of delay
- Utilizes Excel and macros or add-in

Comparison

- Traditional approach
  - Without energy – negative economics
  - With energy – recommended generator now, turbine later (ignores risk)
- Risk/Value approach
  - Quantifies risk of delay
  - Values Run to Failure
  - Recommends generator and turbine based on turbine risk



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