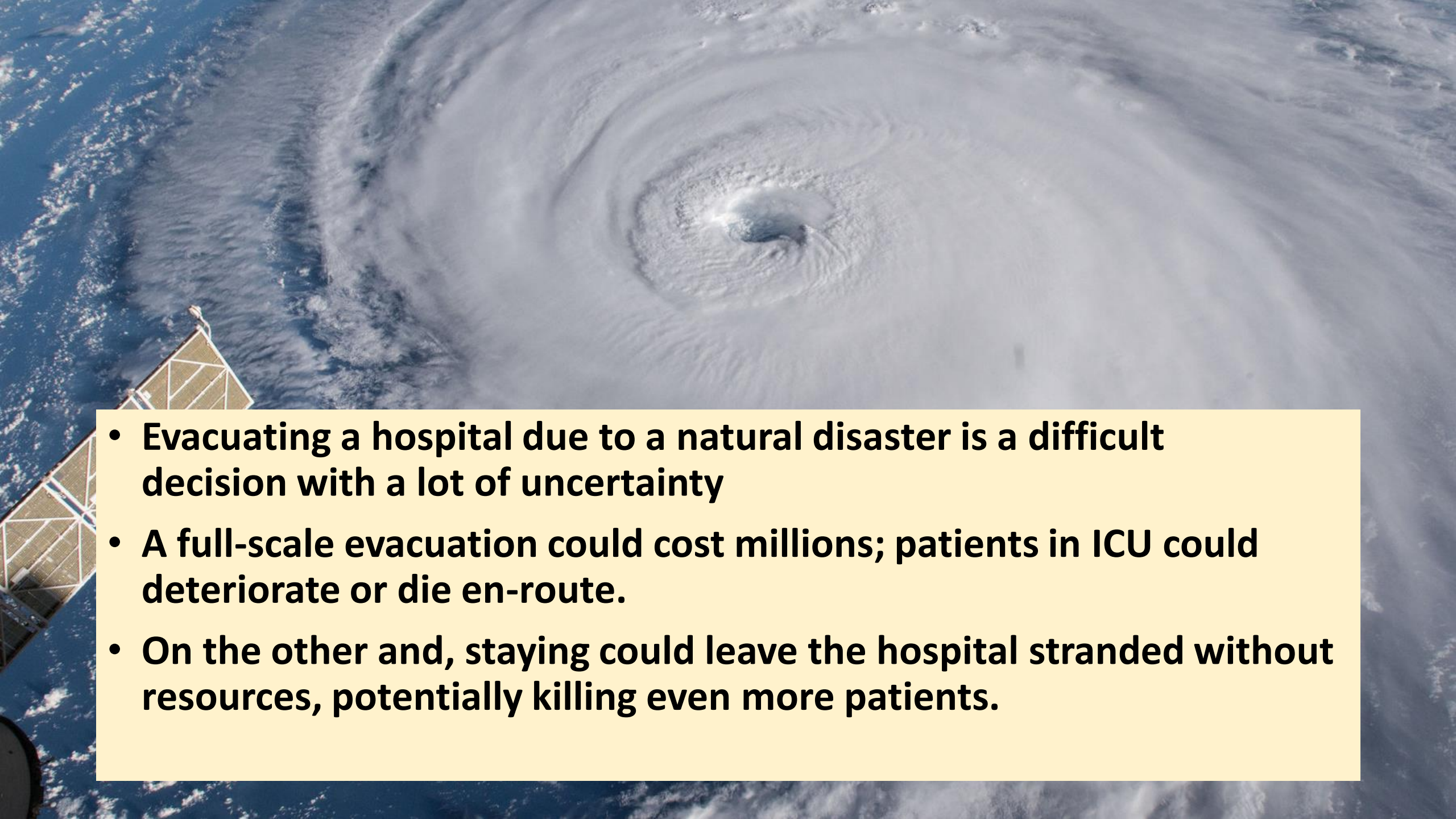
Business Decisions Under Uncertainty

A Hurricane is on its way – Do we evacuate the hospital?

Delores Mincarelli



- **Evacuating a hospital due to a natural disaster is a difficult decision with a lot of uncertainty**
- **A full-scale evacuation could cost millions; patients in ICU could deteriorate or die en-route.**
- **On the other and, staying could leave the hospital stranded without resources, potentially killing even more patients.**

Hurricane Katrina

- None of the hospitals in the New Orleans Parish evacuated in advance of Hurricane Katrina
- One hospital 20 miles north of the city, St. Charles Parish Hospital, evacuated in advance. They believe they made the right decision.
- Other hospitals were stranded with finicky power supplies
- 100-degree heat, depleted water sources, and reduced medical supplies
- Regardless, hospitals were forced to evacuate post-hurricane

Factors We Kept in Mind

Evacuate Decision

- Transportation cost of evacuating
- Probability & cost of an adverse event occurring during transport (Random Variable)

Do Not Evacuate Decision

- Probability of a direct hurricane hit from 72, 48, 24, 12-hour forecast
- Probability of a power outage
- Probability the power outage >= 3 days (Random Variable with Indicator)
- Probability of an adverse event due to power outage
- Cost of adverse event during power outage (Random Variable)

National Hurricane Center Error Data

Date/Time	STMID	T000hT0	T012hT0	T024hT0	T036hT0	T048hT0	T072hT0
31-08-2016/00:00:00	AL072016	6	0	15.8	19	18.6	
31-08-2016/06:00:00	AL072016	5	14.8	9.7	30		
31-08-2016/12:00:00	AL072016	6	20.5	18.7			
31-08-2016/18:00:00	AL072016	4.9	14.5				
01-09-2016/00:00:00	AL092016	5.4					
01-09-2016/06:00:00	AL092016						
01-09-2016/12:00:00	AL09						
01-09-2016/18:							
02-							
0							
0							
03-							
03-							
31-0							
31-08							

Hi Delores,

Is there something in particular that you are looking for in the 2019 storms? The verification database will not tell you anything about the landfall timing, you will need another dataset if that is what you are interested in.

The track errors are calculated as the great circle distance between where the center of the storm was and where the center was forecasted to be. The "012hT01" column does not tell you where the storm was, it only tells you the error for the forecast. The value in the "012hT01" column tells you the track error for the 12 hour forecast that was made at the date in left hand column. When you see "012hI01", that corresponds to the intensity error in kt of the forecast that was made for 12 h into the future,

After the hurricane season is over we double check that we have the most accurate positions for the centers of all the hurricanes. Sometimes we find that we thought the center of the storm was in one place, but it turned out to be somewhere different. This difference is the zero hour track error (000hT01).

So for example look at the the first row in your attached figure. The time and date that the forecast was made was 18Z on May 20th, 2019. The Lat, Lon, and WS tell you where the storm was and how strong it was at that time. The value in the '012hT01' column of 18.7 tells you that the forecast we made for 12 hours into the future (so where the storm would be at on May 21 at 6Z) was off by 18.7 nm.

Let me know if you have any other questions or need some additional clarifications.

Regards,
Ben

Ben Trabing
Tropical Cyclone Applications Developer
CSU/CIRA/NHC
Phone: 352.229.9108
Email: ben.trabing@noaa.gov
Web: http://atmos.colostate.edu/~btrabing/

I got raw data (and coaching, see email above!) from the NHC on their forecast tracking errors.

Tracking Error Definition

Tracking Error Example

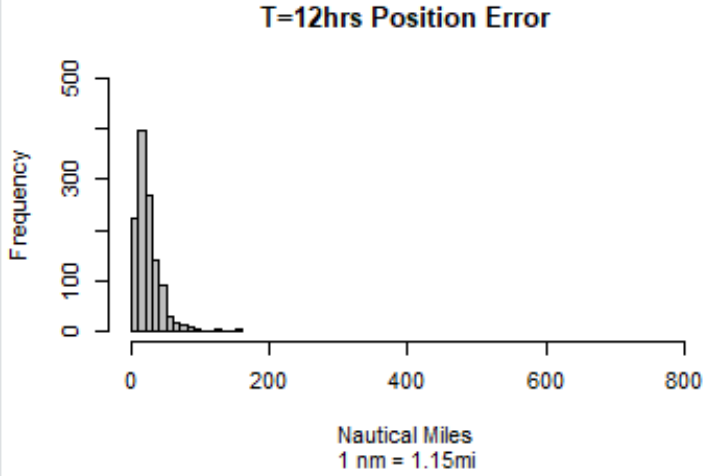
Thursday at 1am a 72 hr. forecast of the hurricane center is made

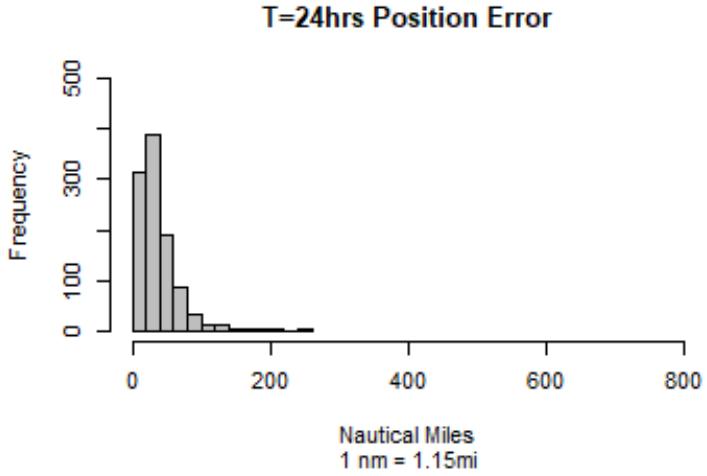
In 72 hours we think it will be here

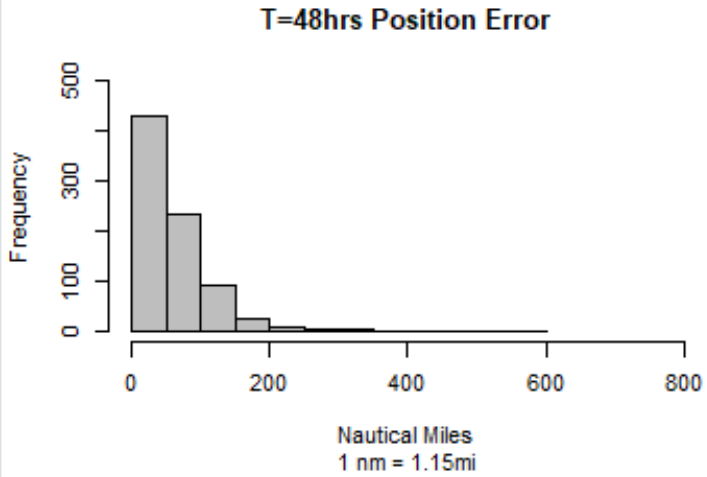
However, the actual location measured 72 hours later is here...

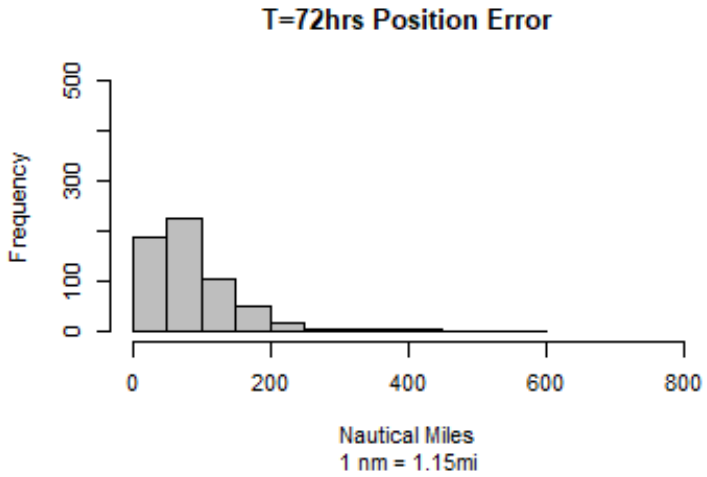
The distance between forecasted location and actual is the error (nautical miles)

Forecasting Error as Function of Time









T=120hrs Position Error

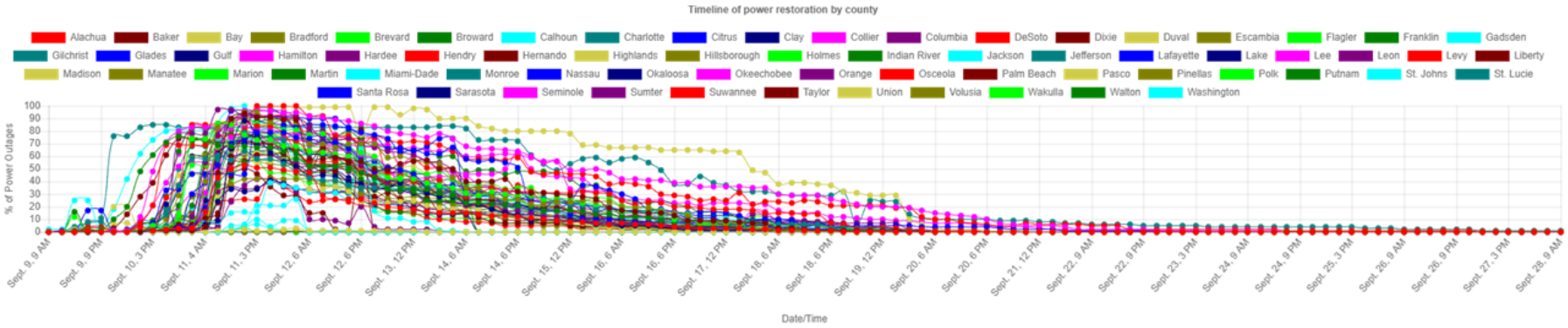
Tracking Error	T=12	T=24	T=48	T=72	T=120
Average N-Mi off	23	35.9	63.9	92.6	170
Standard Deviation	16.3	27.8	57.2	74	115.3
Prob Direct Hit (<=30N-Mi)	0.75	0.51	0.28	0.1	0.042
N	1168	1039	804	614	378

Power Outage Assumptions

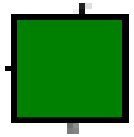
Power outages present the greatest potential damage to the patients.

- No categories
- Incomplete data, and historical data for all types of outages in USA, not just hurricanes
- Shows outages for the United States (outages in Kentucky and Ohio from Ike and Sandy)
- 3 days max on generator

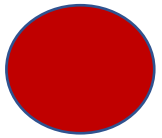
Category	Averages Days out of power	Total number of hurricanes	Outage <= 3 days		Outage > 3 days	
			#	%	#	%
1	2.5425	15	10	66%	5	33%
2	0	0	0	0	0	0
3	5.0783	23	10	43%	13	57%
4	7.5222	16	7	44%	9	56%
5	4.6021	17	10	59%	7	41%



Decision Tree 101



Green Square = Decision



Red Circle = Probability Node

FALSE

FALSE - Non-Optimal Path

TRUE

TRUE - Optimal Path

101300.2231

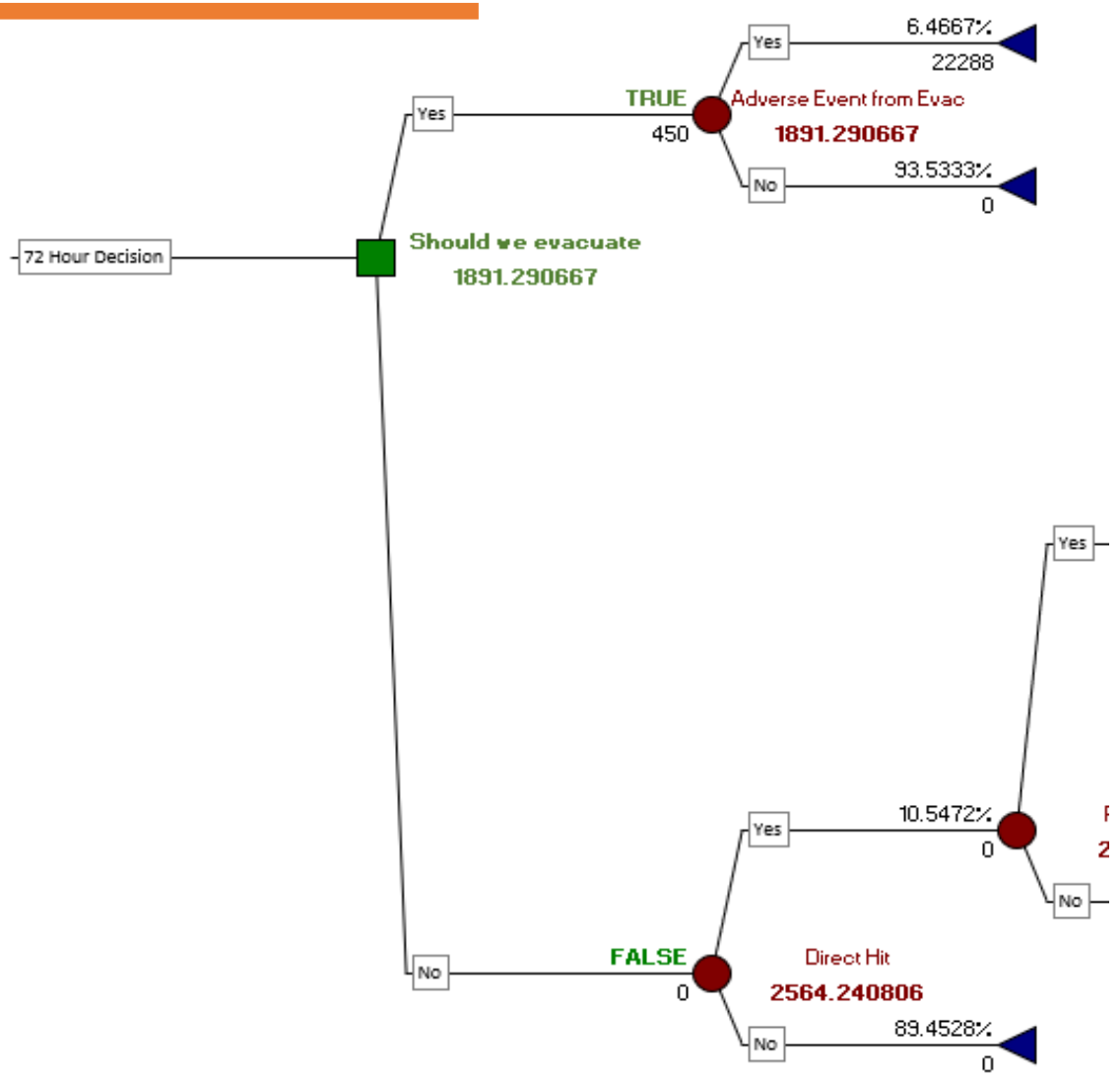
-- Intermediate Expected Value

1891.290667

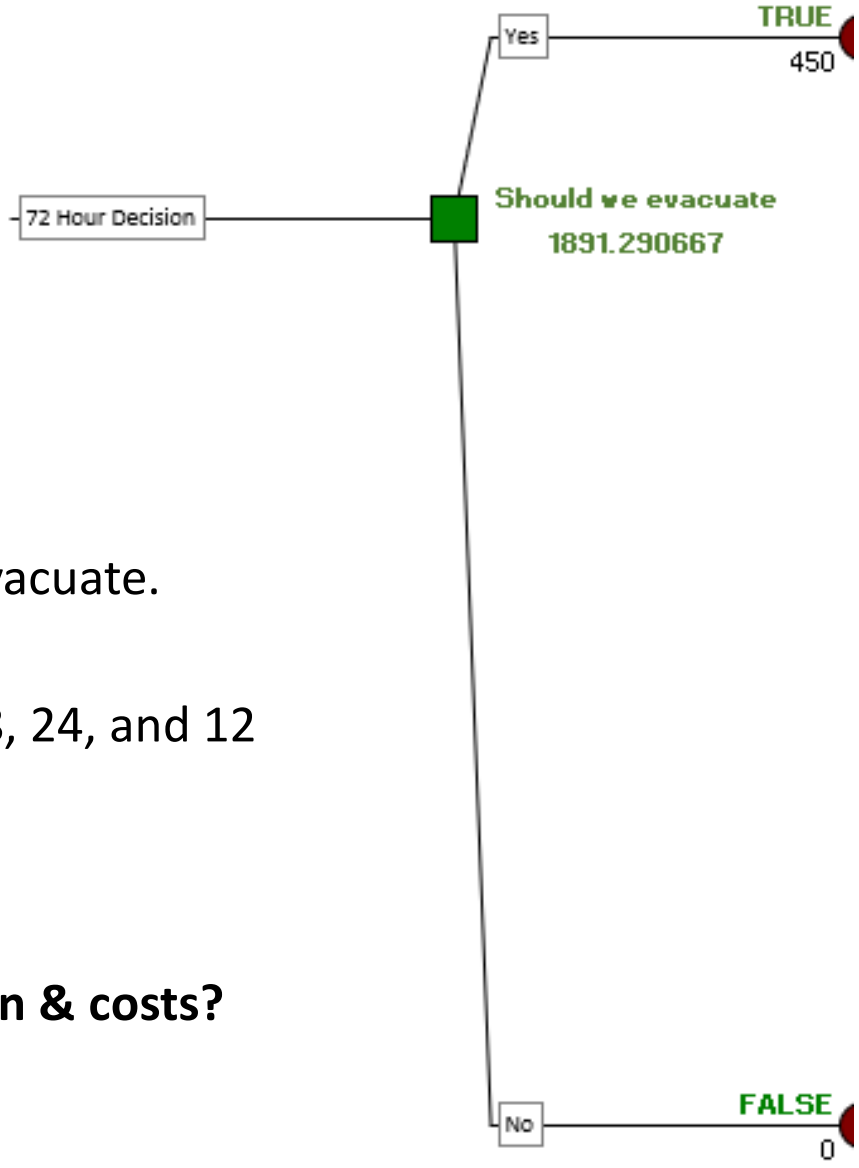
-- Final Expected Value

222880

-- Summary



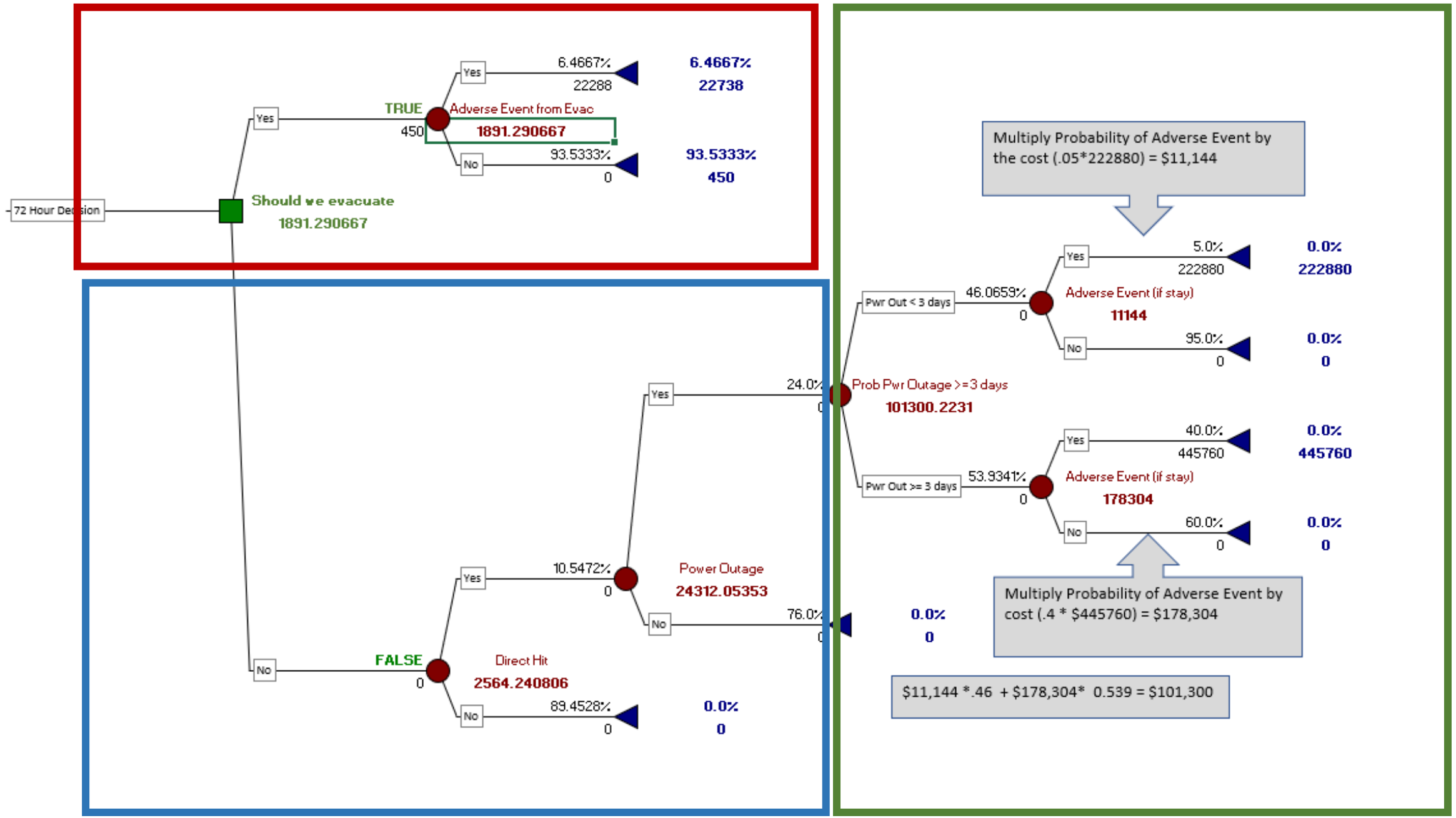
Should We Stay or Should We Go?



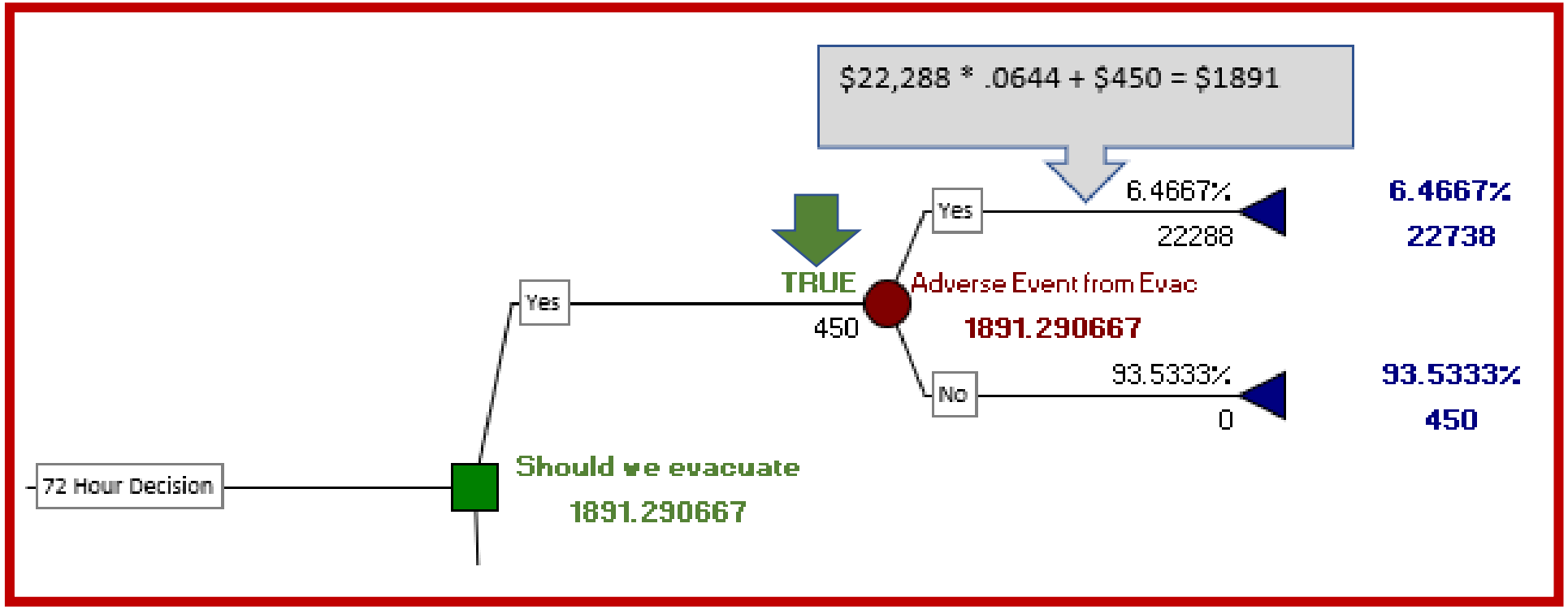
- Two paths: YES - Evacuate, or NO - Do not Evacuate.

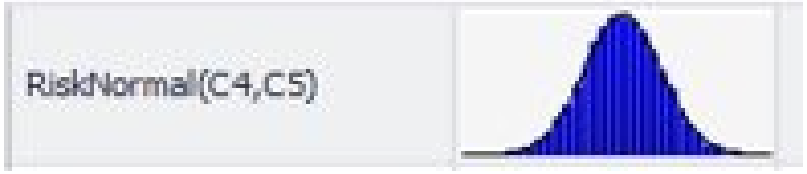
- We evaluated this decision based on a 72, 48, 24, and 12 hour forecast, using cost as our basis.

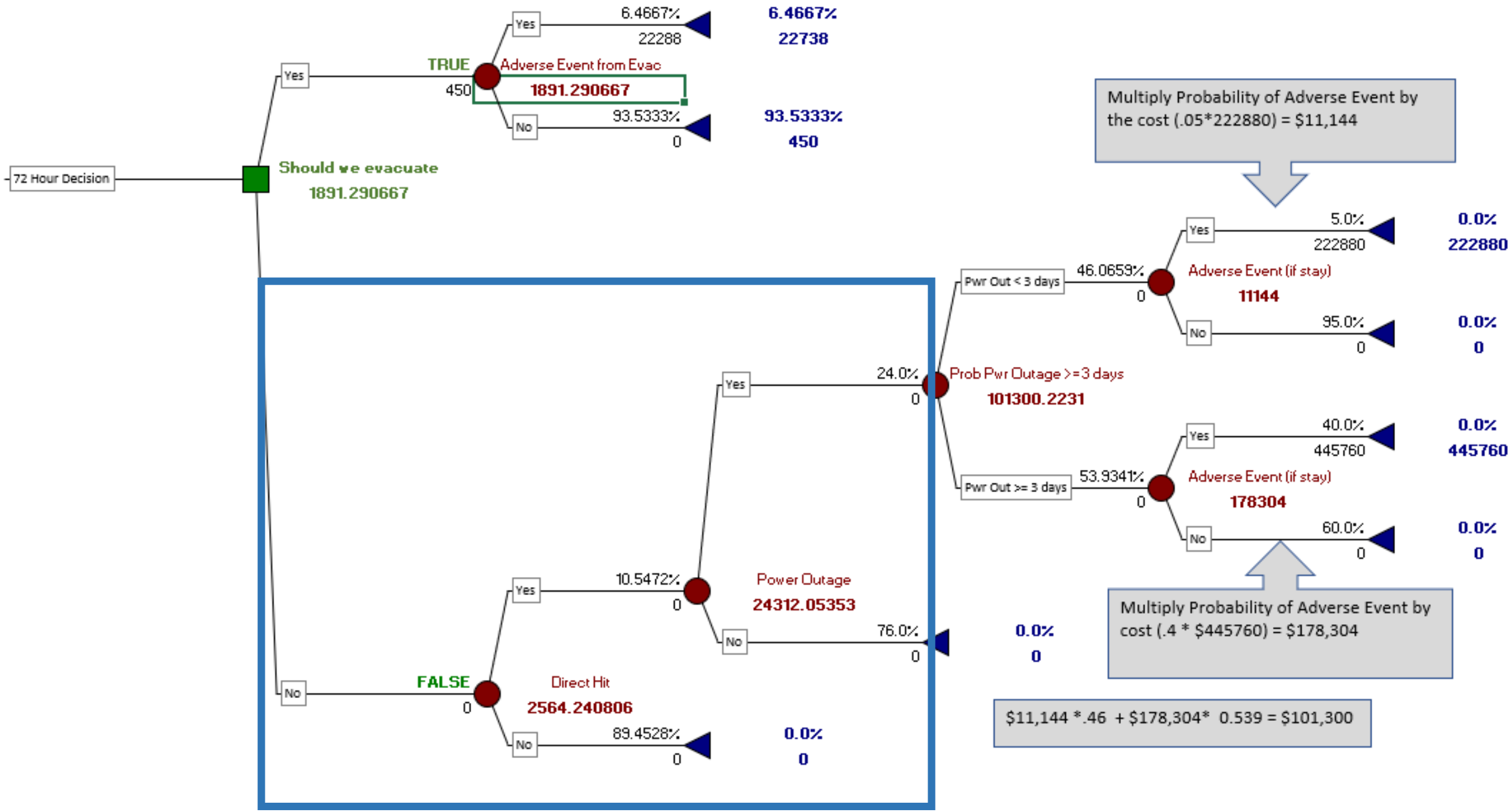
- **Would the element of time alter the decision & costs?**


72 Hour Decision
Should we evacuate
1891.290667
Yes
TRUE
450
Adverse Event from Evac
1891.290667
Yes
6.4667%
22288
6.4667%
22738
No
93.5333%
0
93.5333%
450
No
FALSE
0
Direct Hit
2564.240806
Yes
10.5472%
0
Power Outage
24312.05353
Yes
24.0%
0
Prob Pwr Outage >=3 days
101300.2231
Pwr Out < 3 days
46.0659%
0
Adverse Event (if stay)
11144
Yes
5.0%
222880
0.0%
222880
No
95.0%
0
0.0%
0
Pwr Out >= 3 days
53.9341%
0
Adverse Event (if stay)
178304
Yes
40.0%
445760
0.0%
445760
No
60.0%
0
0.0%
0
No
76.0%
0
0.0%
0
No
89.4528%
0
0.0%
0
Multiply Probability of Adverse Event by the cost (.05*222880) = $11,144
Multiply Probability of Adverse Event by cost (.4 * $445760) = $178,304
$11,144 *.46 + $178,304* 0.539 = $101,300

72 hr. Forecast Optimal Decision is... Evacuate

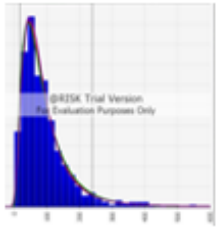




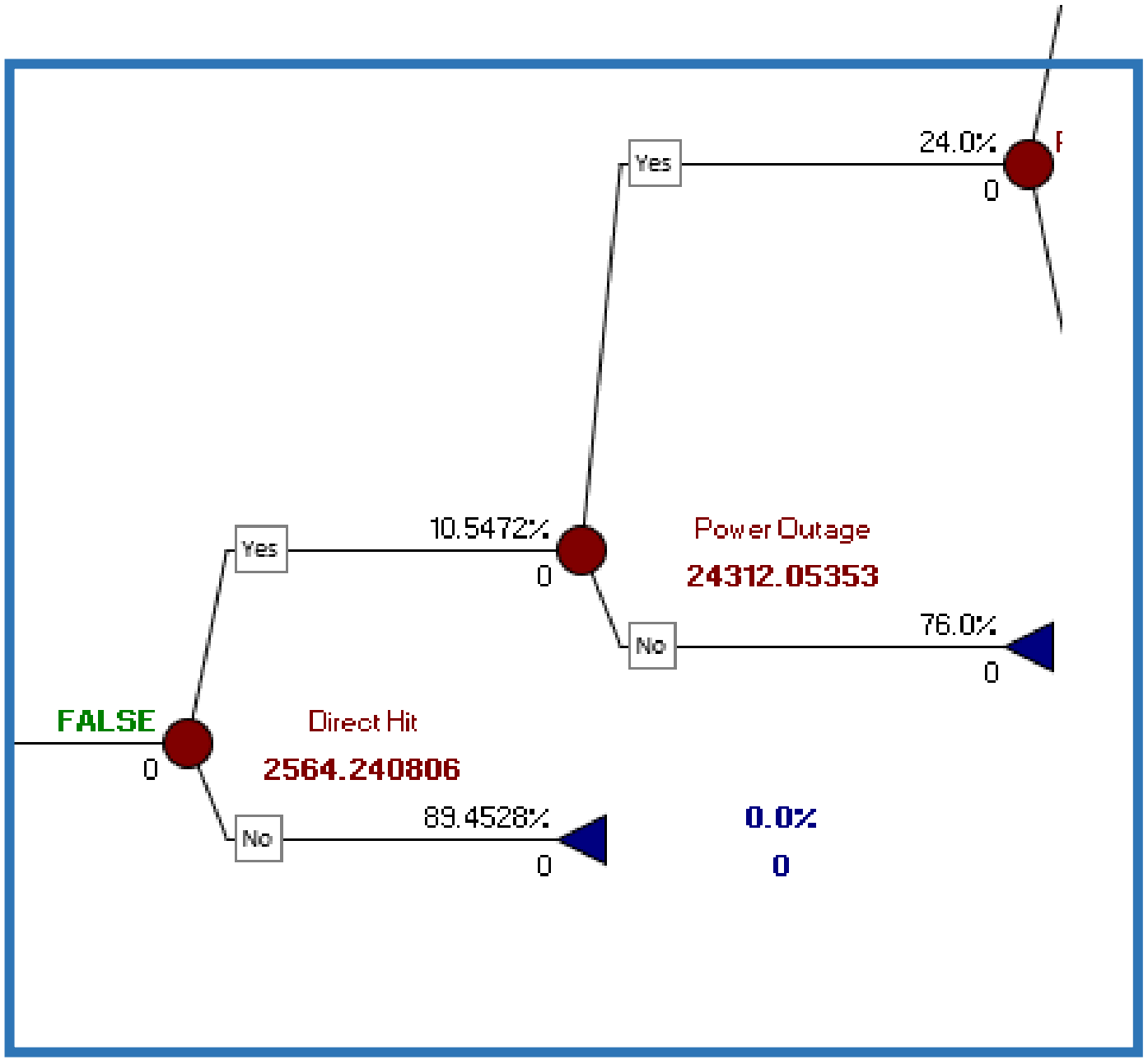

72 Hour Decision
Should we evacuate
1891.290667
Yes
TRUE
450
Adverse Event from Evac
1891.290667
Yes
6.4667%
22288
6.4667%
22738
No
93.5333%
0
93.5333%
450
No
FALSE
0
Direct Hit
2564.240806
Yes
10.5472%
0
Power Outage
24312.05353
Yes
24.0%
0
No
76.0%
0
No
89.4528%
0
0.0%
0
Prob Pwr Outage >=3 days
101300.2231
Pwr Out < 3 days
46.0659%
0
Yes
5.0%
222880
0.0%
222880
Adverse Event (if stay)
11144
No
95.0%
0
0.0%
0
Pwr Out >= 3 days
53.9341%
0
Yes
40.0%
445760
0.0%
445760
Adverse Event (if stay)
178304
No
60.0%
0
0.0%
0
0.0%
0
Multiply Probability of Adverse Event by the cost (.05*222880) = $11,144
Multiply Probability of Adverse Event by cost (.4 * $445760) = $178,304
$11,144 *.46 + $178,304* 0.539 = $101,300

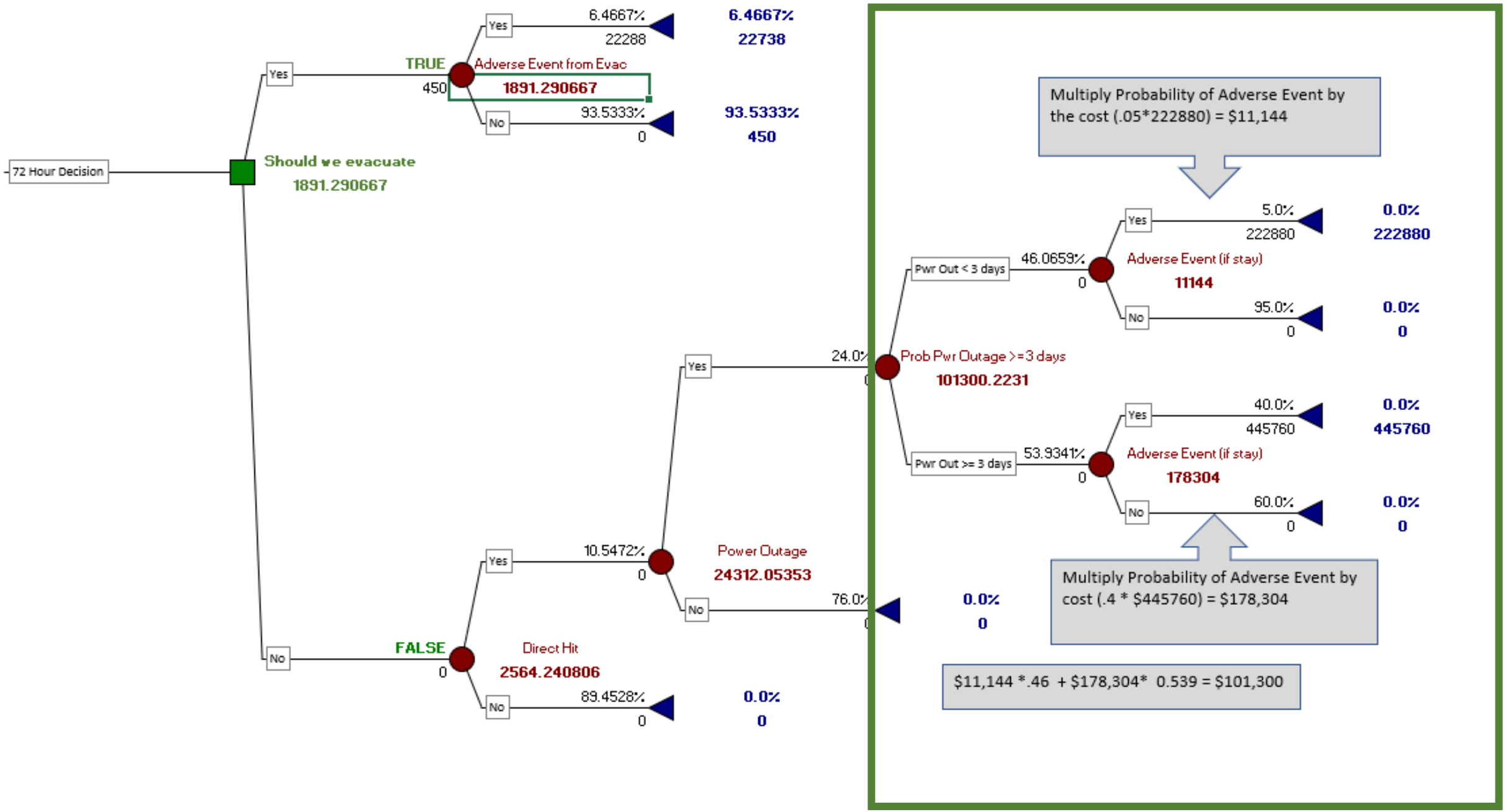
Non-Optimal Branch - Expected Value

Non-Optimal: $2564



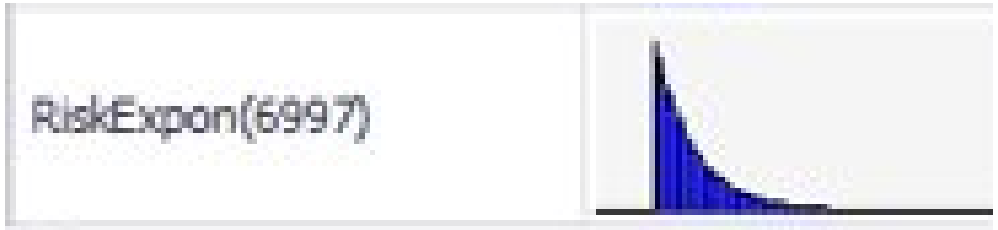
Got CDF from LogNormal distribution of tracking error
in order to get the probability
of tracking error <= 30 miles
(aka, direct hit)

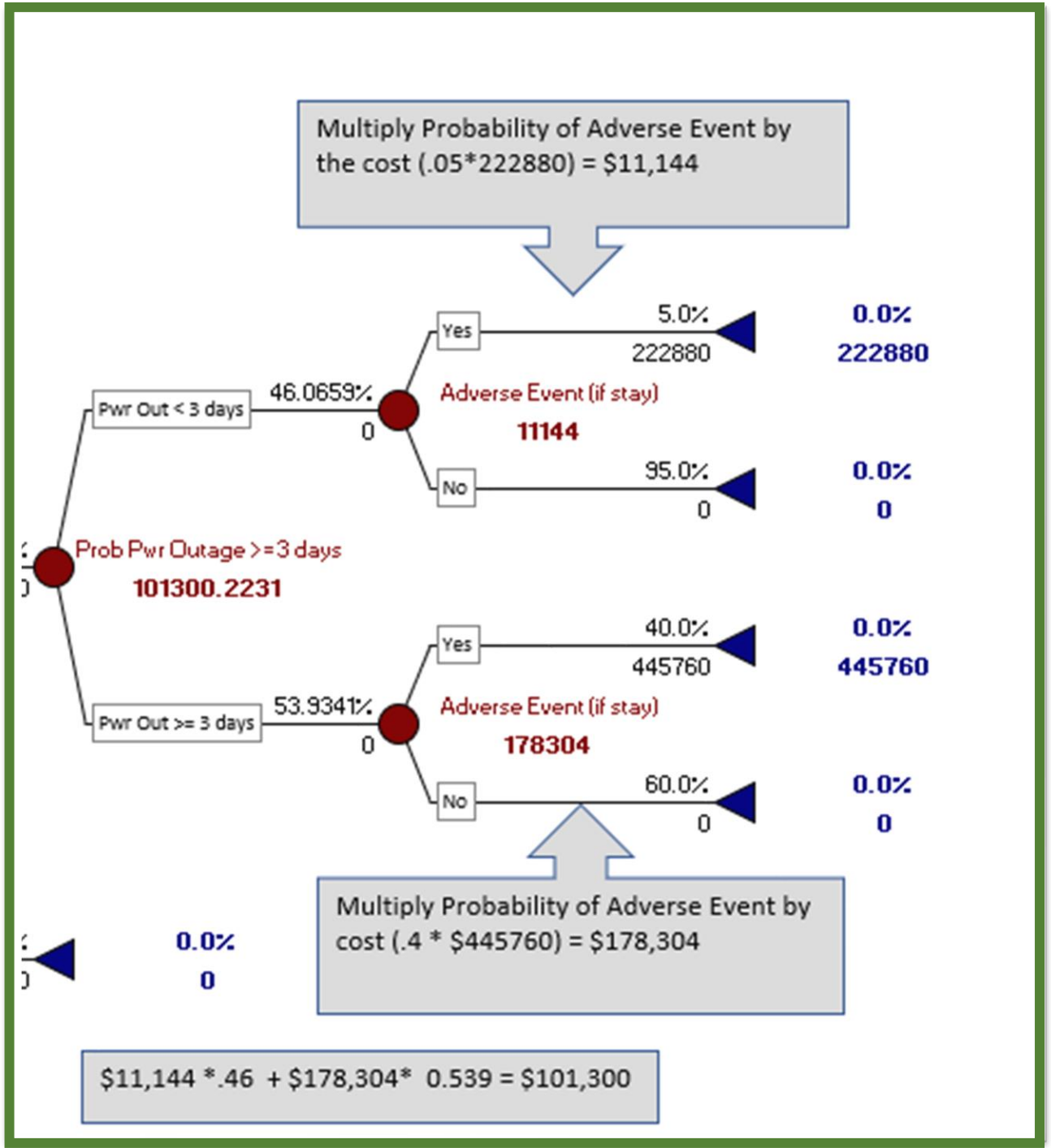



72 Hour Decision
Should we evacuate
1891.290667
Yes
TRUE
450
Adverse Event from Evac
1891.290667
Yes
6.4667%
22288
6.4667%
22738
No
93.5333%
0
93.5333%
450
No
FALSE
0
Direct Hit
2564.240806
Yes
10.5472%
0
Power Outage
24312.05353
Yes
24.0%
0
Prob Pwr Outage >=3 days
101300.2231
Pwr Out < 3 days
46.0659%
0
Yes
5.0%
222880
0.0%
222880
Adverse Event (if stay)
11144
No
95.0%
0
0.0%
0
Pwr Out >= 3 days
53.9341%
0
Yes
40.0%
445760
0.0%
445760
Adverse Event (if stay)
178304
No
60.0%
0
0.0%
0
No
76.0%
0
0.0%
0
No
89.4528%
0
0.0%
0
Multiply Probability of Adverse Event by the cost (.05*222880) = $11,144
Multiply Probability of Adverse Event by cost (.4 * $445760) = $178,304
$11,144 *.46 + $178,304* 0.539 = $101,300

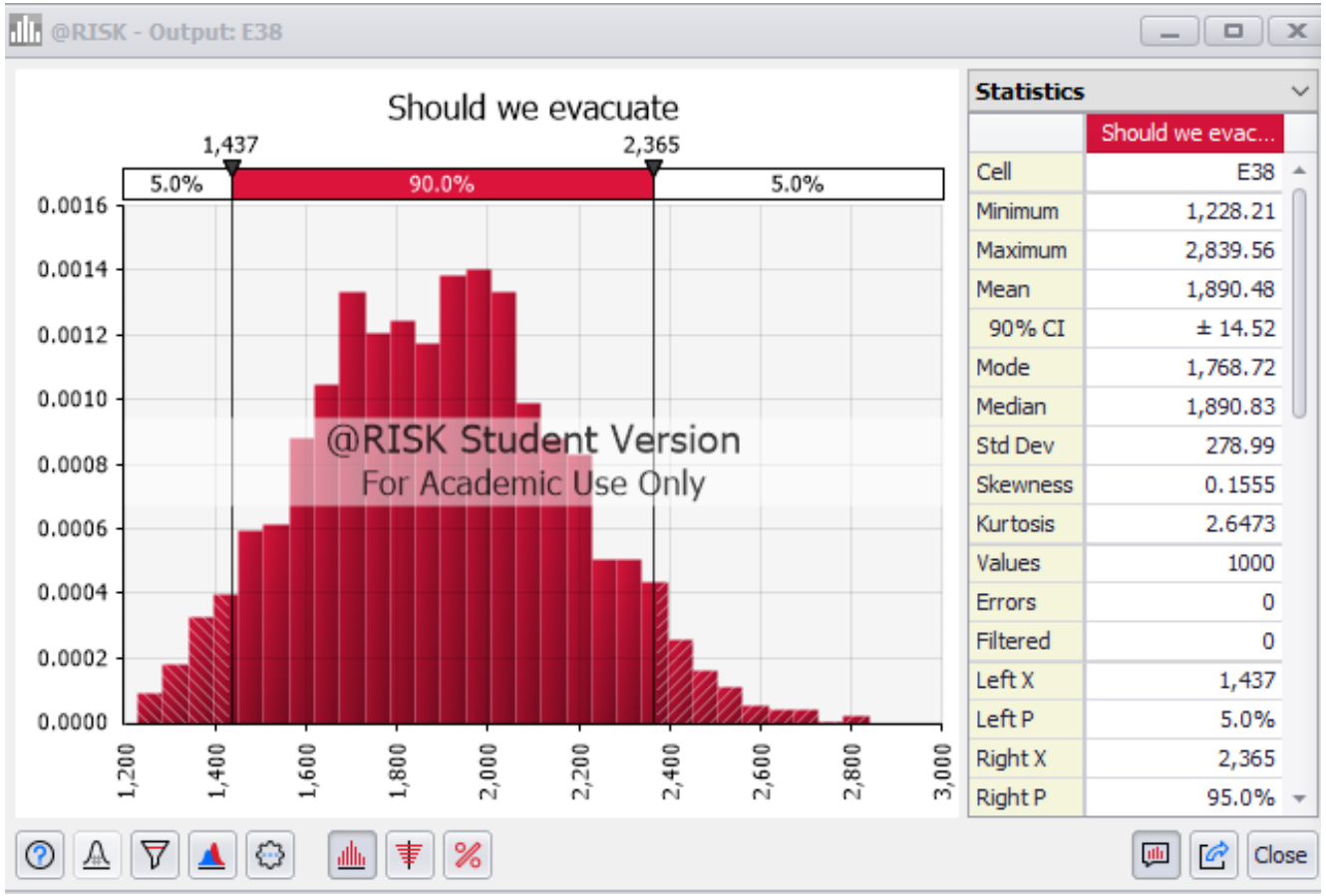
Non-Optimal Branch Expected Value

Expected Value calculations are Probability * Cost, multiplied at each probability node moving from right to left

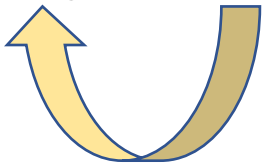




Simulating the Variation in Optimal Decision

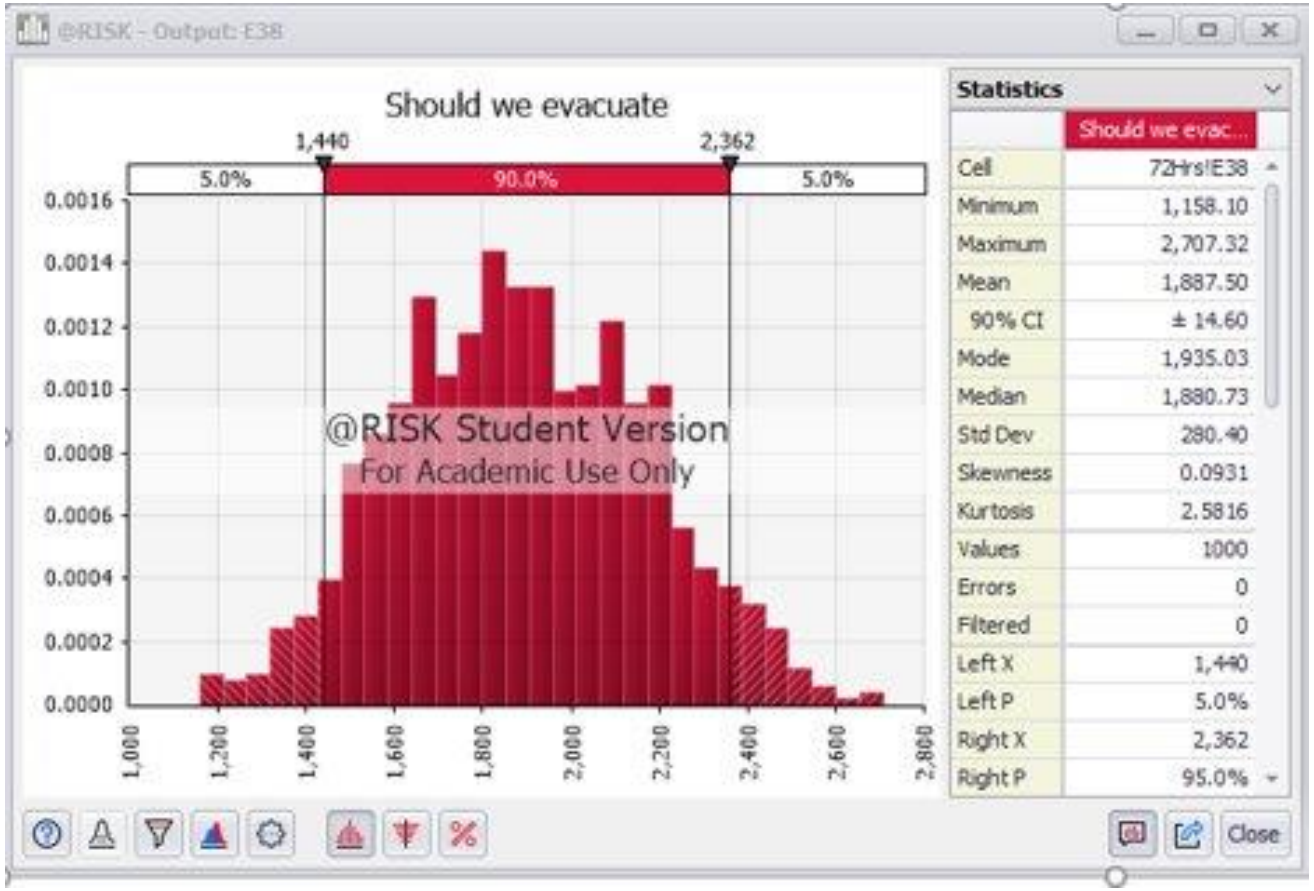


Iteration	Should we evacuate	Yes-EvacuateBranch	No-DontEvacuate
1	1980.593034	1980.593034	2810.311696
2	2036.088078	2036.088078	2543.026743
3	1689.441197	1689.441197	2574.87485
4	1990.119219	1990.119219	2584.14462
5	1685.732698	1685.732698	2470.195703
6	1918.920248	1918.920248	2785.472384
7	2099.676223	2099.676223	2517.561333
8	1789.296511	1789.296511	2256.718299
9	1735.052827	1735.052827	2743.899795
10	1555.4471	1555.4471	2408.686523



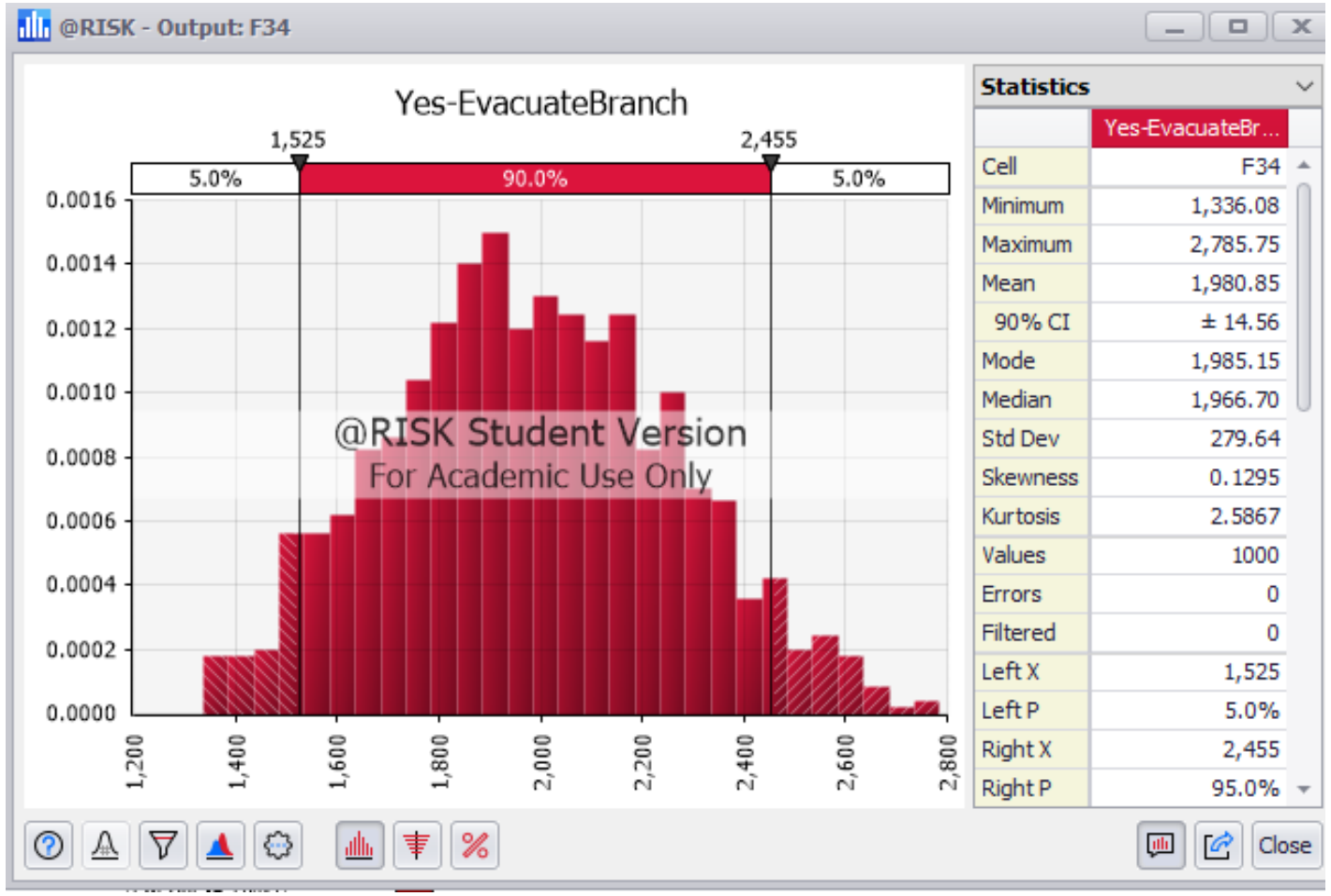
Tree determines Optimal Branch based on Expected Value and then we run a simulation on the Optimal Branch to see the distribution of costs - aka, best case and worst case.

The Value of Perfect Information



Iteration	Should we evacuate	Yes-EvacuateBranch	No-DontEvacuate
1	1491.190982	1491.190982	2434.454544
2	1856.004103	1856.004103	2463.185112
3	2435.079642	2435.079642	2669.855769
4	1469.475956	1469.475956	2466.60025
5	1396.14795	1396.14795	2472.823146
6	2353.948481	2353.948481	2638.294654
7	2180.540865	2180.540865	2449.931244
8	2093.505483	2093.505483	2341.444984
9	1998.987209	1998.987209	2525.010455
10	1795.703966	1795.703966	2233.426068
11	1977.207324	1977.207324	2586.572475
12	1560.949181	1560.949181	2692.546476
13	1743.764011	1743.764011	2676.027673
14	2084.370817	2084.370817	2630.95973
15	2269.592996	2269.592996	3094.838839
16	1923.375485	1923.375485	2346.088873
17	1787.993565	1787.993565	1945.848242
18	2396.838349	2466.843447	2396.838349

Forecasting Horizon of 48 Hours vs 72....



What is the cost/benefit of delaying decision?

1. Price Increase on Evacuation Transportation -- 20%
2. Probability of a Direct Hit doubles from 72 hours, to 28%

Result is an increase in the Mean from $1891 to $1980.

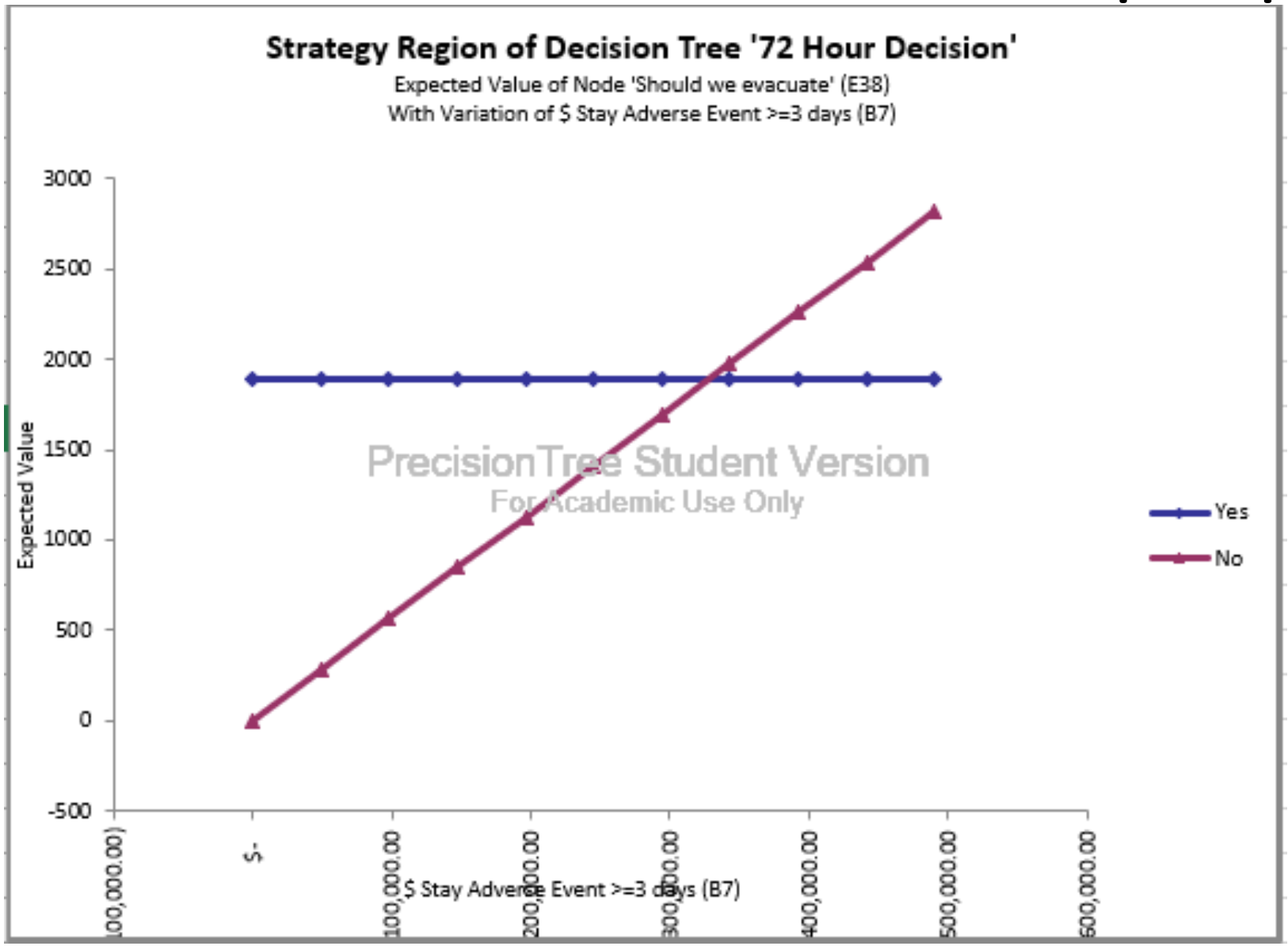
Summary of Costs

Patients are evacuated from United Medical Rehabilitation Hospital in New Orleans on Aug. 31, 2005, after flooding from Hurricane Katrina. Peuters/Rick Wilking

Opportunity cost?

	Expected Cost		
Forecast inAdvance	Optimal-Evacuate	Not Optimal - Stay	Evacuation -- after the hit..
72 hours	$ 1,891.00	$ 2,564.00	
48 hours	$ 1,981.00	$ 6,710.00	
24 hours	$ 2,071.00	$ 12,399.00	
12 hours	$ 2,141.00	$ 19,180.00	$$$$$?

But wait....consider the C-Suite perspective



Input	
Value	Change (%)
$ (0.00)	-100.00%
$ 49,033.60	-89.00%
$ 98,067.20	-78.00%
$ 147,100.80	-67.00%
$ 196,134.40	-56.00%
$ 245,168.00	-45.00%
$ 294,201.60	-34.00%
$ 343,235.20	-23.00%
$ 392,268.80	-12.00%
$ 441,302.40	-1.00%

Evacuate...
Based on 10% probability of direct hit from the 72-hour forecast. ?

Limitations & Opportunities

- Decision Tree is heavily reliant on subject matter expertise
- Difficulty getting data – decision makers have to be confident we have accurate estimates
- Sequential Decisions: Output from one Decision Tree feeds next one
- Difficulty in quantifying certain factors in terms of cost

References

Data
https://www.nhc.noaa.gov/verification/verify7.shtml?
Adverse Events
https://www.oecd.org/els/health-systems/The-economics-of-patient-safety-March-2017.pdf
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5598051/
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5618745/
https://pubmed.ncbi.nlm.nih.gov/15942342/#:~:text=Daily%20costs%20were%20greatest%20on,mechanical%20ventilation%2C%203%2C968%20dollars%3B%20no
Evacuation Costs
https://www.frontiersin.org/files/Articles/385950/fpubh-07-00149-HTML/image_m/fpubh-07-00149-t003.jpg
Hurricane Katrina
https://www.urban.org/sites/default/files/publication/50896/411348-Hospitals-in-Hurricane-Katrina.PDF
https://en.wikipedia.org/wiki/Memorial_Medical_Center_and_Hurricane_Katrina#Outcome
https://en.wikipedia.org/wiki/Ochsner_Baptist_Medical_Center#Post-Katrina
Evacuation Proceedure
https://www.ahrq.gov/research/shuttered/hospevac4.html
https://www.mass.gov/doc/evacuation-toolkit-planning-guide-0/download
SLOSH & Storm Surge
https://www.nhc.noaa.gov/surge/
https://www.nhc.noaa.gov/surge/faq.php#2
https://www.nhc.noaa.gov/surge/faq.php#2
https://slosh.nws.noaa.gov/sloshPub/
https://coast.noaa.gov/slr/#/layer/cof/2/-10536486.547926376/3775255.185074186/6/satellite/none/0.8/2050/interHigh/midAccretion
Uncertainty
https://link.springer.com/referenceworkentry/10.1057%2F978-1-349-94848-2_250-1#:~:text=Risk%20refers%20to%20decision%2Dmaking,unknown%20to%20the%20decision%2Dmaker.
https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/strategy-under-uncertainty
Outage Data
https://data.tallahassee.com/storm-power-outages/
https://www.eversource.uconn.edu/predicting-outages/
https://www.sciencedirect.com/science/article/pii/S2352340918307182#s0015